Book of Abstracts

52nd Annual Meeting of the Ecological Society of Germany, Austria and Switzerland

Leipzig — 12–16 September 2023

GfÖ 2023 LEIPZIG

Table of Contents

Welcome Note 2023

The Future of Biodiversity – overcoming barriers of taxa, realms and scales

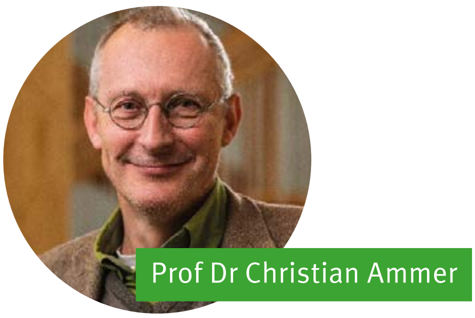
This is the motto of the 52nd annual conference of the Ecological Society of Germany, Austria and Switzerland, and it indicates in several respects where the great challenges of ecological research of our time lie. First, there is the need to take a closer look at the entire ecosystem and to deal with scale effects when it comes to better understanding the functionality of ecosystems. Second, the motto may also remind us to think beyond the boundaries set by humans. Without a global perspective it will not be possible to effectively counter the ongoing loss of biodiversity and the climate crisis.

This year, we are guests in Leipzig. Leipzig University was founded as early as 1409 and is therefore particularly rich in tradition. With its 14 faculties, it is characterised by a great diversity of subjects ranging from the natural sciences to the humanities and social sciences, thus providing a suitable framework for overcoming disciplinary boundaries, which is becoming increasingly important. In the last 10 years, Leipzig University, closely cooperating with the universities of Halle and Jena, has established itself as one of the major centres for biodiversity research in Germany. So, it was quite logical to hold the conference there. As the German Centre for Integrative Biodiversity Research has an explicitly international orientation, the conference also sends out the signal that it is the big questions and challenges that we want to discuss at this conference with our many guests from abroad, who should be given a particularly warm welcome at this point.

The conference in Leipzig is the first GfÖ conference to be held in presence in Germany, Austria and Switzerland since the conference in 2019 in Münster. The great success of last year's meeting in Metz, France, which was organised jointly with our French colleagues, shows how important personal exchange and professional discussion on site is. Although we expected a lively interest in this year's conference, we were completely flabbergasted about the enormous rush for participation. In fact, for the first time we were booked out at a rather early stage. Unfortunately, this also means that not all people interested in the meeting were able to register. With more than 1000 participants, the conference in Leipzig will go down in the history of the GfÖ as a record-breaking annual meeting. However, a conference of this magnitude is only possible if an organisational team can be found to take on such a challenge. On behalf of all participants, I would like to take this opportunity to thank the team around Aletta Bonn, Nico Eisenhauer and Henrique Pereira, who were prepared to do this, but I would also like to extend my thanks to Kati Kietzmann, Heike Kuhlmann and Jutta Stadler, who solved problems and organised in the background.

Now, I wish all of us an advantageous conference, which may combine professional content and personal gain. Perhaps the personal conversation in the evening also offers the opportunity to pause and be grateful for the fact that we are allowed to live in peace in a free country, something that is no longer as self-evident as it seemed years ago.

Christian Ammer
President of the Ecological Society of Germany, Austria and Switzerland (GfÖ)



Dear GfO participants,

We are excited to welcome you to the 52nd Annual Meeting of the Ecological Society of Germany, Austria and Switzerland in Leipzig – also on behalf of our colleagues from the Czech Society for Ecology (ČSPE) with whom we teamed up to organize a joint international event. We are thrilled to have received so many wonderful contributions by the scientific community, with 88 session submissions, nearly 1,000 abstracts, and 1,100 registrations. We were pleasantly surprised by this high level of interest and excited about the excellent quality of the many submissions.

We welcome you to Leipzig, a city with a long history of multicultural exchange. The Roman Via Regia crossed Leipzig as an important ancient trading route, and travelers and traders stopped to exhibit their goods and exchange news. Today, we hope with the German Centre for Integrative Biodiversity Research (iDiv) Halle-Jena-Leipzig, the Helmholtz-Centre for Environmental Research – UFZ, the University of Leipzig, and the National Monitoring Centre for Biodiversity of the Federal Agency of Conservation (BfN), Leipzig has much to offer for wayfaring ecologists and biodiversity scientists, too!

We also welcome you on behalf of iDiv. As you may know, the main topics of the conference are at the heart of iDiv research. Right from the start, iDiv has fostered the exchange of knowledge between researchers at the host institutions and colleagues in Germany and abroad. Only in this way can we tackle some of the most pressing environmental issues humankind is facing. We just celebrated our 10th birthday and have hosted international guests from 66 countries, for instance through our synthesis center sDiv and our sabbatical program. Hosting the GfO conference gives us an opportunity to jointly think, together with you, about the future of biodiversity research and how to provide the scientific foundations to address the biodiversity crisis.

We therefore chose to hold the 52nd GfÖ Annual Meeting under the motto **"The future of biodiversity – overcoming barriers of taxa, realms and scales"**. While we experience an unprecedented global biodiversity loss, the times ahead offer exciting opportunities to bend the curve. The next few years will be important to develop strategies to effectively implement the Kumming-Montreal Global Biodiversity Framework goals of the Convention of Biological Diversity. At EU level, the 2030 Biodiversity Strategy, the EU Restoration Law and the Soil Strategy are pressing, and Germany is currently developing its new Biodiversity Strategy. Integrative biodiversity science, bridging across disciplines, integrating across time, space, and complexity levels is crucial for assisting the implementation of these policies.

In order to discuss these pressing challenges, we are very happy to welcome our esteemed **GfÖ keynote speakers**! **Leonore Fahrig** (Carleton University, Ottawa, Canada), **Esther Turnhout** (University of Twente, the Netherlands), **Vojtech Novotny** (Czech Academy of Science), and **Lilian Busse** (German Environment Agency). We also introduced **a new format of Symposia,** covering different topics on the future of biodiversity research**, to complement the Contributed Open Sessions**. These Symposia are placed at the beginning of the day, overlap with few other sessions, have invited contributions by national and international colleagues, and hope to inspire fruitful discussion and debate to be continued in the contributed sessions.

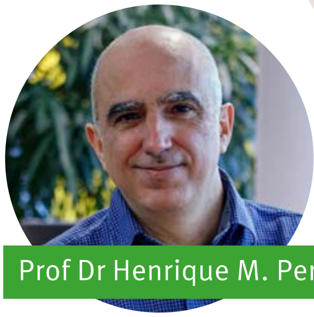
Many helping hands make this conference possible. **We would especially like to thank the brilliant organization team** with Kati Kietzmann, Ronja Wodner and Heike Kuhlmann, and our colleagues in the organizing committee, Helge Bruelheide, Olga Ferlian, David Storch, and Marten Winter, as well as the GfÖ directorate and GfÖ working groups, and all session chairs, pre-conference workshop organizers and field trip leaders!

We truly hope **you enjoy this year's GfÖ conference!** We hope you have plenty of opportunity to discuss your scientific ideas with the community and get to know new colleagues or reconnect with old friends! And of course - we can't wait to hear the line-up of bands and get dancing at the GfÖ party.

Aletta Bonn, Nico Eisenhauer
and Henrique M. Pereira
Conference Chairs


Prof Dr Nico Eisenhauer


Prof Dr Aletta Bonn


Prof Dr Henrique M. Pereira

Keynotes

Bridging the Gap Between Science and Policy for Healthy and Resilient Ecosystems

Lilian Busse[1]

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The German Environment Agency gives policy advice to German and European decision-makers in order to protect and restore terrestrial and aquatic ecosystems. The policy advice is based on applied research that we are conducting together with research partners in the field of sustainability, chemicals and the impacts on ecosystems. In addition, the German Environment Agency carries out enforcement for different classes of chemicals and is thus regulating chemicals and their effect on ecosystems. Our work directly supports the goals of the German Ministry of the Environment as well as the goals of the European Green Deal, including the Zero Pollution Ambition. We are also developing and supporting national regulations and strategies. Currently we are in the process of establishing the National Centre for Environmental and Nature Conservation Information, a central point of access for information on the environment and nature conservation. The presentation will include examples of resarch and policy advice and will also highlight potential obstacles. We will show the process on how to bridge the gap between science and policy for healthy and resilient ecosystems.

How (not) to Prioritize Habitat for Conservation

Lenore Fahrig[1]

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Our most effective means of protecting biodiversity is to protect the natural habitats on which species depend. Exactly which habitats to protect has been the subject of discussion and debate for decades. Two principles that have made their way into many conservation plans are: large areas are prioritized over small areas, and areas with low edge-to-area ratio are prioritized over more 'edgy' habitat areas. While these principles may be relevant at the scale of individual habitat patches, they do not translate, or scale-up, to a landscape scale. For a given total habitat area, landscapes containing many small patches of habitat do not harbour fewer species, or fewer threatened species, than landscapes containing few large patches. Local negative or positive responses to habitat edges do not indicate the same responses to edgy landscapes. Such extrapolations from local- or patch-scale patterns to landscape-scale patterns fail because they do not take into account landscape-scale processes. Global biodiversity protection will require protecting and restoring sufficient habitat in each of the world's ecoregions. Applying patch size and edge density criteria to this effort constrains opportunities and hinders biodiversity protection.

Rainforest Regeneration: Experiments in Papua New Guinea

Vojtech Novotny[1]

[1]*Institute of Entomology, Biology Centre of the Czech Academy of Science, Ceske Budejovice, Czech Republic*

Ecological succession in tropical rainforests is a germane theme for fundamental ecological research. We have a reasonably good, but not perfect, theoretical framework to understand and partially predict successional trajectories, while our understanding of successional mechanisms remains limited. At the same time the share of young successional stages in tropical rainforests keeps increasing as a result of growing intensity of anthropic disturbance, making rainforest regeneration a prominent theme of applied conservation. The analysis of succession trends under changing climate also promises to be an interesting, global-scale ecological experiment with some practical impact. These are sufficient reasons to refocus our research on rainforest succession. That research has been done traditionally mostly by observing the course of succession in various natural and unnatural settings. More recently, the ecologists have come to the conclusions that experimental manipulations are necessary to understand the complex community dynamics. The present talk will outline main approaches to such experimentation and give interesting examples, centered on rainforest manipulation in Papua New Guinea, one of the last tropical areas with rainforests stretching all the way to the horizon.

Nature Beyond Conservation

Esther Turnhout[1]

[1]*Chair of Science, Technology and Society, Section of Knowledge, Transformation, and Society (kiTeS), University of Twente, Enschede, NL, e.turnhout@utwente.nl*

Conservation is not saving nature. This is not because we do not have enough of it, or because conservation suffers from a lack of funding or from problems of implementation. The very concept of conservation is a problem since conservation and exploitation are cut from the same wood. In this talk, I will develop this argument zooming in on the role of science in the parallel constitution of nature, its exploitation, and its conservation. It is for this reason that conservation has been powerless to catalyze transformative change, go beyond reproducing the status quo, and move away from offering false stop-gap solutions that do not address the root causes of nature's ongoing destruction. Although this lack of effectiveness may seem paradoxical because of conservation's self-identification as a 'crisis discipline', the discourse of crisis in fact further facilitates conservation's failure to safeguard human-ecological well-being because it consolidates what has been termed the post-political condition. For conservation, this post-political condition manifests among others in the continued reproduction of a problematic singular concept of nature and an equally problematic singular concept of scientific truth. I suggest that the politicization and pluralisation of nature and of knowledge about nature are necessary antidotes to this situation; to open up and disrupt the post-political deadlock that conservation science and practice are currently trapped in. I will conclude my talk by discussing what this means for conservation and biodiversity science, and why these suggestions will face resistance.

SYMPOSIUM 1:

Nature Exposure and Human Health and Wellbeing

Linking biodiversity and health: Synergies for conservation?

Richard Fuller[1]
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Spending time in nature alleviates many of the stresses and strains of modern life. A regular "dose" of nature reduces the risk of depression, hypertension, diabetes, and a host of other non-communicable diseases. More biologically complex environments appear to deliver greater health benefits, so designing landscapes that simultaneously promote human health and biodiversity could create important conservation outcomes. This idea has begun to permeate environmental management globally, with important consequences for biodiversity conservation. Experiences of nature might also spur a person to care more deeply about environmental issues, leading to downstream conservation outcomes via their behavioural choices. Yet, while intuitive, there is limited empirical evidence on the conservation outcomes of the link between nature and health. I will describe several of our recent attempts to search for the conservation outcomes of enhanced connection to nature, charting what we know about the origins of conservation concern in a person. Multiple lines of evidence suggest that while conservation concern is somewhat correlated with the extent to which a person spends time in nature, many other factors drive the expression of conservation behaviour. I conclude that the link between biodiversity and health has the potential to drive significant conservation outcomes, but that significant research and management gaps remain.

Amplifying health through community gardening

Jill Litt[1]
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Chronic diseases and mental health disorders are among the most important public health challenges worldwide. We tested whether community gardening, as a multicomponent and synergistic lifestyle intervention, could reduce risks for chronic diseases and mental health among age- and ethnically diverse healthy adults.

Methods

We conducted a randomised controlled trial among adults over 18 years old who had not gardened in the past two years. Participants were randomised within waitlists for community gardens in Denver, Colorado. Primary outcomes were diet, physical activity, and anthropometry; secondary outcomes were perceived stress (PSS-10) and anxiety (GAD7). Analysis used intent-to-treat. Difference score models evaluated secondary outcomes.

Findings

From 2017-2019, 291 adults participated. Significant time-by-intervention effects were observed for fibre ($p=0{\cdot}034$) and moderate-to-vigorous physical activity ($p=0{\cdot}012$). There were no significant time-by-intervention interactions for combined fruit and vegetable intake, healthy eating index, sedentary time, body mass index, and waist circumference (all $p>0{\cdot}04$). Difference score models showed greater reductions among intervention participants (T2-T1) in perceived stress ($p=0{\cdot}025$) and anxiety ($p=0{\cdot}044$).

Interpretation

Community gardening improved fibre intake and moderate-to-vigorous physical activity but not combined fruit and vegetable intake, healthy eating index, sedentary time, body mass index or waist circumference. Moreover, community gardening reduced perceived stress and anxiety. These data, drawing from a robust randomized controlled trial, suggest that gardening can improve key health behaviours and emotional health outcomes that are critical for reducing risk for chronic diseases and mental health disorders.

Greenspace, temperature and human health – an epidemiological perspective

Kathrin Wolf[1], Susanne Breitner[1,2], Veronika Huber[1,3,4], Alexandra Schneider[1], Annette Peters[1,2]

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Increasing urbanization and climate change have amplified the importance of understanding the complex relationships between environmental exposures and human health. Air pollution, noise, a lack of greenspace and non-optimal temperatures have been identified as the main external drivers.

This talk provides an epidemiological perspective on the impacts of greenspace and temperature on various health outcomes by presenting the latest research findings and insights from several large EU and worldwide projects (e.g., ELAPSE - Effects of Low-Level Air Pollution: A Study in Europe; EXHAUSTION: Exposure to heat and air pollution in Europe – cardiopulmonary impacts and benefits of mitigation and adaptation; the Multi-Country Multi-City (MCC) Collaborative Research Network) and German? epidemiological cohorts, like KORA (Cooperative Health Research in the Region of Augsburg) and the German National Cohort (NAKO).

Moreover, the talk will also give insights into the multifaceted interplay with other environmental factors but also encompassed the influence of socioeconomic status, neighbourhood characteristics, and individual susceptibility emphasizing the need to consider potential effect modifiers and underlying mechanisms to understand the differential impacts across populations.

In conclusion, this talk provides insights from an epidemiological point of view, underscoring the significance of incorporating greenspace into urban planning and public health strategies to enhance human health and well-being in the context of climate change.

Getting a well-being 'boost' from forest biodiversity

Zoe Davies[1], Jessica Fisher[1], Martin Dallimer[2], Katherine Irvine[3], Gail Austen[1], Sam Aizlewood[1], Robert Fish[1], Peter King[1]

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People rely on well-functioning ecosystems to provide critical services that underpin human health and wellbeing. Consequently, biodiversity loss has profound negative implications for humanity. Human-biodiversity interactions can deliver individual-level wellbeing gains, equating to substantial healthcare cost-savings when scaled-up across populations. However, critical questions remain about which species and/or traits (e.g. colours, sounds, smells) elicit wellbeing responses. The traits that influence wellbeing can be considered 'effect' traits. Using techniques from community ecology, we analyse a database of species' effect traits articulated by people, to identify those that generate different types of wellbeing (physical, emotional, cognitive, social, spiritual and 'global' wellbeing, the latter being akin to 'whole-person health'). Effect traits have a predominately positive impact on wellbeing, influenced by the identity and taxonomic kingdom of each species. Different sets of effect traits deliver different types of wellbeing. However, traits cannot be considered independently of species because multiple traits can be supported by a single species. Indeed, we find numerous effect traits from across the ecological community can elicit multiple types of wellbeing, illustrating the complexity of biodiversity experiences. Our empirical approach can help implement interdisciplinary thinking for biodiversity conservation and nature-based public health interventions designed to support human wellbeing.

Greater biodiversity improves health and pro-environmental attitudes

Kirsten McEwan[1]
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Taking evidence from research cantered on Government urban greening schemes, residents Smartphone data and manipulation of virtual nature, I will describe how greater biodiversity can improve health and pro-environmental attitudes. I will also share research showing that greater perception of biodiversity, noticing and appreciating nature has an even greater impact and could be fostered via mindful outdoor activities such as Forest bathing.

Nature, Biodiversity, and Health: What are the research gaps and implications for policy and practice?

Rachel R. Y. Oh[1], Aletta Bonn[1]
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Over the past decades, the global burden of disease has shifted away from communicable to non-communicable diseases such as cardiovascular diseases, diabetes and mental illness. This entails significant healthcare expenditure, economic losses and general decrease in quality of life.

Simultaneously, the use of nature exposure (i.e. people's contact with nature) to deliver health benefits has intensified recently. For example, urban parks and community gardening are two widely used measures to foster physically active and socially cohesive lifestyles. More recently, North America and UK are applying nature-based social prescriptions wherein a healthcare provider (e.g. a physician) prescribes spending time in nature (to patients).

However, there are still many unknowns impeding the large-scale application of nature exposure as a public health intervention tool, such as the weak evidence base supporting a causal relationship between nature exposure (e.g. time spent in parks or on gardening) and human health outcomes (e.g. clinical depression). Relatedly, the mechanistic pathways through which people receive health and wellbeing benefits from their nature exposure remains uncertain, and the bulk of studies are geographically biased towards western, educated and high-income settings.

Summarising outcomes from an international workshop involving 30 stakeholders from research, practice and policy, this presentation will focus on how nature exposure could be used as an equitable, global public health intervention tool. It will provide an overview of the current nature-health research landscape, and elaborate on the types of evidences necessary to drive future research, practice and policy needs that promote both the wellbeing of natural ecosystems and human populations. Where useful, it will draw on examples from both Europe and beyond.

SYMPOSIUM 2:

Economics of Biodiversity

Carbon Emissions, Biodiversity Loss, And Financial Asset Prices

Gregor Weiss[1]
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The presentation reviews the state of the literature in financial economics on the effects of physical and regulatory risks related to biodiversity loss on economic asset values. It presents the methods that financial economists have developed and applied to observe the effects of both climate and biodiversity on both asset values such as stocks, bonds, house prices, and financial derivatives. Whereas there is robust evidence that climate-related variables affect asset values and derivatives, the evidence for biodiversity is more mixed. The presentation concludes with an overview of current and future research needs at the interface between biodiversity science and financial economics.

Insurance value of ecosystems and its governance

Eeva Primmer[1]
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The notion of insurance value of ecosystems has both conceptual and practical appeal. However, the operationalisation of the concept does not yet match the typical assumptions about the governance of ecosystems and ecosystem service provision. The presentation will provide a comprehensive effort to address this challenge by offering conceptualizations and examples of metaphorical, analytical and operational applications of the concept of insurance value. It will exemplify the varied uses of the concept of insurance value and the ways in which it is positioned in relation to governance. When designing governance solutions for the provision of insurance value from ecosystems, the state of the ecosystem and the activities through which its insurance value generation will be targeted should be clear. The presentation highlights the importance of considering the assumptions and framings regarding how insurance value is generated in the ecosystems, through preservation, sustainable use or restoration, or through a combination of these strategies.

Implementation of Ecosystem Accounting: Current state in Germany

Simon Schürz[1]
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This talk gives an overview of the implementation of ecosystem accounting at the federal level in Germany. We describe the stepwise approach to build regular, standardized and nationwide extent, condition and service accounts using semi-automated processing of geo-data from large number of sources. The involvement of relevant stakeholders, the consistency with international frameworks and reporting systems and the integration with other environmental-economic accounts are discussed. Finally, we give an outlook to a possible monetarization of ecosystem services and assets and explore related challenges.

The cost of biological invasions

Anna Turbelin[1]
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Biological invasions have emerged as a major driver of biodiversity loss, with harmful impacts to societies and the environment, generating large and rising economic costs. The extent of these costs is still being uncovered as documenting the cost of biological invasions is complex and fragmentary with impacts spanning multiple sectors and evolving over time. However, the development of the InvaCost database – a publicly and freely accessible database – has enabled rapid extraction of cost information globally, leading to myriad assessments of invasion costs across geographic, taxonomic, and spatio-temporal scales. In this talk, I will share key results from the costs synthesis drawn from the InvaCost database such as the costs to primary sectors of activity and the relative impact to countries bearing the costs. I will discuss the importance valuing the impacts of biological invasions, and how cost assessments can support policy and decision makers.

Managing Biodiversity Risk in Financial Institutions

Andreas Wagner[1]
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While all eyes are currently still on climate change, the topic of biodiversity is becoming increasingly important for the financial industry. In particular, first estimates related to the dependencies of the financial industry or the economy as a whole on nature and biodiversity in particular, as well as the impacts on nature have led to significantly rising awareness. Furthermore, the evolving regulatory developments and voluntary standards and initiatives are driving activities in the financial industry, with the ultimate aim to embed biodiversity into risk management and client interaction. Here, market participants can leverage on lessons learned from dealing with climate risks and opportunities. However, with major frameworks still evolving, open questions persist with regard to the tools and metrics which should be applied to set biodiversity objectives.

Measuring biodiversity for the purposes of finance

Richard Field[1], Franziska Schrodt[1]

[1]*University of Nottingham, NOTTINGHAM, UK, richard.field@nottingham.ac.uk*

This talk gives updates from working groups of the World Economic Forum and the UNDP/UNEP-backed ‘Biodiversity Credits Alliance’. These aim to develop and guide good practice and ecological standards globally, in coordinating biodiversity credits and related financing of biodiversity conservation.

BioImpacts: Assessing the biodiversity footprint of companies

Alke Voskamp[1], Thomas Kastner[1], Hanno Seebens[1]
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Human consumption and trade lie at the core of ongoing biodiversity loss. Several of the main drivers of biodiversity loss, such as land use change, overexploitation, climate change, invasive species, and pollution, are direct consequences of current unsustainable business practices. In response to the biodiversity crisis, global and European-level initiatives have set ambitious goals and targets for the protection of nature, climate, and people. Consequently, there is a growing demand for companies to measure their impact not only on climate but also on biodiversity. Addressing this need, we bridge biodiversity research with the private sector. Our primary objective is to develop science-based metrics that enable the assessment of companies' impact on biodiversity. To achieve this, we focus on three of the five main drivers of biodiversity loss: quantifying potential impacts of companies on biodiversity through land-use change, climate change, and the spread of invasive species.

SYMPOSIUM 3:

The Functioning of Future Ecosystems

How to study the interactive effects of global change drivers on the functioning of future ecosystems?

Anja Linstädter[1], Anja Linstädter[1]
[1]*University of Potsdam, Potsdam, DE*

Earth has entered an era where profound anthropogenic changes are creating novel conditions that will be discernable far into the future. Multiple global change drivers are altering ecosystem functioning in complex ways. Sometimes, these drivers act independently of another, but often they interact, which makes it particularly difficult to understand their joint effects. Thus, studies that examine multiple co-occurring global change drivers are critical for understanding their effects on future ecosystem functioning.

Among global change drivers, climate change and land transformation are of particular concern, as they are cardinal drivers of biodiversity change, often with detrimental consequences for ecosystem functioning. In my talk, I will present complementary approaches to study the effects of these two drivers on ecosystem functioning and ecosystem service provision (the BEF-BES relationship). I will illustrate these approaches with examples from managed grassland ecosystems. Approaches include (i) crossed gradient studies where regional climate gradients are combined with local gradients of land-use intensity; (ii) full-factorial field experiments; (iii) coordinated distributed experiments; (iv) global network initiatives assembling data from local gradient studies; (v) data-assembly studies and meta-analyses synthesizing data from multiple studies; and (vi) temporal analysis, including paleoecological studies. Together, these approaches provide a comprehensive understanding of how global change drivers act individually and in combination, aiding in effective ecosystem management and conservation. Future ecological research needs to design meta-coordinated global studies, where different approaches are performed with harmonized study designs and sampling protocols.

Finally, I will advocate for interdisciplinary approaches with a social-ecological systems perspective, and highlight their methodological and conceptual benefits and challenges.

Biodiversity – ecosystem function (BEF) research: the challenges and future prospects

Jan Lepš[1], Aleš Lisner[1]
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I will concentrate on the two most frequently studied "functions" of ecosystems: productivity and its stability. I will focus on controversial points: Why do the results of observational studies assessing the diversity - productivity relationships differ from the results of manipulative BEF experiments? How does BEF research reflect potential species loss in real-world ecosystems?

The relationship between productivity and diversity has traditionally been studied from two perspectives. Firstly, diversity as response to the productivity gradient (diversity ~ productivity), usually studied using observations of communities on a productivity gradient or by manipulating productivity by nutrient addition. Secondly, diversity as the determinant of community productivity or stability, studied using diversity manipulation (BEF experiments). These two approaches provided often conflicting results. The humpbacked model was frequently considered optimal for the diversity ~ productivity relationship, but the situation is much more complicated, with results depending on the "productivity" characteristics used. Nutrient additions (both in experiments and real-world eutrophication) are usually detrimental for diversity. In BEF experiments, the commonly used design (correct from a statistical point of view) corresponds to the random species loss scenario, which is highly unrealistic. In this scenario, the increasing number of species leads to (usually asymptotic) increase of productivity and to the stabilization of community biomass over time. We applied more realistic approach (removal of the least abundant species from a community until the desired species number is achieved) and showed that the total community productivity was independent of species richness and three species communities were sufficient to stabilize the community biomass. The fact that productivity increases with diversity in synthetic random assemblages is not a good argument for biodiversity conservation.

Forecasting biodiversity dynamics under future global change

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Biodiversity and ecosystems are degrading worldwide in response to multiple anthropogenic pressures. Yet, our understanding and predictive capacity of these dynamics remains limited. Part of the problem could be the sheer complexity of nature and the human-mediated impacts, but also limited data and uncoordinated modelling efforts. In my presentation, I will outline current incentives for an integrated biodiversity modelling platform to understand and predict biodiversity dynamics at different spatio-temporal and taxonomic scales, test the effectiveness of evidence-based management and mitigation strategies, and guide monitoring and experiments. Improved modelling platforms paired with efficient data science tools could help answering pressing fundamental and applied questions related, for example, to attributing recent biodiversity change to abiotic and biotic drivers, and to guiding conservation and restoration in a dynamic and rapidly changing world.

Collectomics and the extended specimen: from collections to global ecosystem change

Karsten Wesche[1,2,3], Paul Kühn[5], Raymond Umazekabiri[1,3], Vamsi K. Kommineni[2], Jens Kattge[2,6], Julia Sigwart[4], Christine Römermann[2,5], Senckenberg Collectomics Group[4]

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[5]*Friedrich-Schiller-University, Jena, DE*
[6]*Max Planck Institute for Biogeochemistry, Jena, DE*

Global change has multiple dimensions and has altered ecosystems in various respects, many of which still poorly understood. Changes in species composition in response to changing land-use and climate are the perhaps most well explored facet of biodiversity change, but respective inferences are typically based on data with limited spatial and/or temporal coverage. BEF-studies have demonstrated associations between ecosystem functioning and species diversity, but they also demonstrated that species characteristics have an often much more direct impact on processes. Although trait databases have grown tremendously over the last years, they remain incomplete and biased towards certain species groups. Scenario development for biodiversity change thus suffers from a threefold shortfall, i.e. of spatial coverage, of temporal coverage, and of coverage of facets of biodiversity rather than mere species identity.

The world's natural history collections host billions of specimens, and jointly have a unique spatial coverage, cover the last 150-200 years and thus the key phase of the global change, and allow to study multiple facets of biodiversity as typically entire organisms are kept. Recent developments in sensor technology and digital data exchange no allow to unlock this treasure chest. Techniques like high-throughput sequencing, spectroscopy or novel imaging tools give new avenues for collection-based research; they all yield digital data that can be interlinked. Establishing a global, coherent and comprehensive virtual research platform has emerged as an increasingly realistic goal, that is pursued by initiatives like collectomics and the extended specimen. The talk demonstrates this potential by showing case studies on non-invasive detection of changes in nutrient contents, on documenting morphological change, on new data platforms and on how all these can be used for earth system modeling

Plant Genetics: from the lab to Nature

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New sequencing technologies have opened fresh avenues for the molecular characterization of species assemblages in ecosystems and landscapes, many of which are structured by their plant communities. The interpretation of such sequencing data requires a deeper knowledge of the ecological importance of specific genes and alleles. I will present the trans-regio research initiative we have established at the Universities of Cologne and Düsseldorf. The aim of this initiative, called TRR341 Plant Ecological Genetics, is to establish connections between the traits that reflect plant performance in natural complex environments and the molecular traits that genes control. In doing so, we will provide molecular signatures of complex ecological traits that will expand our ability to dissect ecological processes at work in natural ecosystems.

Leveraging whole-ecosystem flux data for insights in ecosystem function and its relation to biodiversity

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This talk treats the utilization of expansive whole-ecosystem flux data as a fundamental tool for unraveling the intricate relationship between ecosystem function, structure and biodiversity. By delving into the dynamics of energy, water, and nutrient fluxes across the ecosystem, this study aims to uncover the underlying mechanistic principles that govern the emergent behavior of ecological systems. Through a comprehensive analysis of these fluxes, this research offers profound insights into the fundamental processes that are governed by the underlying traits. It is evident that species traits and trade-offs propagate to the ecosystem level, but not unequivocally because of scale emergent properties arising from biotic and abiotic processes.

BugNet – a global research network to investigate the impact of invertebrates and pathogenic fungi on plant communities and ecosystem functioning

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Invertebrate herbivores and fungal pathogens strongly influence plant diversity and plant community composition but also mediate different ecosystem functions like nutrient cycling, carbon sequestration and decomposition. Despite their importance, knowledge of the effects of insects, mollusks, and fungal pathogens on plant communities and ecosystem functioning, the context-dependence of their effects, and how such plant-consumer interactions are affected by global warming is limited.

The aim of the Bug-Network (BugNet) is to investigate the individual and interacting effects of different invertebrate consumer groups and pathogenic fungi on plant communities. Together with more than 100 collaborators we seek to exclude these consumer groups experimentally in herbaceous dominated ecosystems worldwide, covering large ecological gradients. This allows us to uncover general patterns which will improve our understanding of their role in ecosystems, their influence on functioning and how outcomes depend on the respective ecological context.

In addition to introducing the BugNet research network, we present a modified experimental design that we will conduct in the Swiss Alps. Using a combined approach of consumer exclusion, experimental warming and transplanting focal plants along an elevational gradient, we will investigate how global warming is affecting the impact of enemies on plant communities, plant mutualists and ecosystem functions. Understanding these mechanisms will pave the way to incorporate biotic interactions into global change models and refine predictions of the effects of global change on ecosystems.

Can trees defend themselves better against herbivores when planted in mixtures?

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For understanding biodiversity-ecosystem functioning relationships and applying that knowledge to biodiversity conservation and restoration, determining the processes connecting multiple trophic levels is crucial. For example, leaf herbivory can impact primary production. Thus, plants defend themselves against herbivorous insects in various ways, including attraction of more or less specialized natural enemies to damaged plant parts (indirect defenses) by changing the volatile organic compounds (VOCs) they emit. The exact compounds associated with the defense response (and possible cues for antagonists) are unknown for most species and might be context-dependent. Moreover, surrounding plant density and diversity can influence leaf chemistry (by growth conditions) and the surrounding natural enemy community (by resource availability) and its prey-finding ability (target-tree apparency). Hence, there might be several mechanisms by which surrounding plant diversity can influence plant defenses, but their relative importance is unclear, especially in forests.

In field studies at the MyDiv tree diversity experiment (Bad Lauchstädt, Germany) in 2021 and 2023, we tested whether native trees (*Fagus sylvatica, Quercus petraea*) planted in monocultures or in mixtures of up to 4 species differ in their indirect chemical defenses. We repeatedly induced a standardized, unspecific anti-herbivore response on single branches of young trees with methyl-jasmonate, a derivative of the plant hormone jasmonic acid, and compared their VOC profiles to non-induced branches. Additionally, we assessed predation rates by birds and arthropods, two main natural enemies of herbivores in forests, with artificial clay caterpillars before, during and after induction treatments. We expected that differences between treated and non-treated branches would increase with repeated treatment, and that tree species richness and height difference to surrounding trees would modulate the treatment effect.

SYMPOSIUM 4:

Transformation Through Agroecology

AGROECOLOGY - European Partnership on accelerating farming systems transition: Agroecology living labs and research infrastructures

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AGROECOLOGY, the European Partnership 'Accelerating Farming Systems Transition: Agroecology Living Labs and Research Infrastructures', is an ambitious, large-scale European research and innovation endeavour between the European Commission (EC) and 26 Member States (MS), Associated Countries (AC) and Third Countries. AGROECOLOGY will support an agriculture sector that is fit to meet the targets and challenges of climate change, biodiversity loss, food security and sovereignty, and the environment, while ensuring a profitable and attractive activity for farmers. Major change is needed to make the agriculture sector more sustainable, resilient and responsive to societal and policy demands. Agroecology builds on natural, biological interactions while using state-of-the-art science, technology and innovation based on farmers' knowledge. It represents is a promising approach with the potential to respond to challenges faced by the European agriculture sector and to meet its needs. Real-life testing and experimentation environments, living labs are an appropriate instrument to accelerate the agroecology transition. Research infrastructures will also contribute to making scientific knowledge on agroecology available for this transition. Together these instruments will allow for ambitious experimentation at different scales, merging science and practice, to provide science-based evidence on the effects of novel approaches and accelerate the agroecology transition. AGROECOLOGY will pool the resources of the EC and the states involved to fund high-level research generating appropriate knowledge and technologies aligned with the core themes described in the Strategic Research and Innovation Agenda (SRIA), while also implementing a series of supporting activities to inform, consult, advise and involve different stakeholders to build capacities, raise awareness and manage and exchange the knowledge and data created.

Thinking the future European network of Living Labs and Research Infrastructures for accelerating agroecology transition

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Living labs (LLs), open innovation arrangements empowering co-design with users in real conditions, are instruments to accelerate transitions. Their use is concerning agroecosystems is expanding since 2018, adding to multi-actor innovation in terms of social and economic empowerment as well as system redesign. One of their particularities is the strong engagement of researchers from many disciplinary fields and of research organisations, up- and outscaling capacities of real-life endeavours. However, such upscaling will be limited if LL do not network. The EU will strongly support their implementation through the AGROECOLOGY partnership The EU H2020 project ALL-Ready aims to prepare the ground for agroecology transition and the future partnership by designing a framework for a future European network of LLs and Research Infrastructures (RIs). The project gathered 15 international organisations to develop a conceptual framework to evaluate how LLs will contribute to this transition with efficiency. The framework outlines the objectives, tasks, relevant participants, and contexts in which LLs can viably contribute to and develop incentives for expediting agroecosystem redesign and AE transition. Criteria, indicators and auto-evaluation surveys have been developed to identify and characterise organisations and stakeholder groups that can strengthen AE transition as well as specific skills and conditions for supporting the empowerment of the actors along the value chain. The project then established a pilot network to explore the needs in terms of co-creation processes, governance, emergence of research questions and challenges of LLs at the actor level, the lived experience. ALL-Ready thereby developed a transdisciplinary approach with the pilot members and consortium to specify the implementation plan for the future network. ALL-Ready outlines the potential for LL to give impulse to redesign the system for a sustainable, ecological farming in Europe; however, in order to reach that level of change, connecting LLs with RIs will be a strong asset.

Living labs as entry points for agroecological transition: testing of the theoretical framework in local, regional and national living labs

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This study is focused on the user-driven LLs for agroecological transitions at different geographical scales: local, regional, and national.

This study is targeted at assessment of the LL's activity, dynamics and potential impact on the territorial development. Three pilot European LLs were created in the Netherlands, Italy (Varaita Valley in the Western Alps, Italy), and in the UK (Ryton, Coventry University, UK) within the project AE4EU.

The main research objective of the paper is to carry out inter-scale comparison of the living laboratories. This objective was achieved through (i) using the adopted framework for carrying out a cross comparative analysis of the three LLs; (ii) assessing the actual and potential impacts of the three LLs on the created networks, agroecological practices and food chains as well as the economic, social and environmental sustainability; (iii) providing a definition of the agroecological LLs.

In order to achieve the main research objective, qualitative and quantitative methods were used. Qualitative methods include collecting data during the workshop with the LL facilitators, and further qualitative analysis. NVivo software was used for coding process. Coded text was used for further cross comparison of the LLs.

Quantitative methods include an online questionnaire for data collection and further statistical analysis (t-test). The questionnaire was developed for impact assessment of the LLs and contains 18 questions based on the 4 points Likert scale. The respondents from each LL have evaluated potential and real impact across 5 dimensions: economic, environmental, social, political and organizational.

Results of the research will contribute to a further development of the living labs and to fostering agroecological practices at different scales.

Agroecology in action: engaging with stakeholders to move towards pesticide-free landscapes

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Effective farming management that strengthens the role of natural enemies in controlling pests can help achieve the critical objective of reducing the use of pesticides in modern agriculture. However, current efforts to achieve this goal tend to concentrate on modifying practices at the field level, overlooking the fact that pests and their natural enemies are also influenced by ecological patterns and processes that extend beyond individual fields and farms. Consequently, enhancing natural pest control will require addressing practices at the landscape scale as well. This situation calls for exploring with farmers how their own management decisions and those of their neighbours can affect pest control in individual fields across landscapes.

Here, we present an operational framework that addresses this need and combines (i) long-term monitoring of natural pest control, landscape-scale farming practices and landscape configuration, (ii) identification with local stakeholders of potential changes in their practices they are willing to engage with and (iii) a spatially-explicit simulation tool predicting natural pest control in response to changes in farming practices at the field, farm and landscape levels. We then report on how this framework has been implemented in two contrasted landscapes of the French long-term monitoring network SEBIOPAG: one arable landscape near Dijon (Burgundy) and one mixed farming landscape near Toulouse (Occitanie). In both situations, we predict that the changes envisioned by farmers will boost natural pest control and that there is much more gain for individual farmers if all neighbouring farmers also engage in the transformation on their own farm. We then describe the stakeholders' perceptions of these outcomes and how they utilized these findings to identify essential actions they are willing to undertake collectively in their landscape.

The KoMBi network: Exploring collective models for enhancement of biodiversity in farmed landscapes

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Achieving a system transformation of agriculture towards agroecological and biodiversity-supporting practices requires deep-rooted initiatives acting at the scale of whole landscapes. KoMBi (Collective Models for the Enhancement of Biodiversity) is a project of the German Federal Biological Diversity Programme, which aims to explore the benefits of collective approaches to landscape transformation for enhancing and supporting biodiversity in farmland. It leverages a network of actors (land users and land care associations) in six model regions of Germany where context-specific and locally adapted measures for biodiversity enhancement are developed and implemented collectively. The resulting transdisciplinary infrastructure forms the foundation for a constructive evaluation of biodiversity-enhancing measures from local to landscape and regional scales. This includes the experimental assessment of ecological, socio-economic and governance mechanisms expected to catalyze uptake and impact of biodiversity-enhancing measures. In this talk, we describe how the structure and approaches of the transdisciplinary KoMBi network are expected to contribute to agroecological landscape change.

BEATLE project: Inter and transdisciplinary assessment of agricultural policy transformation pathways towards a biodiversity-friendly food system.

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The transformation of agroecosystems towards a biodiversity-friendly land use (BFL) requires consideration of ecological and economic aspects. So far, economic simulation models that depict both supply and demand (i.e., market models) consider the costs of BFL but fail to incorporate their benefits. Additionally, a successful transformation can not only be based on economic criteria but has to consider the needs of stakeholders. In the BEATLE project, we generate knowledge towards creating and implementing BFL systems using an inter- and transdisciplinary approach. Specifically, we aim to develop an ecological-economic model that integrates the ecological benefits of implementing biodiversity-friendly measures (e.g., flower strips) on farmland biodiversity and productivity. By including international trade linkages, the model will also allow us to analyze leakage effects (e.g., shifting production to trade partners). The model will then be fed with different transformation scenarios that are developed by stakeholders on a national level (Germany). The transformation scenarios will be based on different options in the agri-food sector on a medium-term time horizon until 2040 (including the CAP period starting in 2033). In the project's first phase, we have developed a conceptual ecological-economic model that captures relevant factors between agricultural land use (e.g., organic and conventional production methods), ecology (contribution of semi-natural habitats (SNH) to the maintenance of pollinator populations), and ecosystem services (pollination) if unlimited knowledge and data on the "true" ecological and economic relationships were available. In order to translate the conceptual model to a validated ecological-economic model, we conduct meta-analyses to synthesize current evidence on the ecological benefits of SNH in agricultural landscapes and its implications on farmland productivity, specifically by quantifying changes in biodiversity and productivity as a result of an increase in the area of SNH in a farm.

Tailored pathways and agroecological action for reviving farmland biodiversity

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The paradigm of infinite growth of agricultural productivity has reached its limits. Increased specialisation and intensification of food production have triggered the farmland biodiversity crisis without ensuring the provision of nutritious food for all and further intensification is not universally possible. Therefore, a paradigm shift is urgently needed. To foster this shift, we advocate agroecology as a scheme ready to speed up the necessary transformation, i.e. fundamentally changing the structure and functioning of agriculture and food systems. Here, we conceptualise future pathways tailored to the characteristics of agricultural land systems and relate these to targeted farming approaches using agroecological principles. The concept depicts a transformative vision to effectively re-establish farmland biodiversity while safeguarding sufficient healthy food production. It has the potential to support a systematic refinement of existing biodiversity and agricultural policies to enhance their impact and benefit for people and nature.

FInAL - Facilitating insects in agricultural landscapes: co-designing transformation towards higher biodiversity and sustainable farming systems in landscape labs

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There is considerable potential for stopping or even reversing the decline of insect diversity and biomass even in intensively managed agricultural landscapes. The research project FInAL (2019-2025) was started to promote a long-term transformation of agricultural landscapes in Germany as a means to achieve an insect-friendly and economically sustainable agroecosystem.

The first objective was to implement the living lab approach and apply and maintain a co-design process involving researchers of different scientific disciplines, farmers, deployed landscape coordinators, and other stakeholders. Within newly established landscape labs (3 km x 3 km each) in three regions, we develop, demonstrate, and evaluate innovative measures for facilitating insects through the integrated cultivation of renewable resources, implementation of alternative cultivation systems, improvement of IPM techniques, and amelioration of landscape elements. The goal is to provide a year-round supply of food and nesting resources for insects in the landscape by increased structural diversity as well as habitat networks for specific insect groups to connect currently isolated overwintering, reproduction and feeding habitats.

The second objective is to evaluate whether the transformation actually takes effect from an ecological point of view on the landscape scale, as well as socially and economically. Thus, landscape structure, insect abundance, diversity, and associated ecosystem services are monitored and assessed annually. Data from landscape labs during the transformation period are compared with data from a baseline monitoring and from parallel monitoring in reference landscapes (BACI design).

Applied methods are developed and adapted, where necessary. Eventually, we will reflect on the contribution of co-learning, the concept of landscape labs, and a long-term perspective as key components of the transdisciplinary approach to the transformation of agricultural landscapes.

SYMPOSIUM 5:

Response Diversity

Food-web structure and response diversity drive temporal stability of community biomass

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Understanding which mechanisms drive the temporal stability of community is a core question in Ecology. In single trophic communities, response diversity is found to be the core mechanism increasing population asynchrony, thereby increasing the temporal stability of the whole community. However, the mechanisms driving temporal stability in multitrophic communities are less known, particularly regarding the effects of response diversity. We investigated the effects of food-web structure and response diversity on the temporal stability of community biomass. We developed an extension of the Bioenergetic food-web model added to stochasticity in mortality rates. We decreased response diversity by increasing the correlation of stochastic mortality rates among species. We measured temporal stability and its partition in population stability and asynchrony. We further simulated food-webs in mesic and enriched environment.

We found that species richness increases temporal stability of community biomass by increasing asynchrony but decreasing population stability, as in previous studies. We found that connectance generally decreases stability by decreasing asynchrony and population stability but that this effect is hastened at high species richness. Interestingly, average interaction strength was found to be destabilizing, but was stabilizing in case of enrichment. This results resonates with previous studies showing that warming and the resulting increase in interaction strength can stabilize food-webs in case of enrichment. We further found that lower response diversity decreases stability by cancelling the effect of species richness on asynchrony. Interestingly, we found that the loss of response diversity in enrichment context had less impact on stability than in mesic environment. Overall our study highlights the joint role of food-web structure and response diversity in driving community stability in multi-trophic communities.

Intraspecific response diversity of beech (*Fagus sylvatica*) seedlings exposed to simulated drought

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Intraspecific diversity is the basis for adaptation to new environmental conditions, but the interactions between genotypic contributions to intraspecific trait diversity and plasticity are still largely unknown. Beech (Fagus sylvatica) is common in Europe and commercially and culturally important. However, it is a drought-sensitive tree species and particularly vulnerable in the seedling and young growth phase. Climate change, including droughts and heatwaves, is likely to change the distribution of beech in Europe and lead to local population declines. For beech to persist, it relies on intraspecific phenotypic and genetic diversity, which underpin the overall response diversity to environmental stress.

To estimate the breadth of response diversity in European beech, we are conducting a common garden experiment with 187 2-year-old beech seedlings originating from 16 populations across the species range and having known population genetic structure. We furthermore investigate whether and how beech tree seedlings can acclimate to drought via phenotypic plasticity within one season. Toward this aim, we expose half of the potted seedlings to a simulated drought (i.e., rain-free days) in early spring and again in early summer. The two drought periods are intermitted by a recovery period. To assess plant responses to drought, we measure leaf physiological traits such as chlorophyll content, stomatal conductance, and leaf water content. Using leaf spectroscopy, we will derive further traits based on spectral indices, such as the Photochemical Reflection Index (PRI), which correlates with the efficiency of photosynthesis. We will thus be able to capture the relevant physiological drought stress responses across beech tree genotypes. Knowledge about intraspecific response diversity in dealing with drought stress will aid foresters in management and support efforts to help beech persist.

Response diversity to temperature fluctuations in closely coupled lab- and mathematical model populations of an insect Host-Parasitoid system

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A key aspect of understanding Response Diversity lies in quantifying how environmental variation filters through interactions within and between species – e.g., for obligate consumers – and across temporal scales. We explored this using a combination of carefully coupled stochastic mathematical models and controlled lab microcosm populations. We investigated how subtle differences in the response of a stage-structured Host (the Indian meal moth, Plodia interpunctella, a globally distributed pest species) and its Parasitoid (the wasp, Venturia canescens) to fixed or coloured stochastic temperature changes (i.e., random temperature change over time [white noise], or either faster [blue noise] or slower [red noise] changes than random), translate to short, medium and long-term abundance and trait dynamics in this trophic system. Our results show that the short-term lab experiments often used to determine species' responses to different environmental conditions, can be used to parameterise simulation models that predict medium-term population dynamics across one year in the lab (~10 generations). However, longer-term simulations across 100 or more generations demonstrate novel emergent dynamical behaviours under different environmental colours, including phenological mis-match between the Host and Parasitoid that result in increased outbreaks in Host, but not Parasitoid, abundances. We explore how host-larval development-time varies with temperature, providing an underlying mechanism for these novel emergent dynamics.

Climate change shapes evenness richness relationships in a subalpine grassland experiment

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Grasslands face an uncertain future due to impacts of land-use change, climate change, and increasing drought risk. However, global change responses of individual grassland plant species and the overall response diversity of the community vary widely depending on management, regional environmental conditions, and community composition. To investigate these combinations of responses and drivers, we draw on richness-evenness-relationships (RER), which quantify links between species abundances and overall diversity. We apply RER to assess effects of increased CO2, temperature, and drought in a long-term (since 2010) subalpine climate change experiment, and test whether reseeding buffers against these effects. We find that increases in temperature, CO2 concentrations, and drought significantly alter RER in our system, but do not alter average evenness or richness themselves. Although reseeding reduces RER differences between global change treatments and controls, it fails to restore the RER found at the start of the experiment. A potential driver of this result is that a dominant grass species, Arrhenatherum elatius, responds differently to each global change factor, largely determining the direction of the RER and much of the overall community response. In particular, we find that high rates of establishment by A. elatius after reseeding are associated with strong decreases in richness – especially when seeded into diverse plots. In contrast, reseeding in low diversity plots enhanced both richness and evenness. Overall, our results suggest that reseeding can increase richness and evenness, but can also lead to the loss of taxonomic and response diversity. Our results also show that RER can reveal community responses to global change that are not apparent from richness or evenness alone, indicating that RER could be an important metric for making sustainable management decisions.

Temperature change and biodiversity impact community stability differently in temperate birds and fishes

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Determining the factors affecting community stability and how they operate is crucial to understand the maintenance of biodiversity in the face of global warming. We disentangled the relationships among various components of temperature change (TC: median, trend, variability, and extremes of temperature time series) and various properties of 1235 birds and 572 fish communities in North America and Europe. TC was related to community stability either directly or indirectly via at least one community property (richness, evenness, overall synchrony, and synchrony at the extremes). Furthermore, we found evidence of interactions between temperature and richness, but a contrasting impact on bird vs fish communities. We explored two mechanistic hypotheses (H1, H2) which explained how TC could affect stability via changing community-level synchrony – the comparatively lesser explored pathways than the usual one (i.e., via changing diversity). Increasing variation in species' response to TC (i.e., response diversity to changing median temperature) decreased overall community synchrony (H1), in particular, for fish. On the other hand, increasing extreme temperature led to more variability among species' thermal tolerance limits which reduced interspecific synchrony at the extremes (H2) for birds. Considering different components of TC in addition to its synergistic effects with richness in terrestrial vs aquatic communities will improve the mechanistic understanding of biodiversity change to global climatic stressors.

Quantifying spatially explicit species-specific sensitivities to multiple threats at the local scale

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This work aims to quantify the species-specific sensitivities to multiple threats at a local scale and generate spatially explicit species-sensitivity estimates. The study combines information on the level of threat, sensitivity of a species overall, and location of the given site on the response curve to identify the key set of threats that the local species community is most sensitive to in each site. The approach uses statistical models of species distributions and explainable artificial intelligence for around 40 river fish species in Switzerland. The study quantifies the spatially explicit sensitivity of 40 river fish in Switzerland and addresses community-level response diversity by understanding the variation of responses both globally (e.g., entire Switzerland) and locally in specific catchments. The study explores further the theoretical implications of this spatially explicit insight, asking questions such as what the spatial structure in species and community responses to threats is, and what are the consequences of this for meta-population and -community dynamics. The study also generates knowledge to support on-the-ground decision making for river restorations and barrier removals through stakeholder engagement workshops including partners from local communities, regional and national governments.

A copula-based approach to quantify response diversity

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Response diversity describing the variation of responses towards perturbations within a community is considered key for ecosystem resilience. It can be estimated either from the variability of 'response traits' within a community or by assessing performance-environment relationships. As so-called copulas capture all scale-invariant dependence of pairs of variables independent on their marginal distributions, they provide a way to quantify response dissimilarity *rd(A,B) = 2*D1(A, B)*, which is the scaled distance (*D1*) between two empirical checkerboard copulas *A* and *B*. Copula *A* models the influence of one environmental variable on the performance of species *SA*, copula *B* the influence of the same environmental variable on the performance of species *SB*. Mean *rd(A,B)*-values of species pairs in a community is defined as response diversity. As this procedure is analogous to the estimation of *qad* (1-3), it requires no assumptions on the underlying data or regression functions and captures monotonic and non-monotonic performance-environment relationships. Thus, our approach is broadly applicable and will avoid potential biases resulting from inappropriate parametric models. Using simulated and real-world data, we demonstrate the applicability of our copula-based approach to quantify response diversity and discuss its importance to ecosystem stability and functionality.

1. Griessenberger, Junker, Petzel, Trutschnig (2021) R-package *qad*. *CRAN* **Version: 1.0.0**

2. Griessenberger, Trutschnig, Junker (2022) *Methods Ecol Evol* **13**, 2138-2149

3. Junker, Griessenberger, Trutschnig (2021) *CSDA* **153**, 107058

Climatic response diversity of insect communities – challenges and solutions

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Response diversity is an important key to understanding and predicting ecosystem stability, including shifts in ecosystem functions maintained by communities under changing climatic conditions. Useful empirical measures of response diversity thus include comparisons of species' reaction norms to temperature or moisture gradients. Response diversity can be well defined mathematically based on temperature ranges or unimodal species responses such as thermal activity curves, where the sum of species niches represents the overall community niche (see Feit et al. 2021 Proc Roy Soc B 288: 20210547, Kühsel & Blüthgen 2015 Nat Commun 6: 7989). Other physiological measurements such as water loss and respiration rates, relationships between traits and responses, and especially trade-offs between physiological responses can help make the response diversity concept more useful in community ecology and functional ecology. And they can help revitalize the field of ecophysiology in a comparative ecosystem context.

SYMPOSIUM 6:

Biodiversity Monitoring

Designing the European Biodiversity Observation Network

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One of the greatest challenges of biodiversity policy is to have up-to-date observations on biodiversity change and its response to drivers and management. However, until now, a coordinated system of biodiversity monitoring has been lacking in Europe and in most member states. EuropaBON is a project designing an European Biodiversity Observation Network to address this challenge. It started by assessing the user and policy needs regarding biodiversity data, particularly in relation to biodiversity monitoring, and by identifying a list of Essential Biodiversity Variables that need to be monitored to response to these needs. Next, it assessed the existing biodiversity monitoring programs for each biodiversity variable, their level of integration across Europe, what spatial, temporal and taxonomic gaps exist, and what bottlenecks limit the flow of information from data collectors to data users. Based on this assessment, workflows for the different essential biodiversity variables are being proposed, including a set of new sites to co-monitor multiple EBVs chosen using an effective sampling design. We conclude our talk with some showcases of how these workflows can be implemented.

Designing Essential Biodiversity Variable workflows for a European biodiversity observation network

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The EuropaBON project (https://europabon.org/) aims to co-design a European Biodiversity Observation Network with the goal to close the gap between the biodiversity data needs of policy-makers on the one hand and the existing reporting streams and data sources on the other hand. In this context, Essential Biodiversity Variables (EBVs) are used by EuropaBON as a core concept to integrate different reporting streams, data sources, and monitoring schemes, and to measure biodiversity change across multiple dimensions in space and time. In my talk, I will provide an overview on the co-design of EBV workflows in the EuropaBON project. We define EBV workflows as a sequence of tasks that are needed to process a set of raw observations (e.g. from in-situ monitoring or remote sensing) through data integration (e.g. standardizing, harmonizing or pre-processing) to modelling the data (e.g. statistical and geospatial extrapolation, trend analysis and short-term forecasting). Through a comprehensive process of stakeholder engagement, EuropaBON has collected information on data collection and sampling, data integration, and modelling for 70 freshwater, marine and terrestrial EBV workflows. I will provide an overview as well as specific examples of current initiatives, emerging tools, and future needs to establish operational workflows for EBV generation at a European level. I will also synthesize which monitoring techniques are of central importance for generating EBVs at a European scale, including structured in-situ monitoring programs, citizen science observations, satellite and airborne remote sensing, and novel approaches to biodiversity monitoring such as eDNA and digital sensors in combination with AI.

Biodiversity monitoring in reality, top-down or bottom-up?

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To understand what is happening in nature over time, we need to measure and follow changes to biodiversity. This is both a scientific question, to understand the world around us, and a legal requirement through national and international legislation and agreements such as the Habitats directive or agreements in the Convention on Biological Diversity. There are a few different indices on biodiversity such as the Red List, The Living Planet Index and the Indicators for Genetic diversity that are attempts at summarizing these processes of biodiversity loss. Today biodiversity is followed by a number of stakeholders such as governments, universities, NGOs, companies and volunteers. Methods are becoming more and more advanced on all scales, from Satellite imagery to eDNA. The need for monitoring is ever increasing with increases in anthropogenic pressures such as climate change and habitat destruction at even higher rates. The accuracy and representativeness of the underlying data from Biodiversity monitoring, is dependent on long term resources being allocated. The key to long term success in biodiversity monitoring may be to use a plethora of methods and resources, as correlations between them can help bridge gaps when funding varies. Here we will look at a few case studies of low and high tech solutions, bottom-up and top-down, their pros and cons and their evaluation for different species, and how we can use simple measures for rather advanced indices.

DiSSCo: Fully AI-Ready Infrastructure for Digitisation and Enrichment of Collections Data

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With the ongoing biodiversity crisis, the value of specimens in collections for science is rapidly increasing. Biological specimens provide a tangible and verifiable source for species that are now extinct and geological sample material provides a tangible and verifiable source for geological sites that are now disturbed by human activity or no longer accessible. Collected over centuries these act as a time machine revealing information from the past, and the more recent development of preserved e-DNA samples now also provides a tangible source in the environmental biotic and abiotic domain. Data from specimens and samples in collections also plays an important role in combination with observation data because collection data shows relative congruence with expected biodiversity patterns as compared with (even) more biassed observation data (Daru, B.H & Rodriguez, 2023).

The usability of collections in science is however hampered by the limited availability of digital collections data. New developments in AI need to be embraced to industrialise digitisation since less than 10% of the estimated 1.5 billion specimens in Europe is currently digitised, and even less of this data is digitised with the minimum required levels of detail and quality needed for science. Also AI has an important role to play in enriching this data with e.g. molecular data or trait information. To achieve this, data infrastructure is needed that is actionable by both humans and machines. For machines this requires persistent identifiers to unambiguously identify and link data, it requires machine readable metadata, and it requires machine readable descriptions of object types and operations. DiSSCo is implementing a novel FAIR Digital Object infrastructure that has all these ingredients and allows AI-driven machines and humans to directly act on the data and provide digitisation, data extraction, linking, quality enhancement and annotations to increase the usability of collections in research.

Estimating temporal change in biological invasions

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The introduction, establishment and spread of invasive alien species (IAS) populations world-wide is ongoing. Growth in their ecological and socio-economic impacts continue. To stimulate action to reduce this problem, Target 6 of the newly adopted Kunming-Montreal Global Biodiversity Framework (GBF) calls, inter alia, for a 50% reduction in rates of introduction. But how these rates are to be measured remains unclear. There are widely underappreciated challenges in producing reliable estimates of rates of introduction from available data. If variable survey effort is not carefully accounted for, rates are wrongly estimated. To support progress in this area, we outline and demonstrate the nature of the challenge, and provide data and modeling options. The collection of data on survey effort, development of standards for doing so, and refinement of existing modelling approaches for this purpose are needed. Improved awareness and investment in developing robust approaches (e.g. collection of survey effort data in surveillance and monitoring protocols) will be needed by Parties for this component of the GBF's mission to be achieved. Meaningful estimates of changes in the introduction rates of IAS are essential to avoid biological invasions from undermining efforts to achieve the mission of the GBF and related policy.

EuropaBON - Biodiversity monitoring in Europe: user and policy needs

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To implement the goals of the 2030 Global Biodiversity Framework, the European Biodiversity Strategy and the EU Green Deal, biodiversity monitoring is a pivotal instrument to achieve accountability and progress in conservation. Monitoring efforts in Europe, however, suffer from gaps and biases in taxonomy, spatial coverage, and temporal resolution, resulting in fragmented and disconnected data which does not provide sufficient evidence for policymaking. To assess user and policy needs in biodiversity monitoring, we employed with EuropaBON (https://europabon.org/) a four-step user-centered stakeholder engagement process, including an international public stakeholder workshop, a standardized survey, semi-structured interviews, and an expert meeting with representatives of EU member states, the European Commission and the European Environment Agency. The resulting insights into national and European biodiversity monitoring schemes identify policy needs, current challenges and potential solutions.

Based on this indepth policy and science stakeholder assessment, we recommend and outline avenues for the establishment of a European Biodiversity Observation Network through a permanent Biodiversity Monitoring and Coordinating Centre to optimize existing observation efforts, harmonize data, and enhance our ability to predict and respond to key challenges related to biodiversity loss in a changing climate in Europe.

Data management and contracts support organismic and landscape surveys for an efficient biodiversity monitoring.

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Agricultural landscapes bear a special responsibility for the preservation and promotion of biodiversity. Main objectives focus on the creation of a scientific resilient data base increasing knowledge of the state and the development of biodiversity. They also aim for solutions towards a sustainable agriculture that protects and promotes biodiversity. Joint efforts of diverse partners and disciplines are needed to increase the success of projects and the visibility of results.

The Julius Kühn Institute (JKI) as the Federal Research Institute for Cultivated Plants (https://www.julius-kuehn.de/) contributes its expertise in collaborative BMEL projects on biodiversity (FInAL - https://www.final-projekt.de/; MonViA - https://www.agrarmonitoring-monvia.de/). Remote sensing techniques are used for an automated assessment of habitat diversity, while organismic monitoring activities range from classic survey methods to molecular (e.g. metabarcoding) and non-lethal (e.g. camera traps) approaches. JKI activities also incorporate the development and provision of central (geo)data management infrastructures including web based GIS applications (http://geoportal.julius-kuehn.de) and support two NFDI consortia FairAgro (https://www.fairagro.net/index.php/de/) and NFDI4BioDiversity (https://www.nfdi4biodiversity.org/de). Contracts form the legal framework with all partners and involved parties and ensure the data use and data protection.

The JKI is committed to the promotion of biodiversity in agricultural landscapes through monitoring and transformation approaches, data management and networking with other biodiversity stakeholders.

SESSION 1:

Innovations for Sustainable Grazing Systems

Linking biodiversity and health: Synergies for conservation?

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Spending time in nature alleviates many of the stresses and strains of modern life. A regular "dose" of nature reduces the risk of depression, hypertension, diabetes, and a host of other non-communicable diseases. More biologically complex environments appear to deliver greater health benefits, so designing landscapes that simultaneously promote human health and biodiversity could create important conservation outcomes. This idea has begun to permeate environmental management globally, with important consequences for biodiversity conservation. Experiences of nature might also spur a person to care more deeply about environmental issues, leading to downstream conservation outcomes via their behavioural choices. Yet, while intuitive, there is limited empirical evidence on the conservation outcomes of the link between nature and health. I will describe several of our recent attempts to search for the conservation outcomes of enhanced connection to nature, charting what we know about the origins of conservation concern in a person. Multiple lines of evidence suggest that while conservation concern is somewhat correlated with the extent to which a person spends time in nature, many other factors drive the expression of conservation behaviour.
I conclude that the link between biodiversity and health has the potential to drive significant conservation outcomes, but that significant research and management gaps remain.

Prediction of pasture biomass using machine learning-based optical sensing: How temporal and spatial variability affects prediction performance

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Species-rich grasslands represent one of the most ecological forms of agricultural land use and provide numerous ecosystem services. The preservation of these areas requires management support for farmers. Pasture management can be supported by accurate and reliable predictions of the current and future pasture biomass. For the prediction of pasture biomass, machine learning-based optical sensing has become a key approach. Evidence for its effectiveness extends to many different plant species, grass mixtures, grazing systems, and optical sensors used. The importance of this approach has been amplified by advances in sensing technology and the greater performance of machine learning (ML) algorithms. Notwithstanding the increased evidence base, little is known about how the temporal and spatial variability of pasture biomass affects the performance of prediction models. This variability must be considered in the interpretation of prediction models reported in the literature. Moreover, insights into the roles of temporal and spatial variability are required to better inform the development of new models for specific pastures. To address this need, we conducted a systematic review to collate the performance results reported in previous studies based on within-pasture variability, plant species, and optical sensors. We also assessed the reporting of performance metrics. Our results show (1) important differences in the temporal and spatial variability of pasture biomass across studies, (2) a negative effect of variability on at least some facets of performance, (3) a greater probability of achieving high performance for models trained on sensor data of smaller distance from the pasture sward, and (4) a lack of consensus regarding the reporting of metrics to comprehensively describe prediction performance. We suggest recommendations for enhanced reporting to reduce barriers to comparing and integrating evidence.

SMILe – Improving grazing with a software-based, multi-level information system for farmers

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We developed a digital, software-based, multi-level information system for grassland farmers (SMILe) which provides decision support for optimized grassland and grazing management. SMILe is used for gathering, storing, managing, and displaying grassland-related information on farm level. The stored information is used as a basis for decision support on grazing and grassland management, and can be used in modern grassland agriculture. SMILe adds to the digitalisation in modern precision farming and allows for a more sustainable and ecosystem-friendly grassland management.

The software SMILe was developed as part of the "GreenGrass" research project as a new and innovative approach to incorporate novel agronomic, ecological and socio-technic aspects into modern cattle grazing and grassland management. As a key innovation within the research project, so-called virtual fences (as an alternative to physical fences) for the application with cattle grazing are developed. Beyond the mentioned features, SMILe can be used e.g. for planning of paddocks or virtual and physical fence placement, for which then an optimised grazing order can be calculated. More generally, SMILe serves as a tool for planning and managing virtual fences within the newly developed "GreenGrass" virtual fencing technology.

Data gathered within SMILe mainly consists of UAV-based remote sensing information on grassland quality (such as crop surface height, biomass and biomass quality), but also incorporates model-based ecological information (e.g. local fauna or flora abundance data) or satellite data (e.g. greenness, dryness, or open soil information).

We present the SMILe decision support software and its main features, show the integration of possible data, and the utilisation of the software as a tool for grassland management.

Using Machine Learning to Analyze Impacts of Mobile Links Movement on Vegetation and Avian Biodiversity in European Grasslands

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Long-term year-round grazing by horses and cattle has been shown to positively influence various ecological parameters, including plant species composition, biodiversity, and vegetation structure, in European grasslands and heathlands. These changes occur due to continuous activities involved in animal movement, such as grazing, trampling, and seed dispersal. However, the exact underlying mechanisms that affect these changes are not yet well understood.

Recent technological advancements in GPS tracking and the development of sophisticated analysis methods, like machine learning, provide us with the possibility to analyze vast amounts of data and detect non-trivial relationships between movement behavior and ecological changes. This research uses high-resolution tracking data from collared animals (Konik horses and cattle) collected over 12 years alongside biodiversity assessments in terms of vegetation and bird surveys from two conservation areas in Central Germany. Using machine learning algorithms, we detect and analyze movement patterns of grazers and correlate these with ecological changes across various temporal and spatial scales.

The results of this study promote our understanding of how the movement of grazing animals impacts vegetation structure and breeding bird diversity and are useful for improving the implementation of grazing as a nature conservation tool in grassland restoration projects.

Structural diversity concepts for precision grazing aided by remote sensing

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Remote sensing (RS) is increasingly employed to map the status of grasslands via vegetation parameters, enabling the management of structural diversity as a major driver of faunal biodiversity. Here we use RS data related to sward height to estimate grazing intensity effects on structural heterogeneity at different spatio-temporal scales. We employed a 2.5m x 2.5m grid cell base over nine paddocks (1ha each) grazed by cattle in three grazing intensities (moderate, lenient, very lenient; replicated three times) at the research station Relliehausen, Lower Saxony, Germany. Sward height was assessed using RGB sensor data from a camera on a multirotor UAV on five occasions related to various grazing activities during 2020. Within grid cells, relative proportions of sward heights were evaluated in five height classes. Pooled over paddocks, we calculated height class evenness and related those to grazing intensities. While the very lenient grazing intensity maintained structural heterogeneity at a high level throughout the grazing season, it peaked early in the season for the lenient grazing system and late for the moderate grazing system. At the grid cell level, we applied a beta diversity approach based on sward height classes to map local contributions to overall structural diversity within paddocks and to identify areas differing most from the overall structure. In the moderate grazing intensity, these areas were aggregated and related to predominantly high vegetation, resembling conservation measures such as fallow strips. In lenient and very lenient grazing, high contribution areas were scattered and predominantly related to recently grazed subplots, resembling a typical feature of extensive grazing for conservation purposes. Overall, this structural biodiversity approach identifies specific locations in intensive and extensive grazing systems and can be used for spatially explicit management for increasing structural diversity for associated grassland biodiversity.

Towards precision grazing: Spatio-temporal dynamics of the relation between cattle, vegetation, and arthropod abundance

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Domestic livestock has largely replaced the ecological role of native mega-herbivores in temperate Europe. Because livestock grazing affects grassland biodiversity and functioning differently compared to free roaming large grazers, management adjustments are required to approximate natural processes as closely as possible without causing major economic losses. The spatiotemporal precision of remote sensing technology available today opens up opportunities to align these conflicting interests. We evaluate the spatiotemporal scales at which cattle presence modulates vegetation biomass and abundance of relevant arthropod groups (ants, spiders, cicadas, hymenopterans, flies, true bugs, beetles). We relate arthropod abundances and vegetation biomass to both static (stocking density at the field level) and dynamic (cattle presence in consecutive days before sampling at sub-field levels) grazing intensity in an extensive grazing system in Lower Saxony, Germany. Grazing intensity at the field scale was a poor predictor of arthropod abundances, indicating a weak link between small-scale spatial heterogeneity, the major factor driving grazing-biodiversity relationships, and field-scale grazing intensity. In contrast, more arthropod taxa showed a distinct response to cattle presence compared to vegetation biomass across all spatial and temporal scales. This relationship between arthropod abundance and cattle presence was positive throughout. The relevance of temporal heterogeneity in cattle presence as the driving force of structural diversity makes a striking point for cattle ecosystem engineering. In combination, high precision cattle location and vegetation status data opens up opportunities to harmonize economic and environmental interests in grassland management.

Can benefits achieved by species-enriched grass-clover pastures for wild bees and carabid beetles translate into ecosystem service provisioning?

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Ecological intensification aims at fostering farmland biodiversity to enhance ecosystem service provisioning and thereby reducing external inputs and increasing sustainability in agricultural production. To achieve this in dairy production systems, crop-livestock integration, crop rotational systems or augmented plant diversity in managed grasslands seem suitable measures. Augmenting plant diversity may support the diversity of higher trophic levels and the associated ecosystem services. Here, we studied the effect of species-enriched grass-clover pastures in an organic dairy production system on pollination and biological control. We quantified yield in faba bean and weed-seed predation and compared grass-clover pastures were compared to conventional maize or permanent grasslands. We found approximately 30% higher yields of faba bean comparing open pollination to pollinator exclusion. No effect of plant species richness was found on faba-bean yield and weed-seed predation. On the species-enriched grass-clover herb mixture, long-tongued bumblebees, essential for bean pollination, utilized ungrazed strips. Yet, there was no increase in faba-bean yield. This may be a consequence of pollinator dilution due to the higher floral resource availability. Weed-seed predation was significantly higher in conventional maize compared to species-enriched grass clover pastures in September. This accords with a higher carabid beetle abundance measured in maize at that time, but may also reflect a resource-poor environment in maize. Other studies found that the species-enriched grass-clover pastures support high dairy yields and reduce climate gas emissions, while we showed beneficial effects on bumblebees, especially if grazing intensity is reduced which highlights the overall potential of the mixture to enhance sustainable dairy production.

Does virtual fencing have a negative impact on the animal welfare of cattle?

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Virtual fencing (VF) is a modern fencing technology for ruminants in which the visual cue of a traditional fence is replaced by an acoustic warning sound. If the animal ignores the acoustic warning, it receives a mild electric pulse. The cues are emitted by a collar that each animal must wear around its neck. The fence lines can be set by the farmer via GPS and are therefore much more flexible than stationary fences. This flexibility is a big advantage of VF, as it makes fencing and grazing management easier, facilitating grazing even in remote and difficult locations such as environmentally sensitive or protection areas. Despite the lately increasing research on VF, there are still concerns about possible negative impacts on the welfare of the virtually fenced animals. In this study, we reviewed the literature and compared the data from physically and virtually fenced cattle from eight studies concerning the animal welfare. For this we extracted data about the live weight gain, lying time, steps, lying bouts and fecal cortisol metabolites (FCM) and conducted a comparison of the means by t-tests or Wilcoxon tests. There were no significant differences between physically and virtually fenced animals, except for FCM ($p=0.0165$). Since the mean FCM of the virtually fenced animals (17.0 ng/g) was lower than the mean FCM of the physically fenced animals (19.2 ng/g), we concluded that there are no signs of a negative impact of VF on cattle according to the current state of research. It is still important to point out that the number of available studies is low and more research on the welfare of virtually fenced cattle is necessary. If proven as animal friendly, the technology and its flexibility could have the potential to maintain permanent grassland and its biodiversity and function as habitat for flora and fauna in the long-term.

Tracking the regrowth of shrubs using satellite remote sensing data to support conservation monitoring

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Semi-natural grasslands are a fundamental characteristic of the Central European cultural landscape. Their origin and conservation are linked to active management through, e.g., livestock grazing or mowing. They are ecosystems with high biodiversity and provide valuable ecosystem services by supporting pollination and biological pest control. Land abandonment, land use intensification and climate change were identified as major threats to semi-natural grasslands. Land abandonment is a problem because biomass removal is a key requirement to maintain semi-natural open habitats. Without a sufficient level of biomass removal through grazing or mowing, open habitats often become subject to succession and shrub encroachment. Clearing shrub-infested open habitats by machinery is costly, underlining the need for other options to conserve these ecosystems. Grazing by wildlife can be an alternative conservation strategy, compared to or in synergy with mechanical biomass removal at the Grafenwöhr military training area in Bavaria, Germany. Grazing by wild red deer (*Cervus elaphus*) can decelerate shrub encroachment substantially, so that the frequency of shrub clearance might be adapted to local browsing pressure. Monitoring conservation activities – including shrub clearance – at large scale is labour and cost intensive and in case of an active military training area often not feasible. Satellite remote sensing data can provide a synoptic view over large areas with repeated intervals, throughout the growing season. This makes remotely sensed data a powerful source for long-term monitoring and planning of conservation measures. Here we show how freely available satellite remote sensing data can be used to characterize and illustrate shrub management activities at the Grafenwöhr military training area between 2016 and 2022. Our findings show how future conservation strategies can be supported and complemented with remote-sensing-based data, by prioritizing areas where shrub management might be most pressing and desired.

Cattle grazing outperforms mowing in wet meadow restoration following plantation forest clear-cut

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Land-use change and ecological invasion are two main drivers of biodiversity loss, and the restoration of semi-natural wet grasslands is needed to tackle invasive species and re-establish grassland biodiversity on former forest plantations. This study tested the effectiveness of two widely used management techniques (grazing by traditional Hungarian Grey cattle and mowing once a year in August) as a restoration method of wet meadows in a former forest plantation invaded by goldenrod species in Central Hungary. We compared the vegetation composition of grazed, mowed, and reference areas with semi-natural wet meadow vegetation based on plant biomass, species richness and cover of species groups of species origin, life span, growth form, and social behaviour types of Borhidi determining the grazing value and the nature conservation value of the grasslands. We found that grazing by Hungarian Grey cattle resulted in a vegetation that was more similar to the reference wet meadows than mowing once a year in late summer. Grazing was superior to mowing in terms of goldenrod control, total species richness and cover, as well as the abundance of natives, perennials, herbs, and legumes. However, in the grazed area, we detected more disturbance-tolerant and annual species than in the mowed area. Despite the improved vegetation condition in the grazed area, we identified substantial disparities between the grazed and reference areas after three years of grazing. Based on our results, we advise using continuous extensive grazing to restore and maintain semi-natural wet meadows.

Assessment of anthropogenic impact on riparian forests in Southwest Kazakhstan. Limitation of growth by lifestock browsing and water availability in arid region of Central Asia.

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Arid biomes in Central Asia are susceptible to effects of climate change and anthropogenic activity. Especially riparian forests along main river systems in (semi-)deserts are under constant threats of habitat loss and the reduction of natural rejuvenation due to anthropogenic use. We investigated the effects of livestock browsing, which is widespread in the entire region, on the stand structure and radial growth increment of poplar trees (*Populus pruinosa*, *Pop. euphratica*) in forest belts along the Syr Darya river in Southwest Kazakhstan. We quantified the browsing-induced bark damage on nine different plots with 625m² each (three regions with an assumed gradient of livestock impact from low to high). We related the growth increment of the trees to the extent of damage to the trees and to the availability of groundwater. We also considered possible effects of edaphic and climatic conditions on the tree growth. According to our results, water supply exerted a larger effect than livestock browsing on the tree growth. However, not only a reduction in water supply but also livestock browsing, pollarding and tree cutting can have negative consequences on the forests due to reduced rejuvenation, which would result in sparser and overmature forest stands and finally to a degradation of these natural forests.

SESSION 2:

Biological Control for Sustainable Agroecosystems

Spatiotemporal isolation of oilseed rape fields reduces insect pest pressure and crop damage

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Agricultural production requires effective pest management, but recent policy shifts and the rise of insecticide resistance have narrowed the spectrum of chemical agents for pest suppression. Identifying the landscape-level resource requirements of pests to complete their life cycles might unveil novel, sustainable solutions to regulate their populations and prevent crop damage. Using a dataset from 56 spring oilseed rape fields sampled over five years in south-central Sweden, we assessed the effects of landscape composition and configuration at different spatial scales on the densities of different pest flea beetle species. As aspects of landscapes composition, we considered the cover of noncrop habitats (permanent pastures and forests), as aspects of landscape configuration, we included the distances to the host crop and an alternative host crop in the previous year, edge density, and crop diversity in the previous year. Both flea beetle densities and crop damage were negatively related to the distance from spring oilseed rape in the previous year across most species and spatial scales. Edge density in the surrounding landscape was negatively related to the densities of two flea beetle species, predominantly at the 500 m radius landscape scale. The cover of permanent pastures and forests but also crop diversity in the previous year were positively related to the densities of a few species at several, mostly larger (1,000 – 2,000 m) spatial scales. In addition, the cover of permanent pastures at the 500 m scale was positively related to crop damage. Our results indicate that there is no one fits all approach in designing landscapes for flea beetle pest regulation as habitat use and scales of effect are species-specific. Considering the ecological traits of the pest species hence is a prerequisite for optimising landscape-based pest management. Increasing the spatiotemporal isolation of host crop fields is, however, a promising and potentially more general means of simultaneously disrupting populations of multiple pest species and thereby reducing crop damage.

FlowerBeet: Integration of flowering strips into sugar beet cultivation for promotion of beneficial insects and biological control of aphids.

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In sugar beet cultivation, virus yellows transmission by aphids (mainly green peach aphid, Myzus persicae) can cause severe yield losses. Insecticides are used against aphids as virus vectors to secure yields. The number of insecticides currently available is limited and resistances against the compounds might emerge. As an alternative, the FlowerBeet project is focusing on biological control of aphids by means of targeted promotion of beneficial insects and in general promotion of biodiversity through tailored annual flowering strips on sugar beet fields. The trials are conducted in sugar beet fields with conventional management in the Rhineland, where aphid pressure is usually high.

In the first trial season 2021/2022, the flowering strips were well established. Within and in the immediate vicinity of the strips, beneficial insects could be increasingly recorded by means of various traps. In spring 2022, there was a massive and early appearance of aphids (especially black bean aphid, Aphis fabae). Aphid populations were significantly reduced compared to control plots with no flowering strips and no insecticide use. With flowering strips, the area showing symptoms of virus yellows was reduced. No yellowing symptoms occurred in plots with insecticide use, even though many aphids were observed.

Without insecticide, there was a moderate reduction in sugar yield. In the area without insecticide application, no significant difference was observed between parts with and without flower strips. However, due to the arid summer of 2022, it is possible that the effects of aphids (virus transmission, suction damage) were masked. In addition, there were strong site differences, some sites showing no differences between conditions and others suffering yield losses of up to 16% without insecticide application. Therefore, the trials will be repeated in 2023.

Wildflower strips enhance pest regulation services in Spanish orange orchards

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Citrus production is affected by a diverse range of arthropod pests, some of which escape regulation and require insecticide application. To support sustainable production, this study investigated the effect of a novel wildflower strip and its management on 1) plant community composition, 2) carbohydrate resource usage by parasitoids, 4) natural enemy abundance, and 4) pest regulation services.

In a randomised block experiment, three treatments were applied between rows of orange trees: 1) a control treatment, where naturally occurring vegetation was managed by cutting four times annually, 2) a standard management treatment, where the novel wildflower habitat was cut once annually, and 3) an active management treatment, where the same novel wildflower habitat was cut two additional times annually at predicted peak generations of the key pest Aonidiella aurantii Maskell (Hemiptera: Diaspididae) to encourage spill-over of natural enemies onto the crop.

The novel wildflower habitats, under both standard and active management, supported a distinct plant community from the control, characterised by greater cover of forbs and less bare ground. When managed under the standard treatment, wildflower strips provided more carbohydrate resources, supporting carbohydrate feeding in parasitoids across the year. The standard management treatment increased natural enemy abundance in the canopy and enhanced pest regulation. Contrary to expectations, the active management did not facilitate spill-over of natural enemies onto the crop.

This research is the first to establish perennial wildflower habitats for pest regulation in Spanish orange orchards and provides novel insight into the effect of management on natural enemies and pest regulation.

Emergence densities of ground beetles (Coleoptera: Carabidae) depending on distance to field margin and soil moisture

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Semi-natural habitats provide heterogeneity in intensively-used agricultural landscapes with large fields thereby promoting biodiversity and ecosystem functions. Kettle holes (small standing water bodies) add a soil moisture gradient as an aspect of this heterogeneity. Ground beetles (Coleoptera: Carabidae) are sensitive to soil moisture and contribute to pest control consuming for example aphids, slugs and weed seeds. This study aims at quantifying the range and strength of the effects of the heterogeneity kettle holes provide in agricultural landscapes, here specifically of the emergence densities of ground beetles.

The study was conducted in the north-eastern part of Germany in the Uckermark region in the AgroScapeLab Quillow. Emergence traps were placed at several distances from the field margins into winter wheat fields. Sampling took place between March and June 2020. The number of emerging arthropods and of those, ground beetles were derived. Mixed-effect models are used to test for the influence of the distance from the field margin and the soil moisture on the emergence densities. Shifts in ground beetle community assemblage and functional groups are analyzed.

Results will help to estimate emergence densities of ground beetles and relevant functional groups in winter wheat fields.

Grass strips in agricultural landscapes host distinct ground spider assemblages of different functional structure than those within wheat fields

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Maintaining semi-natural habitats in agricultural landscapes has been suggested as a strategy to support beneficial arthropod communities. Here, we explored the role of spontaneous grass strips to enhance taxonomic and functional diversity of ground-active spider communities in wheat fields along a landscape diversity gradient in the county of Northeim, Germany. Using pitfall traps, we sampled spiders from eight wheat fields and three habitat types: the field center, the field edge, and the adjacent grass strips. We collected 1222 spiders (1115 adults) from 57 species and 10 families. Linyphiidae and Lycosidae were the dominant families (52% and 31% of all sampled individuals). Habitat type and the landscape diversity did not affect spider activity density, species richness, or functional diversity (GLMM, $p > 0.05$). However, grass strips hosted a distinct spider assemblage including larger, more free hunting and less ballooning species compared to the field center and edge. Our results suggest that habitat rather than landscape factors may play an important role in influencing the taxonomical and functional structure of spider assemblages, and thus show that spontaneous grass strips potentially play an important role in shaping the functional traits and potential ecosystem services of ground active spiders in agricultural landscapes.

The upscaling and out-scaling of ecological intensification: how smallholder farms can inform the science of managing biocontrol at scale

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Current objectives to harness agroecological functioning to improve the biological control of crop pests are conditional on a range of ecological, social, economic and cultural mechanisms that may hinder or support the success of such endeavours. Against the backdrop of ongoing work focused on the push-pull technology, a mixed cropping strategy aiming to increase biocontrol in smallholder farms of Sub-Saharan Africa, we review some key challenges and knowledge gaps associated with enhancing and managing biocontrol practices on farms. While major knowledge gaps exist with regard to ecological processes affecting biocontrol success at small to large scales, these can quickly be trumped in terms of capacity for implementation by non-ecological factors such as the structure of social systems and the existence and effectiveness of training networks. We argue that it is our responsibility to formulate questions for biocontrol research that lead to effective, adaptable and resilient solutions for the real-world contexts in which they should be implemented. Consequently, research aiming to understand ecological processes for improved biocontrol must be increasingly transdisciplinary and leave a wide margin for flexible application of ecological principles.

Smallholder farming affects generalist predator communities and biological control in Southern Africa

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Agricultural intensification is a major driver for the loss of insect biodiversity and a reduction in associated ecosystem services in industrialized countries. In Africa, there are an estimated 33 million smallholder farms contributing up to 70% of the food supply on the continent. Smallholder farmers suffer from local pest outbreaks and invasive species, but a lack of knowledge about the importance of generalist predators for conservation biological control hampers the development of sustainable pest management practices. We studied the importance of natural shrub habitats, adjacent smallholder maize fields and ecotones for populations of ground-active generalist predators in the rainy and dry season in Namibia and Botswana. We also estimated attack rates on dummy caterpillars and the levels of herbivory on maize plants. The ecotone habitat had the highest activity density of spiders, particularly in the rainy season, while predator numbers did not differ significantly between maize fields and natural habitats. Other predators, like centipedes, were exclusively active during the dry season when herbivore numbers were lowest in both countries. Maize plants experienced a severe fall armyworm outbreak in the rainy season with more than 50% of all inspected maize plants per field being infested by the invasive alien pest in both countries. Consequently, herbivory was significantly higher in maize fields than in natural habitats. Attack rates on dummy caterpillars were highest in the natural habitats, suggesting that predators more commonly attacked caterpillars outside of the maize fields. The high predator activity in the ecotone habitat and the high attack rates in the natural habitat both emphasize the potential to utilize natural enemies to promote biological control in adjacent arable fields. The development of practices that promote spillover of predators and associated biocontrol services into smallholder fields should be a major future research focus.

Experimental canopy gaps and deadwood accumulation influence seed use and foraging behavior of rodents

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Seed predation and dispersal are important ecosystem functions that influence plant population dynamics. In forests, granivory and caching by rodents can affect forest regeneration and species composition. Silvicultural practices or natural disturbances can alter habitat quality, e.g., through structural changes such as canopy openings and deadwood, but the effects on seed use might be shaped by forest type or dominant rodent species.

We used a forest experiment covering three regions of Germany differing in geology, vegetation, and climate. The 29 experimental sites ranged in management intensity from unmanaged beech-dominated forests to intensively managed coniferous forests. Experimental canopy gaps of 30 m diameter and deadwood addition were established in a full factorial design. We offered different seed types in camera-monitored cafeterias for 24 h and determined consumer-specific exploitation rates, seed fate (consumption vs. removal) and feeding behavior of visitors.

Mice (Apodemus spp.) and bank voles (Myodes glareolus) were the most frequent visitors, consuming a total of about 20% of the seeds. Preliminary data analyses indicate that mouse activity was lower in forests with high management intensity. Mice used more seeds in experimental gaps with or without deadwood addition but avoided deadwood under closed canopies. The response of bank voles was region-specific, with higher seed use at sites with deadwood addition or in unmodified controls. Bank voles consumed only 20% of the seeds immediately and removed about 80% for consumption or caching, whereas mice consumed between 20 and 60% immediately, depending on the region. For both taxa, the proportion of in situ consumption decreased with seed weight, meaning that large seeds (beech, oak) had a higher chance of being cached, forgotten and contributing to forest regeneration. Our data indicate a complex relationship between structural habitat changes, region-specific conditions and the feeding behavior of common rodent species.

Food web interaction redundancy explains increased herbivore vulnerability with increasing predator species richness

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Mapping trophic interactions in predator-prey food webs can improve the understanding of how predator species richness and prey availability affect herbivorous prey vulnerability - an indicator of herbivorous prey population regulation. Agricultural practices shape predator and prey communities and thus their potential for herbivore regulation. We characterised arthropod predator and prey communities and their trophic linkages with molecular tools in 19 arable fields across the growing season in 2020. The fields encompassed a gradient of agricultural practices: with or without organic fertiliser, and crop rotations with only annual crops or with perennial ley. We analysed structurally explicit food webs to assess herbivorous prey vulnerability, i.e., the average number of predator species interacting with each prey species. We analysed predators' trophic redundancy, i.e. the mean number of predators with shared prey. Alternative prey beyond the herbivores can modulate herbivore regulation. We therefore compared network vulnerability for three prey groups: soil fauna, herbivores and other predator species, i.e., interspecific intraguild prey (iIGP). With this information we identified how more or less diversified agricultural practices affect prey vulnerability across the growing season. We found high levels of iIGP across the season. Vulnerability of soil fauna decreased and herbivore increased over time. Vulnerability of both iIGP and soil fauna prey only decreased in fields receiving organic fertiliser and perennial ley in the crop rotation. Predators' richness and trophic redundancy emerged as the best predictors of herbivore prey vulnerability. Agricultural diversification such as perennial cropping and organic amendments, fosters species rich predator communities that appear to strengthen the regulation of herbivorous arthropods in interplay with predator and soil fauna prey across the season.

Functional redundancy of weed seed predation is reduced by intensified agriculture

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Intensified agriculture is recognised as a key driver of biodiversity loss, which in turn, can impede ecosystem functions and their stability. Although biodiversity is expected to enhance functional redundancy and stabilize ecosystem functions, few studies have explored how agricultural intensity, affects functional redundancy and its link with ecosystem function stability. Within a large-scale study of 60 fields across Europe, we investigated how agricultural intensity affected the functional redundancy of seed predation. By combining metabolic theory with molecular gut content analysis, we quantified functional redundancy in seed predation for 65 weed genera. In addition, to test if functional redundancy enhanced the stability of functioning, we related it to independent field estimates of weed seed predation. We found that across the weed genera, functional redundancy of seed predation is reduced in homogenous landscapes with high field management intensity and simplified crop rotations. As expected, functional redundancy increased the spatial stability of field estimates of weed seed predation. Our results confirm the importance of biodiversity for stable ecosystem functioning across space and suggest that ecosystem functions are vulnerable to disturbances in intensively managed agroecosystems.

Deciphering pest suppression services by insectivorous bats with remote sensing technology

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Insectivorous bats are key contributors to biological pest suppression in various agroecosystems. However, our understanding of the agro-ecological interactions in which they take part remains insufficient to fully appreciate and enhance their contribution. Remote sensing technologies can help unravel and quantify the role of insectivorous bats in suppressing agriculture pests.
We propose a workflow for field studies that combines ultra-sonic passive acoustic recorders, smart pest traps, exclosure experiments, and DNA metabarcoding for diet analysis to identify, quantify and attempt to enhance pest suppression by bats. We present results from Mediterranean field crops, that show predation by Kuhl's pipistrelle bats (Pipistrellus kuhlii) of 27 species of agricultural pests, including pests of key economic concern. With ongoing research using remote sensing technologies focusing on enhancing the contribution of insectivorous bats to suppress the Tomato leaf miner (Tuta absoluta), a destructive tomato pest. Remote sensing offers novel opportunities for monitoring biological control agents in agroecosystems and may support enhancing the services provided by bats for more sustainable pest management strategies.

Birds and bats enhance cacao yield despite suppressing arthropod mesopredation

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Biocontrol by birds and bats benefits tropical commodity crop yield such as cacao, but the ecological interactions driving these benefits remain poorly understood. Birds and bats consume herbivorous arthropods, but may also eat mesopredators such as ants, with unclear consequences for pest control. We used a full-factorial experiment excluding birds, bats, and ants to assess their effects on (a) multiple arthropod groups; (b) predation pressure on arthropods evaluated through artificial sentinel caterpillars; and (c) cacao yield over one year in shaded agroforestry systems of native Peruvian cacao. Birds and bats increased yield by 118%, equivalent to smallholder benefits of ca. USD $ 959 ha^{-1}yr^{1}. They also decreased mesopredation by ants and other arthropods, but contributed to controlling aphids and mealybugs. By contrast, ants increased the abundance of these sap-sucking insects, reducing cacao yield. According to these results, arthropod predation by birds and bats, rather than mesopredation by arthropods, was most responsible for increases in cacao yield. Moving forward, detailed research about their trophic interactions will be necessary to identify the cause of such benefits. Management schemes prioritizing shade tree preservation and adjacent forests in agroforestry landscapes may retain large benefits of birds and bats and minimize disservices by other taxa.

Who do what ? Comparing birds and ants pest control on the Coffee Berry Borer

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There is an increasing interest in identifying functional groups that support agriculture through the delivery of pest control to reduce agriculture's dependency on synthetic pesticides. A clear example is the control of the coffee berry borer (CBB) (Hypothenemus hampei), the most damaging pest in coffee production, by insectivorous birds. Nevertheless, birds also predate coffee mutualists, exerting a top-down control that can directly impact the delivery of pest control and its disservices. Some of these mutualists are ants which can notably reduce CBB damage. Despite the importance of birds and ants as biocontrol agents in coffee crops, the study of their trophic interactions and how this affects crop yield have been poorly studied. To fill this gap, and generate precise knowledge that contributes to the development of integrated sustainable agricultural practices, we designed an exclosure experiment in a coffee agroecosystem. We selected 49 study sites distributed in three different coffee systems: shade coffee, integrated coffee and plantain, and sun coffee. In each study site, we placed three experimental treatments and a control. To exclude birds, we covered two coffee shrubs using bamboo sticks and plastic mesh. To exclude ants, we applied bearing grease on four target twigs in two other coffee shrubs. A third treatment simultaneously excluded birds and ants using the mentioned methods, and the control shrubs did not receive any treatment. The experiment started in the growing season and extended until the harvest, for 8 months. Parallel to the exclosure experiment, we surveyed the ants and bird communities around the experimental units. Our preliminary results highlight birds as the main CBB predator. Their exclusion increased the number of infested berries by 32,96% compared to the control, and an infestation percentage of 6,93%. The exclusion of ants increased the number of infested berries by 10,84% and the combined exclusion by 21,30%. Comparing the different coffee systems, we found a similar pattern, evidencing an antagonistic interaction between ants and birds. Nevertheless, the exclusion of ants and birds produced a striking number of damaged berries in all the coffee systems. Thus, our research evidences the importance of biodiversity in supporting agriculture production and the need to understand trophic interactions to foster biological pest control.

A new bacterial strain as a bio-agent and bio-fertilizer in plant protection and development

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Climate change is one of the biggest challenges facing crop production in sustainable agriculture. The use of chemical fertilizers and fungicides is a well-known contributor to climate change through greenhouse gas emissions and toxic soil depositions. It is therefore essential to introduce alternative methods to reduce the use of chemical fertilizers and fungicides. Biocontrol and the application of microorganisms such as bacteria are environmentally friendly alternatives in plant protection and fertilization.

This work aims to investigate antagonistic bacterial strains as bio-fertilizers and bio-agents against plant pathogens. A large number of bacteria have been isolated from cotton roots. Their antagonism against plant pathogens, the mode of action and the overall growth stimulation of the plants were investigated. Transmission electron microscopy was used to explore the colonization ability of the isolate inside the plant tissues.

Our results showed that strain SZAD2 which was identified as Bacillus velezensis based on molecular attributes had a significantly high biocontrol potential and could colonize the plant systemically. In addition, it exhibited multiple modes of action against the pathogen and played an important role in controlling plant pathogens and stimulating overall plant growth. We recommend strain SZAD2 for commercial exploration as a new and safe bio-agent in substitution of hazardous chemical fungicides and chemical fertilizers.

Context dependency of biological control in a multi-predator community

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Understanding the dynamics of multi-predator communities has practical significance in agroecosystems where questions of biological control and biodiversity go hand in hand. Prior work has shown that both synergistic and antagonistic net effects can dominate the dynamics of biological control depending on the underlying ecology of the community. Here we use the coffee leaf miner, CLM, (Leucoptera coffeella), and its community of predators to understand how predator diversity impacts the success of this insect pest across ontogeny. We focus on the larvae and pupae stages of the CLM, which are attacked by parasitoids, ants and anolis lizards. While prior work has shown antagonistic interactions between two important predators of CLM, an invasive ant, Wasmannia auropunctata and anolis lizards, here we ask about the impact of the larger community of ants on the control of the CLM.

Our results show both net positive and negative effects of ants on the dynamics of CLM. Both dominant invasive ants in the community, W. auropunctata and S. invicta, have a net positive effect on CLM larvae and pupae. Although W. auropunctata, and likely S. invicta, prey on the CLM, these results suggest that their interference with other predators outweighs any potentially beneficial biological control of the CLM. We suggest that these net positive effects emerge from trait-mediated indirect interactions between these two aggressive ants and anoles which are also known to be predators of CLM. Importantly this net positive effect was not found in other ant species in the community such as Pheidole morens and Technomyrmex dificilis, showing that interactions between CLM and the community are largely species-specific and the community of ant predators should not be considered generally. Further studies are needed to understand how interactions among all the predators in the community are structured and their implications for CLM dynamics.

The potential of web-building spiders as biocontrol agents in apple orchards under different management practices

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Apple orchards in Germany are facing frequent pest infestations which may cause significant economic damage. Traditionally, pests are controlled through applications of synthetic pesticides which have side effects on beneficial arthropods. More sustainable pest management options are needed, but to recommend practices it is important to know how they affect the arthropod communities. Spiders are important natural enemies that contribute significantly to biological control services of pests in temperate European apple orchards. The composition of potential prey differs between integrated and organic orchards and between canopy and work row habitats. It remains unknown if these effects on prey communities alter the prey composition of web-building spiders and if the prey composition depends on the composition of potential prey at all. We surveyed apple orchards under integrated pest management (N=8) or organic managements (N=8) in Eastern Germany using standardized visual surveys for web-building spiders and their prey remains and at the same time sampled the potential prey in tree canopy and work row habitats. The realized prey composition of web-building spiders is not significantly related to the composition of the potential arthropod prey in each orchard. The killing ratio (pot. vs. real.) differs significantly among work row and tree canopy under different management practices such as pesticide use or mechanical treatments. The only prey taxa that was represented in spider prey composition relative to its local dominance were Formicidae. Formicidae were primarily killed by Cyclosa conica, Parasteatoda lunata and Phylloneta impressa. The assumption that generalist predators kill prey depending on their local dominance is not valid for web-building spiders, hence local arthropod numbers should never be used as proxy for biological control services by generalist predators. Quantitative results that provide such information are rare, as field surveys are laborious and as similar information cannot easily be derived from molecular prey studies.

Root-associated bacteria as a source of biological control agents of *Jacobaea vulgaris*

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The spread of invasive weeds can threaten native biodiversity and cause public health problems. Although biological control methods are widely used, controlling weeds with bacteria remains far less explored. Common ragwort, *Jacobaea vulgaris*, is an invasive weed in North America, New Zealand and Australia and is an unwanted outbreak species in its native area in Europe. In this study, we used bacteria isolated from roots of *J. vulgaris* to examine how bacterial inoculation of *J. vulgaris* affects seed germination, seedling health, root growth patterns and early plant growth. We also tested direct effects of bacteria (the virulence of bacteria) on an aboveground biocontrol agent of common ragwort, the leaf chewing caterpillar (*Tyria jacobaeae*), and on a model insect (*Galleria mellonella*). We furthermore tested indirect effects of bacteria, via the plant, on the performance of two specialized aboveground herbivores, *T. jacobaeae* and a phloem aphid (*Aphis jacobaeae*). We found that some of the bacterial isolates significantly affected the health and root morphology of seedlings when grown in agar plates. Two bacteria caused limited root growth of the plant. While none of the bacterial isolates significantly affected seed germination on agar plate and plant growth in soil. Some bacterial isolates significantly improved insect mortality of *G. mellonella* and *T. jacobaeae*. Inoculation of the plant with bacteria did not affect aphid performance, while inoculation significantly affect *T. jacobaeae* preference. Our results imply that root-associated bacteria can be used as a so-far relatively undiscovered source for weed control at the early stages of plants. The results also exemplify how belowground plant-associated organisms can interact with aboveground ones and the possible consequences for weed control.

A meta-analysis of biocontrol potential and herbivore pressure in olive crops: Does integrated pest management make a difference?

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Agricultural policies in the European Union (EU) are increasingly promoting organic management and integrated pest management (IPM) as environmentally friendly alternatives to high-input conventional management. While there is consensus that organic management is largely beneficial for biodiversity, including the natural enemies of crop pests, IPM has been much less scrutinized. We conducted a meta-analysis based on 294 observations extracted from 18 studies to compare the effects of conventional, IPM and organic management on biocontrol potential and herbivore pressure in olive, an important cash crop in the EU. Information about the management practices used was also compiled to assess differences in intensity between the three management strategies. Results suggest that IPM is predominantly based on intensive practices, employing chemical control rather than preventive measures as a first resort. Biocontrol potential and herbivore pressure were similar in conventional management and IPM. Moreover, biocontrol potential was higher in organic crops than in crops under IPM, especially when considering canopy-dwelling natural enemies. Although organic management enhanced biocontrol potential, it also benefitted some olive pests, and in both cases effects were more pronounced at warmer temperatures. Our results suggest that, in its current form, IPM might not significantly affect biocontrol potential or herbivore pressure when compared with conventional olive crop management. A shift to a more comprehensive implementation of IPM practices is thus needed, involving the use of proactive measures to promote natural enemies and regulate olive pests before resorting to chemical control. Moreover, greater use of non-chemical inputs might be required for effective regulation of olive pests in organic olive crops.

Effects of habitat type and landscape diversity on the diversity of Carabids in agricultural landscapes

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The simplification of agricultural landscapes can reduce the abundance and species richness of important biological pest control agents like carabid beetles, resulting in a decreased pest control potential. Therefore, it is essential to redesign agricultural landscapes to optimize conditions for biocontrol agents. Diverse landscapes include a variety of habitats with different environmental conditions and resource types and are therefore expected to favor different carabid species with contrasting characteristics leading to a higher functional diversity and increased pest control potential. However, effects of landscape diversity on local arthropod communities remain understudied and may differ between various positions in the field and adjacent semi-natural grassy strips. To further our understanding how the position in the field within the context of landscape diversity effects the local carabid communities, we investigated carabid communities in 38 wheat field along a gradient of landscape diversity (i.e. Shannon Diversity of land use types) and habitat types (field center, field edge, and adjacent spontaneous grass strips). We collected over 7500 carabids belonging to ~80 species/morphospecies. Preliminary results show highest overall carabid abundances (mean +- sd) in field edges (45.6 +- 35.4) compared to the field centers (33.8 +- 32.6) and grassy strips (23.3 +- 16.4; GLMM, x[2] = 22.547, $p < 0.0001$), but no effects of landscape diversity. However, these abundances are mainly driven by few, but highly dominant species. We will analyze the community composition, estimated species richness (Hill 0) and functional diversity of carabids, considering traits such as body size and foraging strategy, which are expected to be sensitive to landscape diversity. Our research will give insights into how agricultural landscapes should be designed to maintain taxonomically and functionally diverse carabid communities and their potential for pest predation services.

Effects of landscape composition and altitude on pest control in Kenyan maize crops

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The global intensification of agriculture has reduced landscape heterogeneity and this compromises biodiversity and ecosystem services such as pest control. Semi-natural habitats and crop diversity often support important ecosystem services in agricultural landscapes, for example by providing habitat for beneficial invertebrates. Additionally, altitude is known to have an impact on biodiversity and may interact with anthropogenic stimuli that change ecosystem services. Higher elevations have been associated with less species richness in many living organisms including invertebrates. Until now, almost all our understanding of how landscape structure and altitude shape pest control services is based on studies from temperate agroecosystems in the Northern Hemisphere while we know almost nothing about what happens in the tropics.

We examined the effects of landscape composition and altitude on the abundance and diversity of invertebrate natural enemies and pests on twenty-four small-scale maize farms in Western Kenya. Natural enemies and pests were monitored across three planting seasons between 2019 and 2020 by examining maize plants, and by using pitfall traps and sweep nets. Preliminary analyses suggest that maize crops at lower altitudes were more diverse in predatory and parasitic arthropod composition compared to higher altitudes. The impacts of landscape composition are currently analyzed and results will be presented at the conference. An improved understanding of how environmental factors such as landscape heterogeneity and altitude affects biodiversity and ecosystem services is critical to understand how to best improve agricultural sustainability in tropical agroecosystems in the future.

Factors affecting the attack rate and composition of ground-dwelling arthropod communities in desert vineyards and their adjacent natural habitat.

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Conservation Biological Control (CBC) might be a viable strategy and better alternative to unsustainable modern conventional agriculture. However, knowledge of the local environmental conditions and the factors influencing the arthropod communities within the agroecosystem must be known a priori. Furthermore, multiple factors might limit the real extent of the provision of Biological Control (BC), and the sole presence of arthropod predators might not necessarily translate into higher predation. Hence, estimation of the biological control potential should be conducted. In desert agroecosystems, knowledge about the factors influencing arthropod communities and the provision of BC is limited. In this research, we analysed the effect of habitat type (crop field vs natural), non-crop vegetation cover and richness on the community composition and attack rate of ground-dwelling arthropods. Using pitfall traps and the sentinel prey method (a proxy for BC potential) we sampled six desert vineyards from May to July. Our results show that, in desert vineyards and their adjacent natural habitat, the composition of arthropod communities in the crop fields differed significantly from those in the natural habitats and were positively affected by the non-crop vegetation cover but not by vegetation richness. Arthropod attack rate was significantly affected only by the vegetation richness. Additionally, most of the variation in the arthropod attack rate was explained by the vineyard itself and by temporal differences, which also affected the vegetation cover and richness, hence indirectly affecting the community composition as well. Our results suggest that desert vineyards might play an important role in maintaining arthropod biodiversity by offering refugia and resources in extreme summer conditions. Sustainable farming practices should be ensured to maintain viable habitat for ground-dwelling arthropods and avoid negative impacts in desert agroecosystem.

EFFECTS OF NON-CROP HABITAT PROXIMITY ON ARTHROPOD ASSEMBLAGES AND ECOSYSTEM SERVICES WITHIN ARABLE FIELDS

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Proximity to non-crop habitats is recognized for supporting biodiversity and ecosystem services (ESs) within arable land. However, the effects may vary depending on specific factors, such as crop identity, field size, and sampling period. We employed a comprehensive approach, encompassing multiple taxa and direct measurements of ESs, to examine the relationship between distance from field boundaries and arthropod communities and ESs.

We sampled eight taxa of beneficial arthropods and directly measured three ESs using vegetation sweeping, pitfall and pan traps, dummy caterpillars, seed cards, and tea bags. Generalized linear mixed-effects models (GLMMs) were employed to synthesize the responses of arthropod abundance, diversity, and ecosystem services levels to variables, e.g., distance from field boundaries, sampling period, and crop type.

Results from the first year of the study revealed an increase in arthropod diversity near field boundaries. However, the responses of arthropods to the studied variables varied across taxa. For instance, ecosystem services such as arthropod and weed predation were primarily associated with the abundance of specific taxa, such as ground beetles.

This study highlights the significance of adopting a multi-taxa approach to determine the impact of non-crop habitat proximity on agroecosystems. Furthermore, these findings serve as the foundation for a four-year study to monitor the long-term effects of non-crop habitat creation (e.g., wildflower strips) on the agroecosystem, explicitly focusing on arthropod abundance, diversity, and the distribution of ESs.

Promoting natural pest control in arable farming: a long term agroecological experiment

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The implementation of biodiversity-based agroecosystems promoting pest control services could represent an alternative approach to mainstream agriculture. Designing combinations of land management options and testing their impact on pest natural enemies requires to consider multiple spatial scales and a sufficient long timeframe. In 2018, INRAE initiated such approach on the CA-SYS platform, an experimental farm covering 125 ha of arable crops in one block, near Dijon in Burgundy. CA-SYS is a disruptive agroecological experimental system, with a shift to zero-pesticide, the creation of a dense mesh of grassy and flowering strips covering 10ha, and the implementation of two cropping systems, one permitting (TS) and the second with no tillage (SD). It is expected that this combination of alternative practices will boost natural enemies and thus natural pest control and that the ecological changes will occur gradually over time.
To assess this, natural enemies and natural pest control are monitored yearly in spring and autumn both on CA-SYS and on reference neighbouring fields conducted by conventional farmers. Here, we present how communities of carabid beetles responded over time to the implementation of CA-SYS during the period 2018-2022, in comparison with the reference commercial fields outside CA-SYS. Specifically, we examined changes in the abundance and composition of carabid communities both in field margins and within the crops, and how this would impact in-field weed seed and aphid predation

SESSION 3:

Advances in Natural Pest Control Research

Assessing the resilience of pest control in agroecosystems

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In general, increased biodiversity is expected to provide more resilient ecosystem functions. This is largely because in diverse communities there are more species that can contribute to the functions (functional redundancy), and because different species are likely to respond differently to environmental variation (response diversity). Attempts to empirically assess resilience of ecosystem functions in relation to relevant disturbances are, however, few not least in agricultural landscapes. We have investigated functional redundancy and climate resilience of generalist predators feeding on pest aphids in Swedish barley crops. To assess functional redundancy we developed a new method linking interaction metrics with metabolic theory that allows for a quantification of redundancy at the level of ecosystem functions. To assess response diversity in relation to global warming we investigated the activity niches of a large number of actively hunting generalist predators in relation to temperature and combined them into a metric of climate resilience. Applying these methods to our generalist predator food webs, we found that both redundancy and climate resilience of aphid predation was significantly reduced in simplified landscapes. Thus landscape simplification will likely reduce the reliability of aphid control in the future. Ongoing work now expands this approach to predator communities along a North-South gradient across Europe (Sweden, Germany, Austria and Italy). Across this gradient, we will compare climate resilience of aphid pest control in wheat fields with conventional and conservation tillage that are located in landscapes of different complexity. To further assess the resilience of pest control we will study recovery rates and resistance of predator communities and pest control following agricultural disturbances.

A high temporal turnover of natural enemies reduces the intensity and stability of their biocontrol potential

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Biological control is a key ecosystem service behind the promising ecological intensification of agriculture. However, almost nothing is known on the drivers of its temporal stability. Using a four to six years dataset composed of carabid collections, local and landscape-level management descriptors from 57 arable fields in France, we examined the biotic and abiotic drivers of the stability of the biological control potential estimated through the carabid biomass. We showed that the mean α-richness increases the stability and mean of the biological control potential. Increasing α-richness enhances both facet of the biological control potential through decreasing the temporal turn-over of the community. Asynchrony and evenness have no influence. Among abiotic drivers, interannual variation of the pesticide use intensity contribute to reduce the temporal turn-over of the community and the landscape-level crop heterogeneity directly increases the stability of the biological control potential. Increasing both the mean and stability of biological control potential is possible via increasing the alpha-richness and reducing the beta-diversity of the natural enemy community.

Biased functional traits representation in pitfall trap samples can be somehow useful for evaluation of predation rates

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Pitfall trapping is a widely used sampling technique that is standardly employed to collect various data on ground-dwelling arthropods. However, the validity of this method as a quantitative tool has been repeatedly questioned as the representation of species is influenced by their relative activity and some species are only rarely collected using pitfall traps. In this study, we compared species lists of carabid beetles recorded by pitfall trapping and hand searching techniques at 41 sites covering a range of typical habitats present in the Czech Republic. In general, hand searching performed by an experienced entomologist can record almost twice as many carabid species compared to pitfall trapping using an intermediate sampling effort. Sampling method also significantly affected the species traits represented within samples. On average, species recorded by pitfall traps were larger, more night-active, more carnivorous, and less colourful and had lower flight abilities. Strong method-specific biases in the representation of species traits can pose a serious problem for studies focused on functional traits. However, this sampling bias can represent a potential advantage for studies investigating ecosystem services. Species with traits well represented in pitfall trap samples, e.g., large-bodied species, are at the same time the most important providers of ecosystem services relevant for agricultural production, e.g., pest predation and weed seed predation rates.

The effect of grassland management on the diet composition of spiders and their role as natural enemies of pests

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Spiders are top predators in temperate grassland biomes, play a crucial role in shaping arthropod communities and influence ecosystem functioning. Identifying the factors that determine the composition of spider diets will contribute to an improved understanding of land-use effects on arthropod communities and will facilitate conservation. In this study, we used individual gut content metabarcoding of over 1500 spider specimens to analyze the composition of spider diets on 60 permanent agricultural grassland plots across a land-use gradient in the three regions of the DFG Biodiversity Exploratories. By comparing the diet composition not only with land use intensity and the taxonomic and trait composition of each spider community, but also with the potential prey and intraguild predator communities of the respective plots, we provide insights into the relationship between environmental conditions, management and spider diet composition. Land-use intensity affects the trait and diet composition in grassland spider communities, we provide insights to the direct and indirect effects of these drivers. We further highlight results that relate to relevant arthropod grassland pests as prey of spiders and how these properties are related to local land-use intensity.

How agricultural landscapes shape the relationship between predator size structure and pest control

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Agricultural landscape simplification often leads to a decrease in the abundance and diversity of predatory arthropod species, potentially impacting the pivotal biological control services they provide. However, the influence of different predator species on ecosystem functionality varies depending on their functional traits and abundance. Body size, a key trait associated with an organism's position in the food web and trophic interactions, plays a crucial role in predicting prey suppression strength. Thus, understanding shifts in body size distributions within predator communities can provide insights into the mechanistic that link biodiversity and pest control services. Here, we examined the influence of predator body size on pest control across a gradient of landscape composition using a comprehensive database of carabid communities and biocontrol data collected from 300 crop fields in five countries. Our findings reveal that landscape composition plays a significant role in shaping the relationship between predator body size and prey suppression. In simplified landscapes, we observed a significant increase in the density of a few large-bodied predators, which enhanced pest control. Yet, increased body size in simplified landscapes was associated with a reduction in body size diversity. Conversely, lower levels of pest control in complex landscapes resulted from increased proportions of large-bodied species. However, complex landscapes exhibited higher body size diversity and a more even distribution of body sizes, potentially benefiting overall predation. These findings highlight the trade-off between promoting a more diverse and even predator community and maximizing suppression of target pest populations. Moreover, they underscore the importance of considering both body size and landscape context when examining predator size structure impacts on pest suppression, highlighting the challenges in generalizing the effect of body size on ecosystem functioning.

Modelling natural pest control across the world's agroecosystems – an archetype approach

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Control of crop pests by shifting host plant availability and natural enemy activity at landscape scales has great potential to enhance the sustainability of agriculture. However, mainstreaming natural pest control requires improved understanding of how its benefits can be realized across a variety of agroecologies. Empirical studies suggest significant but highly variable responses of natural pest control to land-use change. Current ecological models are either too specific to provide insight across agroecosystems, or too generic to guide management with actionable prediction. We propose instead to harness the joint benefits of empirical, theoretical and methodological knowledge for natural pest control modelling across systems by combining trait-mediated understanding from correlative studies with the explicit representation of causal relationships achieved by mechanistic modelling. To link these frameworks, we adapt the concept of archetypes, or context-specific generalizations, from sustainability science. Similar responses of natural pest control to land-use gradients across cases that share key attributes, such as functional traits of focal organisms, indicate general processes that drive system behaviour in a context-specific manner. Based on such observations of natural pest control, a systematic definition of archetypes can provide the basis for mechanistic models of intermediate generality that cover all major agroecosystems worldwide. Example archetype models based on general ecological theory and knowledge of American and African agroecosystems explain responses of natural pest control to changes in landscape composition and configuration across Europe. Analysing global datasets on drivers and components of natural pest control and mechanistic models of the resulting archetypes can resolve inconsistent responses to land-use change, and improve prediction of natural pest control potential, as well as synergies and trade-offs with other ecosystem services.

Land-use change and biological control, what can we learn when considering the evolutionary potential of natural enemies' prey?

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Conservation biological control in agricultural landscapes aims to promote natural enemy populations to mitigate short and long-term pest damage on crops. Short-term effects of, for example, land-use change show that high landscape heterogeneity promotes biological control. Nevertheless, despite evidence of rapid evolutionary responses of insects to anthropogenic selection forces, insect adaptation to land use and its effect on biological control are largely unknown. We used here a trait-based and spatially explicit model of interacting natural enemies, pest and alternative prey to elucidate how land-use change can affect biological control across eco-evolutionary timescales. We simulated land-use change through changes in plant resources available in a semi-natural grassland adjacent to a crop field by either reducing plant diversity or shifting the dominant plant resource. We then assessed the adaptation of pests and alternative prey's preferred resources and feeding specialization in consequence to land-use change to understand how this affects interactions across trophic levels and biological control. As expected, land-use change renders biological control less efficient before evolution. Simulations on resource preference evolution show that pests and alternative prey adapt to the grassland and populations recover, resulting in a mitigation of the reduction in efficiency of biological control. When reducing plant diversity and allowing herbivore resource preference and niche width to evolve simultaneously, the pest adapts to become less efficient at feeding on the crop. Nevertheless, the evolution of pests and alternative prey to the new landscape conditions results in natural enemy populations declining with negative effects on biological control. We thus conclude on the importance of considering evolution after land-use change land when aiming to achieve long-term sustainable biological control practices in the future.

Habitat specialisation of pest natural enemies: A species-habitat network approach

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In the last decades, agro-ecology and landscape ecology have provided key information to maximize natural biocontrol and minimize pest damages across agricultural landscapes. Natural enemies depend on multiple resources, such as overwinter sites or alternative hosts or prey, occurring across both crop and non-crop habitats. Their capacity to locate and use these resources depends on their habitat specialisation and dispersal ability but also on landscape composition and configuration. Understanding habitat selection patterns of entire communities is challenging due to the inherent large spatial scale and high number of species involved. We recently proposed a species–habitat network approach that is capable of quantifying the level of specialisation of the involved organisms and allow to fully describe the complexity of these spatial relationships. Here, we present an application of this approach by sampling spider and carabid communities in all major habitat types occurring across multiple agricultural landscapes and use species–habitat networks to determine how habitat specialisation changed along gradients in landscape composition and configuration. Although it is well known that landscape simplification often causes the loss of specialists and the dominance of a few generalists, our results provided evidence for intraspecific variation in habitat specialisation, highlighting how carabids can adapt their way of selecting habitat resources depending on the landscape structure. In particular, carabids can use an increasingly broad set of resources and persist also in highly impacted landscapes, while spiders appeared to have a reduced flexibility in their habitat specialisation. From a policy perspective, a deeper understanding on how habitat-species networks work can open the door to effective landscape management for both beneficial insects and pests.

Early detection of pests in agricultural crops using different volatile collection methods.

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It is well-known that when plants are attacked by herbivores, they release volatile organic compounds (VOCs). These compounds can either act as direct plant defenses or act indirectly by attracting natural enemies of herbivorous insects. In agriculture, the early detection of VOCs could support a more targeted and efficient usage of pesticides on crop plants. The well-established method of collecting volatiles using a dynamic push-pull system coupled with gas chromatography-mass spectrometry (GC-MS) is not especially suitable in an agricultural setting. Instead, the electronic nose (e-Nose), a novel technology used in food quality assessment has the potential to expedite the detection process of herbivore induced plant volatiles in agriculture. In this study, we tested the capability of the e-Nose to detect changes in the volatile profile of *Capsicum annum* after herbivory by *Spodoptera exigua* and compared the results with the push-pull system combined with the analytical accuracy of GC-MS. Furthermore, the study sought to determine whether the e-Nose is capable to detect herbivory at an early stage.

The results demonstrate that the e-Nose was capable of detecting the major classes of herbivore-induced plant volatiles identified by the push-pull-GC-MS system, including terpenoids, green leaf volatiles and aromatics. It also accurately distinguishes between the pest-infested and control treatments. However, it was observed that the e-Nose required a significant level of damage to accurately detect the presence of pests. Consequently, early detection of pests using the e-Nose may not be feasible. Nevertheless, surveys of further plant and herbivore species under additional levels of damage need to be conducted to determine the advantages and limitations of this new technology in more detail.

Towards a functional understanding of biocontrol: Which ground-active beetles climb plants?

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Insect pests in the foliage of crop plants pose a significant threat to crop yields. The contribution of ground-active predators, such as carabids and staphylinids, in controlling these pests is an ongoing topic of debate, as these pests spend little time on the ground. However, climbing enables ground-active predators to access insect pests in the foliage and may also support the regulation by non-climbing predator species, e.g. by increasing the dropping propensity of aphids. This study provides the first comprehensive overview of the plant-climbing behaviour of ground-active beetles, including the plants they climb, the prey they consume, and the triggers and modulators of their plant-climbing behaviour. The literature review was conducted through a systematic search in Web of Science, Scopus, and Google Scholar, which yielded 42 relevant studies from 15 countries and 15 cropping systems. Preliminary results suggest that several common carabid species, incl. *Pterostichus melanarius*, *Poecilus cupreus* and *Bembidion lampros,* have been observed to climb crop plants. Notably, *P. melanarius* has been found to climb a wider range of crop plants (e.g. potato, alfalfa), while *B. lampros* appears to climb only certain crops (e.g. maize but not barley). Furthermore, Staphylinids have also been reported to climb crop plants with members of the genus Tachyporus frequently observed climbing winter wheat and preying on aphids in the foliage. The review highlights the potential of ground-active predators for biological control of insect pests in the foliage. The ability of these predators to climb plants suggests that they could effectively regulate insect pests in the crop foliage. However, field research is needed to validate and quantify climbing and foraging in the foliage. A solid understanding of the plant-climbing behaviour of carabids and staphylinids may facilitate the optimization of ground-active predator communities and promote sustainable management of insect pests.

Boosting beneficial arthropods in nature protected areas to strengthen biological control – the project „Schutzhochzwei“

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In nature protected areas in Germany, the use of particular insecticidal pesticides, with risks for bees and other pollinators, is prohibited. Current discussions about extending these bans to other regions, such as Natura2000-areas, are causing farmers to fear lower crop yields and associated income losses. The project „Schutzhochzwei“ (funded by BfN – Federal Agency for Nature Conservation) will investigate whether the abandonment of these pesticides in combination with the consistent implementation of integrated pest management on cropland in nature protected areas, results in the promotion of beneficial arthropods and consequently in an increased natural pest control. Furthermore, additional actions for ecological enrichment will be elaborated to increase these target values.

Systems of pests and beneficial arthropods on cereal fields in nature protected areas, which are already affected by pesticide restrictions, are investigated. The beneficial arthropods present are monitored by the use of pantraps and sweep netting. The occurrence of aphids, the main pest in cereals, is assessed, as well as the presence of aphidophagous predators and of aphid mummies to determine parasitism. The beneficial arthropods of particular interest are hoverflies due to their important pest regulating role in arable crop systems. During further work process, specific interventions for the ecological upgrading of the fields and their surroundings, like flower strips and alternated hedgerow management will be developed and their effects examined. Positive results from this project may have the potential to reduce the concerns of affected farmers and further provide an indication of possible reduction of crop losses by avoiding insecticidal pesticides through the help of beneficial insects.

Moving towards reliable generic landscape-scale models of natural pest control: considering associations between crops, pests and biocontrol agents is important

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Managing agricultural land to maximize the supply of natural pest control has the potential to reduce pesticide use. Tools that are able to represent the relationship between landscape structure, field management and natural pest control would play an important role within farmers' decision making processes, helping in deciding which management practices should be used and where. So far, however, the reliability and the predictive power of generic models of natural pest control is largely unknown. We applied an existing generic model of natural pest control potential based on landscape structure to nine sites in five European countries and tested the resulting values against field measurements of natural pest control. Subsequently, we added information on local level factors to test the possibility of improving model performance and predictive power.
The results showed that there is generally little or no evidence of correlation between modeled and field-measured values of natural pest control. Moreover, we found high variability in the results, depending on the associations of crops, pests and biocontrol agents considered (e.g. *Oilseed rape-Pollen beetle-Parasitoids*) and on the different case studies. Factors at the local level, such as conservation tillage, had an overall positive effect on natural pest control, and their inclusion in the models typically increased their predictive power. Based on these results, our presentation will underline the importance of developing predictive models of natural pest control which are tailored towards specific associations between crops, pests and biocontrol agents, consider local level factors and are trained using field measurements. They would serve as important tools within farmers' decision making, ultimately supporting the shift toward a low-pesticide agriculture.

Functional biodiversity in agrophotovoltaic systems

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In order to achieve climate protection targets set by the German Government, an enormous expansion of renewable energy will be necessary, including photovoltaic (PV) systems. To avoid a land-use conflict between agriculture and energy production, agrophotovoltaic (APV) systems could be increasingly used. In APV systems, the PV modules are either installed elevated above the crop itself or vertically next to the crop, so that the area below or in between the modules can still be used agriculturally.

Currently, there is still a substantial knowledge gap regarding the compatibility of the dual agricultural and PV use. Especially, the potential impact on the functional biodiversity as an important guarantor for high yields and healthy crops in APV systems is still unexplored. Therefore, the aims of the interconnected research projects 'Solarnützlinge' and 'VAckerBio 2' are (1) to explore the influence of APV systems on the functional biodiversity and (2) determine how APV systems can be designed to support settlement and promotion of beneficial arthropods and hence reduce certain pests. Project partners are the Fraunhofer Institute for Solar Energy Systems, the University of Hohenheim and Next2Sun Technology GmbH.

In cooperation with operators of APV systems, the projects will investigate the biodiversity and abundance of beneficial arthropods around existing APV systems, with a focus on hoverflies, Spheciformes wasps and spiders. In order to promote beneficial insects the project is developing and field-testing the performance of various elements that can be integrated in APV systems (e.g. flowering strips or nesting aids installed in the mounting fixtures). Overall, the projects aim to provide knowledge about how APV systems can be designed in an environmentally friendly way generating additional benefits to agriculture through pest control and pollination.

SESSION 4:

Biodiversity Crisis – Focus on Agricultural Landscape

Experiments, not just monitoring, are needed to quantify the main causes of insect decline

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Sparked by reports of insect declines of unexpected extent, there has been a surge in the compilation and analysis of insect time series data. While this effort has led to valuable databases, disagreement remains as to whether, where and why insects are declining. The 'why' question is particularly important because successful insect conservation will need to address the most important drivers of decline. Despite repeated calls for more long-term data, new time series will have to run for decades to quantitatively surpass those currently available. In addition, very few new monitoring projects have actually started, with Germany being a case in point. Here we argue that experimentation in addition to quantitative analysis of existing data is needed to identify the most important drivers to insect decline. While most potential drivers of insect population change are likely to have already been identified, their relative importance is largely unknown. Researchers should thus unite and use statistical insight to set up suitable experiments, to be able to rank drivers by their importance. Such a coordinated effort will also result in increased monitoring and new time-series, but is likely to produce the knowledge necessary for conservation action.

Measuring the biodiversity impacts of food consumption

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Land-use change due to agricultural expansion is one of the main drivers of biodiversity loss. The Global Biodiversity Framework (GBF) lists several targets associated with a more sustainable food system, for example promoting sustainable production, enabling biodiversity friendly consumption choices, and reporting of biodiversity impacts. For all of these targets to be implemented in a meaningful way, we need the appropriate measuring tools. Several biodiversity footprinting methods are being currently being used or developed aiming to fulfill this need. In our project, entitled "Global impacts of agricultural trade and consumption on ecosystems and biodiversity (GRADED)", we develop tools to quantify the biodiversity impacts on a national level. Here, I will present some of the methodological advances achieved by this project, show some of the data produced that will enable a concise assessment, and also touch upon the communication challenges we face when talking to politicians, business or the general public.

Pesticide Effects on Soil Fauna Communities - a Meta-analysis

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The wide use of pesticides to limit crop losses raises concerns about their impacts on biodiversity. Soil invertebrate communities represent a significant fraction of global biodiversity and play crucial roles in terrestrial ecosystems, but there is currently no quantitative synthesis of their response to pesticide use.

Here, using a meta-analysis of 54 studies and 294 observations, we quantify pesticide effects on the abundance, biomass, richness and diversity of natural soil fauna communities across a wide range of environmental contexts. We also identify scenarios with the most detrimental effects on soil fauna communities by analysing the effects of different pesticides (herbicides, fungicides, insecticides, broad-spectrum substances, and multiple substances), different application rates and temporal extents (short- or long-term), as well as the response of different functional groups of soil animals (body size categories, presence of exoskeleton).

Pesticides overall decreased the abundance and diversity of soil fauna communities across studies (Grand mean effect size (Hedge's g) = -0.30 +/- 0.16), and had stronger effects on soil fauna diversity than abundance. The most detrimental scenarios involved multiple substances, broad-spectrum substances, and insecticides, which significantly decreased soil fauna diversity even at recommended rates. We found no evidence that pesticide effects dampen over time, as short-term and long-term studies exhibited similar mean effect sizes.

Our findings demonstrate that pesticide use can threaten soil biodiversity. The detrimental effects of multiple substances revealed here are particularly concerning given that realistic pesticide use often involves combining several substances to tackle several kinds of pests and pathogens over the crop season. Our study highlights that pesticide application has significant detrimental non-target effects on soil biodiversity, eroding a substantial part of global biodiversity and threatening ecosystem health.

Effects of Diverse Cover Crops on Soil Health and Yields

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It is well established that increased plant diversity can benefit multiple ecosystem functions as services as different species perform different functions within the ecosystem due to their differing traits. This raises the question as to whether more diverse mixtures of cover crops grown for a full season within a potato cropping system can also promote agroecosystem services, such as improving both abiotic and biotic aspects of soil health. While mixing species that differ in their traits by which they influence the ecosystem can have positive effects, mixing species may also result in their competition and thus effects on ecosystem properties are due to the dominant crop. Here I will present results from a four-year full-season cover crop project assessing the effects of increasing crop species, functional groups and crop trait diversity on the soil abiotic attributes, such as nutrient capture, building soil particulate organic matter, aggregate stability, and soil biotic properties represented by the composition of desirable (i.e. mycorrhizal fungi and N-fixing bacteria) and undesirable (i.e. potential plant pathogens) in soil microbial communities. Importantly, I will present whether effects of cover crop mixtures on these soil health aspects translate to the succeeding potato cash crop yield.

Balancing agricultural production and promotion of biodiversity: Landscape Experiments to answer complex questions

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Embracing sustainable cropping practices can transform agriculture into a powerful tool to achieving the sustainability goals. To do so, a holistic understanding of agroecosystem functioning and complex relationships between diverse processes and phenomena in a real-world set-up is required. This can hardly be achieved by simple monitoring or conventional experimentation under (semi)controlled conditions. Meanwhile, landscape experiments (LE) aim at elucidating interactions between various landscape structures and functions, and use heterogeneity as the source of information.

Heterogeneity is claimed to be a key factor for promoting biodiversity while minimising trade-offs with other production and environmental goals in farming systems. At the same time, increased biodiversity may serve as a natural driver to reduce the use of harmful substances in agricultural pest and weed control, inducing regulatory functions into the agroecosystem. Yet, knowledge in this area remains limited and rather case-specific.

patchCROP is an example of LE, established by ZALF in cooperation with the farmer community. It aims at studying effects of landscape diversity on biodiversity, crop yield, and weed pressure, pest and diseases. Its area (70 ha) consists of 30 patches (field units) under nine different crops, field elements and managements, surrounded by reference fields. . The design considers explicitly spatially varying soil properties. patchCROP serves as a base for investigating multiple processes of different spatial (from within-field to landscape) and temporal scales. It allows to accommodate a larger species diversity in search for more general solutions, and to collectively consider multivariate effects within the agroecosystem in their interaction. Understanding of synergies and trade-off between selected indicator species and multiple environmental or agronomic factors will support developing solutions satisfying different interests.

Mapping pollination demand and supply globally

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Preserving biodiversity and ecosystems services (ES) has become one of the greatest challenges of the Anthropocene. Among the ecosystem services of major interest from an agricultural perspective, pollination has received a lot of attention, with the presence of pollinator-rich communities known to be influenced by a multitude of variables, such as nesting and floral resource availability and diversity, climate conditions, and the application of agrochemicals.

Despite the attention, knowledge gaps still exist regarding global levels and distributions of pollination supply, as well as links between pollination supply and demand. Existing global pollination models are often based on limited empirical data or contain highly simplified yield-pollination relationships. The aim of our study is to build a global pollination model that estimates pollinator abundances and translates these into ES delivery by confronting the potential supply of pollination with the presence of pollinator-dependent crops, representing the pollination demand.

Capitalizing on the increasing availability of pollinator monitoring databases, we aim to build a global pollinator model that accounts for multiple environmental variables that are expected to influence pollinator abundance, such as edge density, amount of natural vegetation cover, chemical inputs, and crop diversity. In order to translate pollinator abundance into ES delivery, we develop yield functions for different crops, accounting for their specific pollinator dependencies. These functions will provide new insights in the link between pollination supply and demand and allow for the global mapping of ES delivery. The results of our model could hence shed light on regions experiencing pollination shortfalls, as well as increase the knowledge base necessary for developing future food security and biodiversity policies that aim towards agroecosystems in harmony with nature.

Biodiversity-production feedback effects lead to intensification traps in agricultural landscapes

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Intensive agriculture with high reliance on pesticides and fertilizers constitutes a major strategy for 'feeding the world'. However, such conventional intensification is linked to diminishing returns and can result in 'intensification traps' – production declines triggered by the negative feedback of biodiversity loss at high input levels. We developed a novel framework that integrates biodiversity in crop-yield assessments to evaluate risk and magnitude of intensification traps. Simulations grounded in literature reviews demonstrated that intensification traps emerge in most agricultural landscapes (73%), but rarely in major calorie production systems. Small reductions in maximal production by just 5-10% could be frequently transmitted into substantial biodiversity gains, resulting in small-loss large-gain trade-offs prevailing in landscapes with and without intensification traps. However, systematic sensitivity analyses revealed a strong context-dependence complicating the identification of optimal management practices at the field level. Hence, management safety margins need to be considered to prevent the double loss of biodiversity and food security linked to intensification traps.

Feedback loops of biomass production on plant biodiversity mask positive biodiversity effects in managed grasslands.

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Multiple experiments have demonstrated that in controlled settings, random losses in plant biodiversity decrease aboveground productivity. However, in "real-world" systems, such as managed grasslands, plant biodiversity does often not correlate positively to productivity. We argue that this is due to reciprocal relationships between biodiversity and productivity. Although overall, evidence is still scarce, previous studies mostly relied on cross-sectional data (measured at single time point) and structural equation modelling to examine reciprocal relationships. However, novel causal inference tools using panel data (measured at multiple time points) allow for greater flexibility in controlling for confounding variables and time lag effects, increasing the robustness of inferred causal relationships. In this study, we apply advanced causal inference tools and seasonal short-term data to compare the relative strength of relationships between biodiversity and productivity. Specifically, we use data on productivity, standing biomass and species richness collected over two years in both spring and summer across 150 managed grasslands in Germany differing in land-use intensity. We show that reciprocal relationships between biodiversity and productivity are present in managed grasslands. Furthermore, we show that, while positive biodiversity-ecosystem functioning relationships in managed grasslands are possible, they are masked by negative feedback effects of productivity on biodiversity. Ultimately, advancing our understanding of the reciprocal relationships between biodiversity and productivity will help us to resolve the long-running debate about the nature of biodiversity-productivity relationships.

Agroecosystem requirements of high biodiversity without yield loss

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Balancing ecological-economic trade-offs between biodiversity and yields is a key challenge in the current biodiversity crisis, mainly driven by agricultural intensification and expansion. Restoring or maintaining biodiversity in land-use systems is in line of the 2021-2030 United Nations Decade on Ecosystem Restoration. In this talk, I aim at identifying major conditions and requirements of agroecosystems simultaneously managed for high yield and high biodiversity. The main focus of the agricultural policy in the European Community is on certified organic farming as a fundamental alternative to conventional agriculture. However, organic farming suffers from reduced yield and lacks regulations to effectively enhance biodiversity.

Agroecosystems that have been shown to provide both high biodiversity and high yield can be characterized by different characteristics. First, tropical agroecosystems, in particular tropical agroforestry, exhibit high yield gaps, so managing for both higher biodiversity and yield is much easier than in temperate monocultures with their only small yield gaps. Second, substantial crop diversification and reducing field size (down to 1ha) greatly can enhance biodiversity without compromising yield. Third, landscape-level improvements (>20% habitat) reduce extinction rates and allow improved agroecosystem colonization by beneficial organisms. Fourth, field boundary management for crops benefiting from pollination often leads to both higher biodiversity and higher yield, while effective and economically viable biological pest control can be difficult and context dependent.

InsectMow – Development and Evaluation of insect- and spider-friendly mowing technique

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Several studies show that a large proportion of spiders and insects living on agricultural grassland are damaged and/or killed during mowing. Therefore, it can be assumed that intensive mowing of agricultural grassland, which damages not only adults, but also larvae and nymphs, amounts to an "overfishing effect" that has significantly contributed to the current insect decline on agricultural land. The interdisciplinary project "InsectMow" of the Universities of Tübingen and Hohenheim is investigating how the negative effects of mowing on grassland ecosystems can be reduced by a technical modification of standard disc mowers. Therefore, the project aims at pursuing the development of (1) a modified disc mower that causes fewer arthropod losses without economic disadvantages, and (2) an effective insect flushing bar that enables insects to flee. For this purpose, direct, medium- and long-term effects of mowing with various mowing technology on spiders, as well as important pollinating, herbivorous, and predatory insects will be investigated.

From Science to Practice: Disentangling and Mitigating the Effects of Mowing on Grassland Arthropods

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Insect declines have been documented in many regions, with intensive land use being the primary cause. In grasslands, mowing machinery and techniques have a strong negative impact on arthropod abundance and diversity. Mowing causes arthropod mortality but also has indirect effects such as changes in microhabitat and increased predation. It is therefore important to disentangle the effects of mowing techniques on arthropods in real-world grasslands in order to improve grassland management for biodiversity.

Using extended data from grasslands in Germany, we analyzed the influence of different mowing techniques on arthropods. We found a strong reduction in arthropods after mowing, with abundance reduced by up to 1/8 compared to 100 days after mowing. Furthermore, the mulcher resulted to be the most damaging machine. Increased mowing width had a positive effect on orthopterans, but not on other arthropod orders.

Mowing itself has the strongest negative effect on arthropods, while our results show that changes in mowing techniques can also have positive effects. Therefore, to reduce the overall negative effects of mowing, we suggest not only the use of more arthropod-friendly machinery, but also management changes such as less mowing, partial mowing, and extensive grazing. However, biological research alone is not enough to mitigate insect declines and improve arthropod-friendly grassland management. We also need to study biodiversity from a humanities perspective and communicate our findings to the public.

Arthropod pests and aphid diversity in European apple orchards

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As a perennial fruit crop, apple orchards offer a stable ecosystem for arthropod biodiversity. More than 200 phytophagous insect species have been recorded in apple orchards in Europe, of which several species are considered as economically important pests. In a review of the published literature on arthropod pests in European apple orchards, 177 studies from 34 countries were analysed. The research on apple arthropod pests throughout Europe has a strong focus on Southern European countries (Italy, France, and Spain). Hemiptera and Lepidoptera pest species were most frequently addressed (70% of all studies), with pests in the families Aphididae (mainly Dysaphis plantaginea, rosy apple aphid) and Totricidae (mainly Cydia pomonella, codling moth) being most commonly studied. In an empirical study, aphid samples were collected by beating apple tree canopies and suction sampling in the work rows in 16 apple orchards in Eastern Germany from June to November 2021. Aphid communities differed significantly between orchards of different management (Integrated Pest Management [IPM] vs. organic), between sampling periods, and between microhabitats. Notably, the identity of dominant aphid pest species in each management type differed in the second sampling period, with Dysaphis spp (rosy apple aphids) being most common in organic orchards and Eriosoma lanigerum (woolly apple aphid) in IPM orchards. Moreover, during that sampling period, individuals in the genus Dysaphis were significantly more abundant in the work rows, whereas individuals of Eriosoma lanigerum were mostly recorded in the tree canopy. These findings highlight the complexity of aphid communities in apple orchards, with different species thriving depending on the sampling period, microhabitat, and orchard management. The results have implications for pest control and provide a better understanding of aphid pest ecology in perennial fruit tree systems in a previously understudied region.

Practitioner knowledge on grassland restoration – bridging the knowledge gap to science

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In Central Europe, species-rich grasslands have strongly diminished over the last century. The transfer of seed-containing plant material from donor sites with a desired species composition to restoration sites is a well-established method to restore species-rich grasslands. However, despite a plethora of available literature, restoration projects with plant material transfer often fail or do not reach the planned goals. Practitioners' knowledge is a highly important but underexplored source of information on factors deciding about success of restoration projects. At the same time, it is unclear to which degree scientific findings on success factors are known and considered by practitioners, and if science actually investigates the most relevant aspects for practice. To bridge the gap between practitioners' knowledge and restoration science, we conducted semi-structured interviews with 33 practitioners involved in plant material transfer projects. Using qualitative content analysis, we analysed the interviews for success factors, and compared them to success factors of plant material transfer as investigated in peer-reviewed European studies on the method. We found that science investigated a broad range of practical, technical, and ecological success factors, and that practitioners were generally well aware of this evidence, trying to make use of the knowledge. Failure of practitioners' projects often resulted from organizational obstacles, which were founded in lacking trust and low experience levels among the involved people. We advise unexperienced practitioners to involve more experienced practitioners in their projects if possible. Furthermore, we emphasize the importance of identifying relevant local stakeholders and building trust. Interdisciplinary scientific studies considering success factors beyond practical and ecological aspects are required to support widespread successful grassland restoration with plant material transfer.

Crop-weed competition and weed community shifts due to increased fertilizing in organic spring wheat

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Agriculture is one of the major land uses in the current age, associated with a lot of environmental impacts. Thus, the need for sustainable farming is an urgent matter. Organic farming has been suggested as a more sustainable alternative to conventional farming. However, due to lower yields the environmental benefits of organic farming are less prominent, and discussions are heavy of the to be or not to be of organic farming. Less so, the discussion focuses on the possibility of increasing organic yields without loosing its benefits. This study aimed at investigating if organic yields can be increase by higher fertilizing and if this will increase competition with weeds or sacrifice weed diversity. A field experiment in spring wheat was setup in 2022 with four levels of fertilizing, from none to a surplus. Half of the plots were then completely removed of all weeds and the other half left untouched. An interaction of fertilizing and weeding on yield was found, such that by fertilizing weed levels are increased and cause a yield loss. We can also show that by fertilizing the weed community changes, species richness is not affected during this initial year, but evenness decreases with fertilizing. This community shift increases the frequency of troublesome traits such as weed canopy height which suggests competition increases and weed problems are enhanced. In addition, the decrease in evenness by fertilizing potentially forecasts a loss of plant diversity in the long term. Achieving a higher yield in organic farming is possible, however care must be taken to investigate trade-offs between management interests and environmental impacts. More research is needed to find where trade-offs and especially synergies can be found to finally understand what is a sustainable yield level.

Vineyard terracing: a solution to promote biodiversity and preserve cultural vineyard landscapes on steep slopes

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Viticulture on steep slopes has shaped both landscape and biodiversity in wine-growing regions. However, viticultural area suffered strong declines in recent decades due to insufficient profitability. A solution to reduce further abandonment and maintain cultivation economically viable could be vineyard terracing. Yet, little is known about the effects of vineyard abandonment and a change of vineyard management type on biodiversity.

Over three years, we determined the effects of vineyard management types (vertically oriented vs. terraced) in contrast to vineyard fallows, local conditions, and the surrounding landscape on plant, Orthoptera, wild bee and spider diversity in 45 study sites along the Upper Middle Rhine Valley (UMRV) in Germany.

The small-structured landscape of the UMRV supported high species diversity, high numbers of threatened species and diverse species communities across vineyard management types and fallows. Species responses were group and taxon specific and driven by distinct management intensities, local vegetation structures, and landscape structure. In brief, plant and Orthoptera diversity profited from terraced vineyards and nutrient-poor and extensively managed terrace embankments. Wild bee diversity was determined by their distinct nesting needs and particularly supported by woody structures of fallows while spiders benefited from the high landscape complexity.

In summary, heterogeneous landscapes, including actively managed and abandoned vineyards and natural elements that complementary provide resources were critical to fulfilling the many specific needs. However, to preserve the characteristic flora and fauna of steep slope viticultural landscapes, active vineyard management is mandatory. Especially when revegetated with regional seed mixtures, terraced vineyards have high biodiversity potential and can contribute to combining economically viable viticulture on steep slopes and nature conservation objectives in a land-sharing approach.

Effects of surrounding land use on invertebrate herbivory in semi-natural grasslands

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Invertebrate herbivory, serving as a pivotal process in regulating plants' growth, development, and reproductive success, is inherently susceptible to alterations induced by land use changes, encompassing modifications in landscape patterns, habitat quality, resource availability, and species interactions, etc. However, the relationship between land use changes and invertebrate herbivory, although extensively studied, continues to exhibit inconsistent effects across different ecological contexts, and the underlying mechanisms driving these intricate dynamics remain elusive, emphasizing the need for further research. In our study, we accessed the invertebrate herbivory and five key morphological traits in a diverse assemblage of 14 plant species commonly found in semi-grassland habitats across 18 field sites differing in the surrounding land use intensity in Southern Sweden. We found that: 1) Within four landscape parameters, the percentage of permanent grassland had the most pronounced influence on herbivory. Both permanent grassland and forest generally had positive effects on herbivory. In contrast, leys were more likely to have a negative impact, while the percentage of arable crops had the least effect. 2) Some plant species like Achillea millefolium, Ranunculus acris, and Galium verum are particularly sensitive to land use changes, emphasizing their vulnerability and ecological significance in the grassland systems. 3) Plant morphological traits, particularly plant height, also can affect herbivory. However, the effects of these traits vary inconsistently across different species, indicating the need for further studies to better understand their role. Further analysis are currently addressing the covariation in insect herbivory and flower visitation, as well as the herbivorous insect communities along the landscape gradients.

Pollen limitation and pollen parentage determine crop production in a cultivated mass-flowering tree

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Pollen limitation is most prevalent among bee-pollinated, self-incompatible and tropical plants. However, we have a limited understanding of the extent to which pollen limitation affects fruit set in mass-flowering trees despite tree crops accounting for ~600 million tons of the annual global food production. Furthermore, flowers in some tree crops can be self-pollinated by the same cultivar or cross-pollinated by a different cultivar, and yet most mature fruit result from cross-pollination. It is unclear whether few flowers are self-pollinated or, alternatively, few self-pollinated fruitlets are retained by the tree during premature fruit drop.

We determined the extent of pollen limitation in a bee-pollinated, partially self-incompatible, subtropical tree by hand cross-pollinating most flowers on mass-flowering macadamia trees. We measured kernel paternity, tree yield and kernel quality to determine levels of outcrossing in orchards and to assess effects on nut yield and quality. Moreover, we investigated whether pollen parentage determined which fruit abscised during premature nut drop.

Macadamia trees were pollen-limited. Supplementary cross-pollination increased kernel yield and fruit set by as much as 109 % and 92 %, respectively. The proximity to trees of another cultivar determined the extent of pollen limitation. Pollen parentage affected kernel mass, kernel recovery and kernel oil concentration. Most of the abscising and the retained fruit at 6 weeks after peak flowering were undeveloped or self-pollinated, whereas both the abscising and the retained fruit at 10 weeks after peak flowering were cross-pollinated.

Improved pollination can drastically increase crop production, and consequently farm-gate income. Nuts retained by the tree to maturity are almost all cross-pollinated, highlighting the critical importance of improving cross-pollination. This may be achieved by enhancing cross-pollen flow, for example, by interplanting cultivars more closely.

How useful are pollinator tools?

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Widespread declines of insect pollinators are both a conservation concern and threaten the pollination of wild plants and crops. As a result, a plethora of tools have been created to facilitate decisions relating to insect pollinators and pollination in agricultural landscapes. These tools provide invaluable information that help to understand drivers of insect population changes, as well as to project future population trends because of various actions. However, to date there is no comprehensive list of the different tools available, and there has been no overview of the usability of these tools for decisions. We undertook a systematic map to explore the tools that have been developed to facilitate decisions relating to insect pollinators and/or pollination in agricultural landscapes. We mapped the usability of these tools, focusing on the design, purpose and applicability of the tools. This process identified the current tools and highlighted the knowledge clusters and gaps. We provide recommendations for tool developers based on this.

The Digital Agricultural Knowledge and Information System (DAKIS): a novel tool to integrate biodiversity objectives in agricultural management

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Rising human resource needs and the associated expansion and intensification of agricultural production are seen as main drivers in biodiversity loss globally (Foley et al., 2011). To reverse the trend of declining biodiversity, it is necessary to integrate objectives of biodiversity conservation and regeneration of ecosystem services in the management of agricultural systems at landscape scale (Kremen et al., 2012; Mander et al., 2007; Pérez-Soba et al., 2008).

Agricultural advisors and farmers themselves are faced with the challenge to decide how best to achieve multi-objective management of agricultural landscapes: Which agri-environmental measures at which spatial design are best suited to enhance biodiversity and ecosystem services while also maintaining the economic sustainability of farms? The use of digital technologies can provide critical support to facilitate the design and implementation of sustainable agricultural systems (Ingram and Maye, 2020).

In this talk we present the Digital Agricultural Knowledge and Information System (DAKIS), a digital decision support system that is developed to integrate remote and in situ sensors and landscape-scale data.

To develop the DAKIS, we first identified core requirements of the new tool in an iterative process of exchange with stakeholders and members of the DAKIS developers' team. We refined these requirements by using results of a literature review. The DAKIS functionality was further tested through concrete land-management use cases, i.e. hedgerows, grassland buffers and flower strips. By using rule-based analysis, DAKIS facilitates comparison of different scenarios and calculates trade-offs between the provision of multiple ecosystem services, biodiversity conservation and economic objectives. On this basis, recommendations for diversified cropping systems and the placement of agri-environment-climate measures are generated.

Mass-flowering crops and semi-natural habitat mediate niche overlap between honeybees and wild bees

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Resource competition between wild bees and managed honeybees has the potential to detrimentally impact biodiversity and pollination ecosystem services. Here, we undertook a field experiment in semi-natural grasslands in Southern Sweden to assess how floral resource use by wild bees and honeybees was affected by proximity to large apiaries and the amount of mass-flowering oilseed rape (OSR) and semi-natural habitat in the surrounding landscape. We placed large apiaries in semi-natural grasslands in landscapes of low honeybee density and commercial bumblebee colonies at four distances from the apiaries (‹100 m, 500 m, 1000 m and 2 km). We then measured honeybee density, bumblebee colony foraging activity, and each species pollen diet during and after the OSR blooming period. During, but not after, the OSR bloom, high honeybee densities in grasslands close to apiaries affected bumblebee foraging activity in semi-natural grasslands. Yet, despite honeybees and bumblebees exhibiting distinct pollen diets, we found that there was significant niche overlap during, but not after, the OSR bloom. Furthermore, niche overlap was negatively correlated with distance from apiaries and the amount of semi-natural habitat in the surrounding landscape. Our results suggest that large managed apiaries can have a detrimental effect on bumblebee foraging behaviour, but that niche overlap primarily occurs in conjunction with mass-flowering crops. The potential for competition with wild bees for floral resources should be considered when using managed apiaries for pollination services of mass flowering crops. As such, conservation of semi-natural habitat in agricultural landscapes is crucial to reduce niche overlap between managed honeybees and wild bees by providing floral resources which facilitate niche differentiation.

Securing crop fruit set with biodiversity - the effect of wild floral resources on crop pollination

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Changes in land use and climate have sent pollinators, like many insects, into worldwide decline. With the majority of European crops depending at least partly on insect pollinators, human food production directly benefits from supporting flower-visiting insects and the provided ecosystem services by increasing, for instance, the quality and quantity of wild floral resources in arable landscapes. We tested the effects of wild floral resources of (i) flowering fields and (ii) extensively managed fields on insect pollination of two entomophilous crops, i.e. winter rapeseed and strawberry. Following a space-for-time approach, data was collected in two climatically contrasting regions of Bavaria to allow for predictions on the effectiveness of pollinator supporting measures under future climate conditions. Adjacent to each plot, we sampled the local pollinator community as well as visiting pollinators on the flowers of potted phytometer plants and analysed pollinator abundance and diversity. Preliminary results show increases in pollinator abundance and group-level diversity in response to higher wild floral resource availability, and suggest a seasonal complementarity of extensively managed fields and flowering areas. The results provide valuable insights in the current and future relevance of pollinator-supporting schemes for crop production in arable landscapes.

Insect conservation in agricultural landscapes: is crop heterogeneity really the key?

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Identifying landscapes that are suitable for both biodiversity and agriculture is a major challenge. Traditionally, much research has focused on biodiversity conservation outside of agricultural production areas, e.g., in semi-natural habitats. In contrast, recent research has focused on the potential of a heterogenous crop matrix, including enhanced crop diversity and reduced field size, for biodiversity conservation. However, this remains little studied. In this study, we investigated the effects of landscape composition (crop diversity), landscape configuration (field size), and the proportion of semi-natural habitats on insect diversity. We sampled insect communities in an agricultural region around Stuttgart, Germany, using pan traps in 32 study landscapes covering independent gradients of landscape composition and configuration. We identified insects using DNA metabarcoding. Contrary to the general expectation that increasing crop diversity leads to a linear increase in insect diversity, we found a unimodal relationship between insect richness and crop diversity. This result may indicate an area-heterogeneity trade-off, where high crop diversity reduces the effective habitat area available to species. Insect richness was not significantly affected by landscape configuration, i.e., field size. A higher proportion of grassland in the landscape increased the richness of rare insect species. Our study suggests that increasing crop diversity is a viable strategy to promote insect diversity in agricultural landscapes; however, high levels of crop diversity may lead to trade-offs with the effective habitat area available to species in highly complex crop mosaics. Furthermore, crop diversity is more important than crop configuration in our study region, while semi-natural grasslands can further support rare species.

Functional responses in habitat selection as a key to evaluate agri-environment schemes for farmland birds

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Farmland bird populations declined over decades with increasing land-use intensification. Agri-environment schemes (AES) as part of the European Union Common Agricultural Policy are aimed to prevent the loss of farmland biodiversity. However, the results of the ecological effectiveness of AES on farmland birds varied among previous studies. Such variation can occur when individual birds change their habitat selectivity depending on the available habitats, which is known as functional responses in habitat selection. Here, we tested functional responses in the habitat selection by farmland birds, considering AES field patches as components of species' habitats in an agricultural landscape. We analyzed monitoring data of four farmland bird species from 20 line-transect surveys in the Mulde region in northern Saxony, Germany, during the breeding season in 2022. We built mixed-effects models of habitat selection analysis with transect identity as a random effect to estimate marginal effects of both AES and non-AES land-use variables on the occurrence of farmland birds. We then examined if the species' habitat selectivity for land-use variables changes with the respective available land-use area around each transect. All species decreased the habitat selectivity for certain AES land-use variables with the increasing available land-use area. Therefore, differential effects of AES on farmland birds can be explained by the functional responses in habitat selection. Our results suggest the importance of farmland diversification to increase bird diversity and stress the relevance of science communication with farmers and conservation advisory boards to conserve biodiversity in agricultural landscapes in the long term.

Effects of agricultural stressors and habitat quality on farmland birds in the Netherlands

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Pollutants in agricultural landscapes can have a significant effect on the health and diversity of plant and animal populations. For example, agricultural runoff containing excess nutrients from fertilizers can lead to eutrophication of waterways, causing oxygen depletion and harming aquatic life. Similarly, pesticides can have direct toxic effects on non-target organisms, including birds, insects, and amphibians, which can disrupt the balance of ecosystems. In this study, we use measures of water and soil pollutants as indicators of habitat stressors and quality in agricultural landscapes and identify areas that are under stress for farmland birds. We use geospatial data on agricultural stressors and long-term monitoring data of farmland birds to ask 1) what are the over-arching effects of water and soil pollutants on the distribution of farmland birds in the Netherlands 2) how does land use and agricultural production account for the presence of these stressors in the landscape. Using spatial modelling, we found that farmland birds in the Netherlands are under increasing pressure from a range of agricultural stressors such as deposition of pollutants that includes nitrogen oxides (NOx) ammonium (NHx). Since the distribution of farmland birds in the Netherlands is closely linked to the availability and quality of habitat in agricultural landscapes, a range of strategies, including the adoption of best management practices to reduce the use of agrochemicals and the restoration of natural habitats will be required. In addition, engaging farmers and other stakeholders in conservation efforts, and providing incentives for the adoption of sustainable practices, will be critical to achieving success in these efforts.

Effects of historical land use on biodiversity in Baden-Württemberg, Germany.

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The transformation of landscapes by human activities does not necessarily have negative consequences but can also lead to positive outcomes for biodiversity. It can result in a more diverse landscape, providing habitats for a greater variety of species. However, the decline in habitats and the subsequent loss of biodiversity pose significant challenges for nature and species conservation in the 21st century. This study aims to investigate the effects of historical land use on biodiversity in Baden-Württemberg, Germany. To investigate these effects, we analyzed forested areas surrounding castles that were repeatedly cleared and utilized as open land. Specifically, Burg Teck, Hohenneuffen, and Hohenurach were selected due to the availability of historical records spanning several hundred years, allowing for the reconstruction of deforestation events. Vegetation assessments were conducted to compare and evaluate biodiversity among areas with varying frequencies of deforestation.

Data collection, including vegetation assessments, is taking place this summer, and first results will be presented in September. This research seeks to understand the impact of historical land use on biodiversity, providing valuable insights into the potential positive outcomes of past landscape transformations.

Does the vulnerability of Hessian arable weeds correlate with plant characteristics?

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Arable weeds have suffered drastic losses in diversity and abundance in Central Europe over the last century. The loss of species is largely due to intensification and the associated changes in agriculture - especially the use of herbicides and significantly increased nitrogen levels. Here, we investigate the extent to which the expression of plant traits of Hessian arable weeds correlates with higher endangerment according to the Hessian Red List. The trait expressions "lower maximum growth height," "later flowering onset," "lower nitrogen number," "higher reaction number," and contrary to expectation, "lower moisture number" correlated significantly with higher vulnerability. Many plants classified as vulnerable have similar characteristics to the endangered and critically endangered plants on the Red List. Although this survey is based only on correlations and not on causalities, it can be used to identify particularly endangered arable weeds at an early stage and to take timely protective measures.

Floral trait variety in a flower strip

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The interactions between pollinators and their host plants are mediated by a variety of floral traits, such as colour, scent, morphology and floral resources. Bees show preferences for distinct floral cues but the cues preferred in complex bee-flower communities are largely unknown. In modern day agricultural landscapes, flower strips counteract the lack of suitable food resources for bees and attract diverse bee species, whereby a high plant species diversity coinheres with a high bee species richness. However, it is not much known about the trait diversity in floral strips and which of these traits are preferred by the visiting bee species. In this project, we investigated various floral traits of species-rich flower strips that were established within the BienABest project (www.bienabest.de). We analysed the morphology, colour, scent, nectar amount and pollen nutrients of the flowers of about 40 plant species. We are currently analysing bee visitation rates to identify clusters of floral cues that are preferred by distinct bee species or groups of bee species. To better understand the correlatively analysed visitation rates, we performed behavioural experiments with three German wild bee species. We used standardised artificial flowers to test for preferences in single floral traits. We found a strong across-species preference for more intense colours, and for example no preference for complex scent bouquets versus simple scent mixtures. The results of this project can play an important role in improving flower strips to promote diverse wild bee communities and understanding wild bees' behaviours.

Butterfly communities in South Tyrol erode from extensive grasslands to intensively used farmland and urban areas

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The biodiversity crisis occurring in the European agricultural landscapes demands an evaluation of the different land-use practices. In Europe, butterflies are considered an important ecological indicator for biodiversity and a pollinator taxon, especially in grasslands. Most butterfly species require human interventions to sustain their populations and land-use change and management intensification are currently responsible for their overall decline.

We compared 93 butterfly communities occurring in seven widely distributed land-use types, viz. extensive meadows and pastures, semi-intensive meadows, vineyards, arable land, settlements, and apple orchards in South Tyrol. Overall, we recorded high diversity in supposedly high nature value (HNV) grasslands comprising extensive meadows and pastures. All other land-use types scored significantly lower, with decreasing diversity from semi-intensive meadows to intensive apple orchards. Functional traits uncovered a general trend: extensive grasslands supported more specialized and sedentary communities whilst all other non-HNV land-use types supported communities characterized by mobile generalists. Community composition differed among land-use types and was influenced by plant-based indicator values for nutrients, light and temperature.

We found supporting evidence for the effectiveness of regional Agri-Environmental Measures (AEMs) and the general European conservation strategy focused on the preservation of HNV grasslands. We suggest a dedicated subsidies program to conserve extensive pastures, especially at lower elevations, where a diverse and threatened butterfly community was recorded. Furthermore, we recommend taking steps leading to an extensification of non-subsidized (semi-) intensive meadows (avoiding additional management intensification to silage meadows or corn) and to a radical change in the management of intense apple orchards, both would greatly benefit the butterfly fauna in the region.

What explains agricultural diversity, landscape diversity, and ecosystem diversity patterns?

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Agricultural intensification resulted in simplified landscapes over Germany, threatening biodiversity and associated ecosystem services. A number of strategies have been suggested to conserve and enhance biodiversity by diversifying local crop diversity or landscape diversity. Both spatial scales are expected to be interlinked but often considered independently. How the different scales of diversification are linked and spatially organised within the landscape is poorly understood.

We aim to identify both local and landscape diversity patterns by analysing a set of spatial maps including soil, climate, land use land cover, biotope classification, and crop rotational diversity in the case study region Brandenburg, Germany. Machine learning methods were applied to test the relation of both crop rotational diversity and landscape diversity together with potential drivers - in particular soil and climate characteristics. Further understanding of what drives the diversity patterns was assessed using explainable artificial intelligence methods. We found that soil and climate regulate the regional patterns, and the diversity metrics are associated with each other.

This study allows for the first time to analyse the interplay among crop rotational (local), landscape, and ecosystem diversity patterns and their link to soil and climate characteristics. This can help promote a holistic understanding of diversification of agricultural landscapes across multiple scales. Our findings will support enhancing biodiversity through diversification by taking into account surrounding landscape characteristics and context dependency. We will also demonstrate how this approach can be used as a case study to work with stakeholders, including farmers and landowners to transform the agricultural system in a transdisciplinary way.

Which agricultural management practices increase biodiversity and yield? A synthesis of meta-analyses.

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During the last 20 years there is a big growth of meta-analyses examining the trade-offs between yield and biodiversity under different management practices. In theory, a certain management practice can have three potential outcomes regarding biodiversity and yield; either it can be a win-win situation (i.e. both biodiversity and yield increase), or a lose-lose situation (i.e. both biodiversity and yield decrease), or a trade-off (i.e. biodiversity increases and yield decreases or biodiversity decreases and yield increases). We call these outcomes “scenarios”. Here we present a database consisting of meta-analyses that examine the impact of different management practices on biodiversity and yield. We also visualize the effect sizes of multiple meta-analyses in a “scenario space” in order to provide a comprehensive and simplified representation of the outputs of various management practices. Our database provides a clear picture of which practices produce win-win scenarios and under which conditions.

Persefone.jl: simulating landscape-scale biodiversity impacts of agricultural practices

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Although much research has been done on the detrimental impacts of modern agricultural practices on nature and the environment, the loss of biodiversity in agricultural landscapes continues unabated. One reason for this is the difficulty of transforming ecological knowledge into actionable advice for decision-makers, which needs to be based on evidence, specific to their region, and economically practicable. To help deliver such actionable advice, we are currently developing Persefone.jl, a social-ecological model for "**P**olicy **E**valuation for **R**esilient, **S**ocial, and **E**cological **F**arming **O**perations i**N** **E**urope".

Persefone.jl integrates a regional agent-based model of farmer decision-making (developed by Lea Kolb) with an individual-based model of multiple animal species. The two components are linked through a shared dynamic landscape, which is affected by, and affects, both farmers and wildlife. The model also includes weather inputs and a crop-growth submodel. Synthesising research from a broad spectrum of disciplines thus allows us to forecast the response of farming systems and agroecosystems to different socio-economic, political, or environmental scenarios.

This talk focuses on the ecological submodel of Persefone.jl, which is based on empirically-validated principles of animal physiology and behaviour. This mechanistic approach enables us to trace the effects of habitat availability, landscape structure, and anthropogenic disturbance on important indicator species at local and landscape scales. We show first results of a study on the biodiversity impacts of the Eco-schemes, a new set of agri-environmental measures in the European Common Agricultural Policy (CAP). With this example, we demonstrate how Persefone.jl can be used to provide evidence-based, localised advice that can help decision-makers navigate the necessary systemic transformation towards a more biodiversity-friendly agriculture.

The effect of landscape heterogeneity within a highly anthropogenically impacted cultivated area on cavity nesting bees and wasps

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Agricultural intensification causes serious declines in species diversity through habitat loss, fragmentation and degradation. Cavity nesting Hymenoptera provide pollination services to a wide variety of crop and wild plants, are vital hosts for other animals like rare parasitic Hymenoptera, and some act as biological control agents. They are therefore an important element of biodiversity. Studying communities of cavity nesting bees, wasps and their natural enemies allows us to use them as bioindicators of habitat quality.

Here, we investigate the relative influence of habitat availability and connectivity on nest colonisation by cavity nesting bees, wasps, and their parasites within the highly anthropogenically impacted Günz valley in South-West Bavaria. We placed out standardised nesting resources (i.e. trap nests) at 8 pairs of meadows distributed across the entire Günz valley, each site within a network of extensively managed sites paired with a site that was isolated from this network. Field placement took place in spring 2021 and trap nests were collected in autumn 2021 to determine their contents. We combined DNA barcoding and morpho-taxonomy for the identification of bees and wasps. Trap nests were readily occupied but also showed high variance in occupancy, ranging between 0-88%. Species richness ranged between 0 and 6 for bees and 0 and 5 for wasps. In total, we detected 10 bee and 17 wasp species in our trap nests, including the highly endangered leafcutter bee *Megachile ligniseca* and the rare cleptoparasitic bee *Coelioxys alata*.

Further analyses of our data with the use of land cover and management information is used to evaluate the importance of habitat connectivity and landscape heterogeneity for cavity nesting Hymenoptera in the dairy farming dominated Günz valley. This knowledge will support stakeholders and conservation management in general to help reduce the negative effects of habitat loss and fragmentation on the abundance and diversity of cavity nesting bees, wasps and their parasites in agricultural landscapes.

Assessing the Mowing Intensity on Grasslands and its Applications to calculate Effects on Biodiversity

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Agricultural grasslands have undergone rapid change in recent years: Only a few decades ago colorful, small-scale, heterogeneous, species-rich hay meadows or extensive pastures were prevalent and have been often replaced by species-poor, uniform, large-scale multi-cut meadows. Technological advances and agricultural efficiency increased at the cost of a high level of biodiversity in grasslands.

Within the Biodiversity Exploratories 150 grasslands plots in three regions in Germany (Schwäbische Alb, Hainich and Schorfheide-Chorin) were investigated. We provide an overview on mowing practices since 2006 and propose a new compound index for estimating the site-specific mowing intensity, in order to facilitate assessments of the impact of mowing intensity on biodiversity and ecosystem processes. Based on published studies potential impacts of different mowing techniques on meadow-dwelling species were considered. The mowing intensity index takes into account information on the farmer's mowing practices like the mowing machine, mowing height, the conditioner usage, and as basis the number of cuts applied per year.

Here, we want to present the mowing intensity index and its applications to calculate effects on biodiversity, which further could be used to offer subsidies to farmers when employing environmentally-beneficial mowing practices.

Especially grassland arthropods were confronted with this more intensive land use and its associated changes in conditions in recent decades. Many species were unable to cope, and a sharp decline in species richness and abundance was noted. However, some species have been found to cope well with these conditions. In total, we analyzed 1352 species of four arthropod orders (Araneae, Coleoptera, Hemiptera and Orthoptera) to determine whether they emerged as winners or losers from 2008 to 2018 with the applied mowing intensity.

SESSION 5:

Agricultural Transformation for More Biodiversity

Introduction to Agricultural transformation for more biodiversity - where are we?

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Biodiversity loss in agricultural landscape is associated with the loss of structural heterogeneity. To accomplish the required system-change to protect biodiversity it is now necessary to integrate biodiversity enhancing measures in existing agricultural systems, considering economic and social factors, and including farmers in the design and decision-making process. This talk will set the stage for the session, summarize where we are in this transformation process, review the recent literature, show examples of successful applications but also highlight obstacles. We aim to open a discussion to establish a straightforward strategy for implementing scientific knowledge in real world agroecosystems.

Trade-offs and synergies of economic and ecological functions across oil palm systems

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Mitigating economic-ecological trade-offs of oil palm cultivation is essential to safeguard biodiversity and ecosystem functioning in tropical growing regions. Mitigation options encompass increased heterogeneity within oil palm plantations, e.g., from enrichment with trees, and reduced inputs such as from mechanical weeding. In addition, the role of smallholder vs. commercially-cultivated palm oil is controversially discussed. Here, we aimed to identify pathways towards more sustainable palm oil production by comparing the economic and ecological performance of multiple uniformly aged oil palm production systems in Sumatra, Indonesia. Covering oil palm cultivation in upland and riparian smallholder plantations, conventionally and extensively managed estates and estates enriched with tree islands, we focused on identifying environmental and management factors that enable economic-ecological win-wins. Oil palm yields were lowest for smallholders and highest for conventionally and extensively managed estates. Ecological indicators exhibited great variability, independent of yields, highlighting potential for economic-ecological win-wins in all systems. Improved weed control in smallholder systems is a promising management lever to close yield gaps without necessarily jeopardizing ecological targets. In estates, extensive management did not reduce yields but improved ecological functions, making it the most economically and ecologically efficient system overall. Increasing rainforest cover surrounding plantations improved ecological outcomes in all systems. Overall, our study highlights pathways to reconcile economic and ecological interests in palm oil production, including potentials to improve the efficiency of existing plantations and the creation of more sustainable plantations in future.

Determining the ecological value and farmers' perceptions of set-aside land in northern Saxony

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Set-aside fields, such as fallow or flowering areas, are considered effective measures for maintaining biodiversity in agricultural landscapes, although their ecological value depends on their specific management and landscape context. Here, we assessed a multidimensional index of the ecological value of plant communities in 16 set-aside fields of four different management types and used interview data to show which other ecological, economic, or social values farmers associate with these fields. Self-vegetated fallows had a higher ecological value than sown flowering areas. Moreover, perennial set-asides had higher species richness and diversity than annual set-asides. Differences in soil parameters or landscape diversity were small, suggesting that differences in plant communities were primarily driven by the management type. Farmers highlighted the value of perennial set-asides as habitat for wildlife, but there was little confidence in the overall ecological value of set-aside fields. However, they acknowledged their economic and social value, especially in areas where soil quality is low, and at times when societal expectations for farmers to manage their land for biodiversity are high. In conclusion, fallows had higher ecological values than flowering areas, but this often played only a secondary role in farmers' decisions to set-aside land. Our results illustrate the general complexity of evaluating the success of conservation measures, which not only depends on the biodiversity outcome but also on farmers' perceptions of these measures and thus on meaningful communication and monitoring strategies.

Ecologically-Informed Precision Conservation: A framework to optimise agricultural landscapes for biodiversity and crop production

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Conservation actions are urgently needed to tackle biodiversity loss in intensively managed agricultural landscapes. Production lands are usually heterogeneous and contain low-yield areas that can be set aside for biodiversity conservation without serious yield losses. Here, we introduce Ecologically-Informed Precision Conservation, a framework that integrates yield mapping and ecological theory to select the best areas to create new set-asides while ensuring high crop yields at the farm/landscape level. Long-term yield maps can be generated using globally available satellite data and basic information on field/farm crop yield from farmers. Ecological principles are then used to select the subset of areas with the highest potential for biodiversity conservation by prioritising those that increase connectivity, maximise habitat heterogeneity and decrease landscape grain size. The created non-crop habitats can be permanent and thus ensure biodiversity support over time. In addition, agricultural management efficiency can be enhanced by improving field shapes. The framework provides the basis for a practical, user-friendly tool that informs all interested stakeholders on how to optimise agricultural landscapes using already-existing farming systems and available technologies. High cost-effectiveness from an economic and conservation perspective, along with the creation of heterogeneous non-crop habitats, make our framework a promising solution to re-design agricultural landscapes.

Can we simultaneously reach the dual biodiversity goals of preserving rare and ecosystem service provisioning species in farmland?

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Biodiversity conservation both concerns halting the loss of threatened species and maintaining local biodiversity for providing ecosystem services. However, because of potential mismatches in terms of which actions and their spatial placement to reach these goals, it remains unclear if there are synergies or trade-offs when pursuing these goals. In farmland, policies such as agri-environmental schemes and greening measures under the Common Agricultural Policy in the EU, aims at conserving biodiversity, which could potentially benefit both rare species and ecosystem services provided by biodiversity if formulated well. Using a theoretical model, we demonstrate that spatial targeting of habitat conservation and modulation of agricultural intensity could result in overall more effective conservation than uniform strategies, by promoting species conservation in less productive landscapes and benefitting ecosystem service providers in more productive landscapes. This was caused by spatial variation in the opportunity costs of conservation as such as well as the marginal benefit of increasing ecosystem service providers. In a landscape study, we evaluated the combined use of conservation of semi-natural grasslands and organic farming across landscapes to benefit plants and pollinators. Using data on farm economy and biodiversity, we used economic-ecological modelling to evaluate the benefit of changing existing agri-environment schemes, to achieve multifunctional landscapes delivering both biodiversity conservation and ecosystem services at regional scales.

From Trialing to Adaptation: Embracing Nuanced Farmers' Adoption for Agroecological Transitions

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Agroecological intensification is progressively recognized as a potential solution to balance food production, biodiversity, and socio-economic and environmental sustainability. However, maximizing full benefits and scaling up agroecological practices hinges on farmers' acceptance of these practices. Most existing research views farmers' adoption of new practices as a static event, often in binary terms (i.e., adopted/not adopted), focusing on a single practice. This perspective overlooks the complexities and synergies that could facilitate effective packaging and dissemination of agroecological knowledge to reach farmers across diverse contexts and conditions. Through a scoping review, we examined how adopting more nuanced measures of adoption could underpin diversified policymaking and tailored interventions, thereby fostering agroecological transitions in tropical smallholder farming systems. We synthesized studies that applied metrics, such as the scale of adoption, combined/composite adoption, consistency over time, and intensity of implementation. Our findings delineate the diverse ways farmers engage with new practices, including instances of transient, experimental, and sequential uptake, along with instances of abandonment and occasional rebound, all conditioned by farmers' capabilities, economic conditions, socio-cultural norms, how practices are promoted, agroecological environments, and support systems for improved ecological knowledge. We argue that a strict "one-size-fits-all" approach to knowledge dissemination, technology transfer, and packaging could impede agroecological transitions. Rather, securing farmers' buy-ins, facilitating their experimentation, providing the right mix of practices, and options for adapting practices to local contexts are essential for sustained adoption. We emphasize that nuanced adoption metrics that recognize farmers' agencies and their heterogeneity could help foreground their varied pathways and reshape strategies for lasting agroecological transformations. Finally, we explore the potential applicability of these findings to the European farming context.

Scientists support the EU's Green Deal and reject the unjustified argumentation against the Sustainable Use Regulation and the Nature Restoration Law

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To halt biodiversity loss, mitigate global warming, and maintain long-term viability of rural and urban areas, timely action is required. Environmental pressures need to be reduced and nature's capacity to recover and deliver life-support services must be restored. The Sustainable Use Regulation of plant protection products (SUR) and the Nature Restoration Law (NRL), proposed by the European Commission in June 2022 as a cornerstone of the Green Deal, can serve as important elements in reaching these targets.
Both legal proposals are facing strong resistance and criticism on the grounds of adverse effects on farming, fisheries, forestry and society at large. Yet many specific claims contradict scientific evidence as we show in this paper. Evidence shows that restoring nature and reducing the use of agrochemicals are essential for maintaining long-term production and enhancing food security; can help generating new employment opportunities and stimulate innovation; is an investment with high return rate and multiple beneficiaries across society, including mitigating future costs of environmental degradation; and can foster a transition to sustainable production and consumption models.
We further demonstrate that establishing marine protected areas is an effective approach to sustain and possibly even boost fisheries;
Europe can contribute to food security by reducing its overproduction and overconsumption, especially regarding animal-based food and 1st-generation biofuels; protecting and restoring carbon-rich forests is a much more cost-efficient way of mitigating climate change compared to burning biomass, and without the losses of biodiversity and other ecosystem services caused by the latter. Societal and political debates are essential instruments in democratic societies, and a valuable means to drive societal transitions. Such transitions are urgently needed in this era of multiple environmental and socio-economic crises. To this end, ›6,000 signatories are welcoming, and keen to support, an evidence-based dialogue at the EU level and within the Member States.

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The effects of crop type, landscape composition and agroecological practices on biodiversity and ecosystem services in tropical smallholder farms

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Smallholder farming in the tropics characterizes some of the world's most biodiverse landscapes. Agroecology as a pathway to sustainable agriculture has been proposed and implemented, but potential co-benefits with biodiversity and ecosystem services is assumed, but not often tested. Similarly, the contribution of landscape elements, such as shrubland or grassland cover in interaction with agroecological management on biodiversity and ecosystem services is unknown. To address these knowledge gaps, we performed an interdisciplinary study in 24 landscapes with varying shrubland and grassland cover in Malawi. We assessed biodiversity of eight taxa of functional importance (birds, carabids, spiders, ants, parasitoids, other waps, bees and soil bacteria) and ecosystem services in relation to crop type (bean monoculture, maize-bean intercrop and maize monoculture), shrubland and grassland cover at three different scales and the number of agroecological pest and soil practices. We show that the responses to crop type, landscape composition and agroecological management practices are not consistent across taxa and ecosystem services. The effects of crop type were modulated by surrounding shrubland cover. For example, natural enemy abundances were higher in bean monoculture fields situated in landscapes with little surrounding shrubland, leading to lower bean damage in monocultures compared to intercropped fields. Therefore, our results suggest that maintaining biodiversity and ecosystem services on smallholder farms is not achievable with a 'one size fits all' approach but should instead be adapted to the landscape context and the priorities of smallholders. However, we find evidence that the maintenance of landscape scale shrubland cover, legume cultivation, and the implementation of agroecological soil management practices are all important components for fostering the sustainable development of smallholder agriculture in the tropical agroecosystems of sub-Saharan Africa.

Identifying measures to support pollinator diversity in an agricultural landscape

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Increasing agricultural intensification is considered one of the main drivers of biodiversity loss through habitat destruction and fragmentation. At the same time, public interest in biodiversity conservation has increased significantly in recent years, and pollinators such as wild bees and their ecosystem services have become the focus of public attention. However, not only the general public, but also policy makers are taken into responsibility, and many farmers, although often criticized, see the need for biodiversity conservation in agriculture and are motivated to take action. EU-wide agri-environment schemes have been introduced to promote biodiversity and provide financial compensation for environmentally friendly farming. However, the effectiveness of such measures, their interactions on landscape-scale and effects on pollinators remain unclear.

In our study, we assessed abundances and species composition of four major pollinator groups (solitary wild bees, bumble bees, honeybees and hoverflies) across agricultural landscapes. Our study sites were located in agricultural landscapes characterized by a compositional gradient of organic farming, seminatural habitats and mass-flowering crops. In each landscape, we surveyed agricultural fields, differing in management intensity (ecological vs. conventional) and floral resources at different points in time (early and late mass-flowering crops). Furthermore, we surveyed perennial habitats, differing in quality and management intensity, namely ecological and conventional fallow-strips, hedges and calcareous grasslands.

In our study, we want to disentangle effects and interactions of agricultural biodiversity measures on pollinators. Moreover, we aim to provide recommendations for efficient measures not only to decision-makers, but also farmers, to support pollinators in agricultural landscapes.

Fallow strips promote species-specific plant-pollinator interactions in agricultural grasslands

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Agricultural intensification is a major cause for biodiversity loss in open landscapes. Intensive mowing regimes in grasslands result in homogeneous areas. The low structural diversity results in a decline in habitats and food resources for interacting species such as pollinators. Fallow strips, i.e. agricultural grasslands taken out of management, add an ecological contrast in agricultural grasslands. In this way, they could increase resources for wild bees and hoverflies while maintaining the majority of the land under cultivation.

We sampled eight different grassland sites across Hesse (Germany), each divided into a fallow strip and three control strips with constant management of 10 m x 40 m. In two sampling campaigns five to eight weeks after mowing the control strips, we sampled wild bees and hoverflies from visited flowers and recorded species identity for both interaction partners.

Most of the host plant species were found only in the control strips, while fallow strips had the fewest visited plants. An intermediate number of host plant species was found in both areas. While wild bee and hoverfly species followed this general pattern, the resulting number of unique interaction links in fallow strips between plants and pollinators add ecological complexity to managed grasslands. However, this pattern varies greatly from region to region. The local identity of plant species appears to modulate the distribution of unique links in grasslands with fallow strips. This resulted in pronounced differences in the contribution of wild bees and hoverflies to plant-pollinator network structures. Thus, fallow strips contribute little to grassland species richness but provide novel interaction patterns that are otherwise lacking in poorly structured grassland systems.

Multi-taxonomic assessment in fallow areas in northern Saxony

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A socio-ecological transformation that includes changes in current agricultural practices is needed to halt the ongoing loss of biodiversity. One conservation measure that has traditionally been used as a common agricultural practice and is now supported by the CAP is fallow fields. Fallows are a simple but highly effective measure. They improve soil fertility, but also provide food and habitat for various species, especially due to their structural richness. However, their effectiveness depends on the land use history and on the structure and complexity of the landscape.

To understand the interlinkages between these influential factors and the ecological effectiveness of fallows for different taxonomic groups, we studied 23 fallows in differently structured landscape areas in northwest of Saxony, Germany. The selection of the areas was done in cooperation with local farmers and the23 fallows have different management histories, but are all managed in the same way since the last funding period.

Plants, pollinators, bats, and birds were assessed in May and June 2023. Specifically, plants and pollinators were mapped on multiple plots per field, while bats and birds were recorded by AudioMoths. Structural richness at the landscape level was determined by calculating the landscape SHDI using the biotope type and land use mapping of Saxony and agricultural diversity (IACS data).

Here, we would like to present the first results of this study, which shows that fallow farming is a relatively easy and cost-effective for farmers to increase structural heterogeneity on their farms and support multiple taxonomic groups simultaneously. Fallow practices, thus give farmers the opportunity to actively participate in biodiversity conservation and the socio-ecological transformation.

Blocks and Stripes: Does shape matter? Conservation elements and Insects.

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Sown wildflower strips (WFS) have been implemented across Europe as part of the Agri-Environmental Schemes (AES) to counteract insect decline, but have been subject of ongoing criticism regarding their effectiveness and suitability as a part of sustainable insect conservation. The innovative concept of the Rolling Wildflower Blocks (RWB) seeks to improve the effectiveness of the AES by changing the shape of the traditional strip to a block shape and by combining several WFS of different successional stages. On the basis of this data, we are trying to promote an improvement of the AES, which would require a change in the subsidies in agriculture, as clustered WFS are explicitly not supported.

In the summer season of 2022, the first year of the implementation of the RWB, stripes and blocks only differed by shape (150x50m2 versus 50x50m2), but were equal in size. We set 200 pitfall traps in five arable fields with two elements each in German agriculture (Havelland, Brandenburg) to investigate the effect of shape on diversity, abundance and biomass of insects. In addition to overall insect abundance, we specified diversity of carabids, which, with their diverse and often perennial life cycles, are often less considered in the development of AES as part of insect conservation.

During the first year of establishment we found both higher abundance and richness of insects in the traditional WFS, likely due to a longer border area towards the adjacent uncultivated field margins, which attracts insects from the surrounding habitat disproportionately. Border length might affect colonisation of WFS elements, but does not guarantee adequate quality of WFS as suitable and persistence of habitats for insects over time. We will discuss the effects of differently shaped flowering elements as a way of improving the profit of AES.

Inter-row vegetation of vineyards to increase biodiversity

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Although positive ecological and agronomic effects of inter-row vegetation have been demonstrated in several recent studies, soil tillage to remove this vegetation is still widespread. In particular, Mediterranean vineyards are often managed without permanent vegetation cover to avoid water competition with grapevine plants. In the framework of the EU project Life Vineadapt, we studied in a first step the role of inter-row vegetation characteristics in driving the abundance of arthropod groups involved in biocontrol and pollination. In a second step, we tested the effects of different mixtures on arthropod abundance. We further analysed effects on grapevine performance and yield. The study was set up in the Luberon mountains in South-Eastern France including 37 and 15 vineyards, respectively, for the analysis of vegetation characteristics and the sowing experiment. The sowing experiment included five vineyards for each of the following treatments: (1) high plant diversity using 22 plant species of local origin, (2) low diversity including two grass species, (3) a tilled control with low vegetation cover. We used direct observation and net hunting (2x2 m²) to measure the abundance of ladybirds (larvae, adults), hoverflies (larvae, adults), parasitic wasps, crab spiders and wild bees. Sentinel cards with Lucilia larvae were placed on grapevine plants to simulate caterpillar predation.

We found that the abundance of ladybirds (adults, larvae), crab spiders and parasitic wasps was positively correlated to flower cover in vineyard inter-row vegetation. Ladybirds (adults), hoverflies (adults), crab spiders and the predation of Lucilia larvae were favoured by species richness of the inter-row vegetation. Grass cover had a negative effect on parasitic wasp abundance. The sowing experiment clearly demonstrated the positive effect of vegetation cover on all measured arthropods without changing yield or grapevine performance. However, first year data did not reveal significant differences between the high and low diversity treatment in terms of arthropod group abundance or predation. Second year data need to be included in the analyses since many sown perennial plant species do not flower in the first year.

Best of both worlds: mineral-ecological cropping systems to overcome biodiversity-profit trade-offs in the organic/conventional farming dichotomy

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Organic agriculture can promote farmland biodiversity, but crop yields in conventional agriculture are often twice as high. Overcoming the resulting trade-off between biodiversity and productivity is a key challenge for the agriculture of the future. Recently, mineral-ecological cropping systems (MECS) have been proposed as an alternative to conventional and organic agriculture. MECS follow an intermediate cropping system approach, allowing no chemical-synthetic pesticides but mineral fertilizers, thus combining organic and conventional practices with novel farming techniques. Here, we compared the ecological and economic performance of MECS with conventional and organic farming systems in a large-scale crop rotation experiment. We used DNA metabarcoding to assess arthropod diversity of cropping systems and derived profits from multi-year yields and agricultural subsidies. MECS had higher arthropod abundance than conventional systems and similar arthropod richness to organic cropping systems. Profits from MECS were intermediate between organic and conventional systems. In summary, MECS is an ecologically and economically viable future farming system that can mitigate some of the biodiversity-productivity trade-offs that exist in the current organic/conventional farming dichotomy.

Temperate Alley-Cropping Agroforestry benefits Earthworms and the Soil Microbiome

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Cropland agroforestry systems are land-use systems that combine trees with crops and have numerous environmental advantages over monoculture croplands including promotion of soil life. In the temperate zone, alley-cropping agroforestry systems that alternate rows of trees with rows of crops are gaining popularity. Here, we aimed to investigate tree-species and tree-distance effects on soil biota in a temperate alley-cropping agroforestry system.

Our study was conducted at a paired alley-cropping and monoculture cropland system. The tree rows of the agroforestry system comprised of blocks of three different tree species (poplar Fritzi Pauley, poplar Max 1, and black locust). Within the agroforestry system, soil microbial and earthworm communities were collected along transects spanning from the center of the tree rows into the crop rows. Earthworms were identified to species level and classified into ecological groups using morphological identification. The abundance of archaea, bacteria, and fungi was determined using real-time PCR and the community composition of fungi was deciphered using amplicon sequencing.

Tree rows promoted the abundance and biomass of earthworms by up to 1,134 % and 3,384 %, respectively. We attribute this mainly to tree litter input and the absence of tillage. Abundance of anecic earthworm was only promoted under the trees whereas endogeic species showed a gradual decline of density from the trees into the crop rows. Tree rows showed an increased proportion of ectomycorrhizal fungi within the tree-row associated mycobiome. The proportion of Blumeria graminis, the causal agent of powdery mildew, increased with increasing distance from the trees. This suppression through the trees might be caused by enhanced microbial antagonism, increased earthworm densities and/or altered microclimate. Tree-species effect had a minor influence on soil communities at our study site.

Overall, agroforestry benefits the abundance, diversity, and function of soil biota as compared to monoculture cropland.

Evaluating the ecological effectiveness of perennial wildflower strips

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The EU has introduced agri-environmental measures such as flower strips as part of the Common Agricultural Policy to counteract the decline in biodiversity and associated ecosystem services on agricultural land. Flower strips are designed to promote biodiversity by providing shelter and food resources for various animal species, such as pollinators and farmland birds. Starting in 2014, perennial wildflower strips had to be sown with wild seed mixtures containing 30 forbs from certified regional seed propagation in the state of Saxony-Anhalt (Germany). From 2017 to 2019, we evaluated the ecological effectiveness of these wildflower strips throughout the state, which were established by farmers under real-world conditions.

Structural and soil parameters, vegetation composition, breeding birds, and wild bees were surveyed on 40 and 20 (bees) perennial wildflower strips and on 20 and 10 (bees) arable fields without wildflower strips. In addition, all landscape structures were recorded within a 1000-meter radius of all study plots. To estimate the provision of nectar- and pollen resources, we used the newly developed Pollinator Feeding Index (PFI).

Plant species diversity, species numbers and abundance of birds, and wild bees were significantly higher on wildflower strips compared to arable fields. Although sown native forbs contributed most to high PFI values, spontaneously established forbs expanded the total range of species and related nectar- and pollen resources considerably, especially in early spring and late summer. Overall, shading and grass cover had the greatest negative effect on the performance of the sown forb, and a forb-rich vegetation was the main driver promoting birds and wild bees.

We conclude that wildflower strips have a high potential to enhance farmland biodiversity. High flower strip quality as well as implementation in open conditions maximise their ecological effectiveness.

Effectiveness of flowers strips and role of abandonment in the alpine grassland

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Intensification of grassland management and land abandonment are the two influential factors on insect diversity. Increase in mowing intervals have a negative impact on the diversity of insects. Further, land abandonment is a multifaceted, nonlinear, worldwide phenomenon that is influenced by a variety of factors. The overarching goal of the two studies were (i) to investigate the restorative effect of flower strips on adjoining intensive grasslands to preserve and restore native grassland insect diversity, (ii) to analyze the significance of land abandonment for insects in three grassland management regimes that include abandoned, intensive, and extensive alpine organic grasslands. Heteroptera and syrphid species richness and syrphid abundance were significantly higher in flower strips compared to other studied grasslands. However, butterfly abundance and species richness were significantly higher in extensive grasslands compared to flower strips. Syrphid abundance was significantly higher in the intensive grassland compared to the separated intensive (control). Extensive grasslands had significantly higher heteropteran and syrphid abundance compared to abandoned grasslands. Large numbers of unique species (25.5% Heteroptera and 21.5% Syrphidae) only occurred in the abandoned grasslands. Flower strips seem most effective to enhance syrphid abundance that showed potential spill-over effects to intensive grasslands. Likewise, undisturbed abandoned grassland is not a threat to insect diversity, and supports the survival of more unique heteropteran and syrphid species. Overall, restoration of insect diversity is a relatively slow process, in which colonization by each insect group is affected by the presence, distance, and connection of source habitats.
A mosaic landscape consisting of flower strips and abandoned grassland along with grassland having different, mainly extensive management intensity could be an ideal arrangement for biodiversity conservation.

A review on grassland re-seeding: stakeholders, seed mixtures, establishment rates and temporal trends

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Grassland biodiversity correlates with productivity and stability, while land-use change leads to local extinction of species and declining ecosystem functions. Therefore, the design of grassland mixtures is paramount for restoration and management. To understand how different stakeholders perform grassland reseeding and to identify knowledge gaps in the design of seed mixtures, we conducted a systematic review on reseeding during the past 30 years. We extracted information on stakeholder focus, starting conditions of reseeded sites, species selection and monitoring of grasslands. The review produced the following results: (i) There were five stakeholder groups with varying focus along a gradient of biodiversity control. In turn, the starting conditions of reseeded sites changed with dissimilarity in relation to the vegetation of reference grasslands. (ii) The design of grassland mixtures varied in provenance of the selected species, seed origin and quality. (iii) While mixtures targeting vegetation structure and forage biomass showed high establishment rates, grassland reseeding with strong biodiversity focus was less successful. (iv) The seed mixtures changed markedly during the past three decades. Species numbers in mixtures, i.e. the biodiversity focus and the proportion of forbs, decreased for most stakeholders; the number of ecosystem services monitored also declined. Such findings indicate an increasing specialisation of stakeholders, in contrast to current trends towards multiple ecosystem functions of grasslands. The results on the drivers of grassland reseeding should be applied to advance the design of grassland mixtures in the face of climate change and current biodiversity losses. The different success rates of stakeholders offer an opportunity for knowledge transfer among groups to achieve the same level of success in restoration and conservation professionals as seen among turf managers and farmers.

Development of diversified re-established grasslands over six years for insect conservation in comparison with EU's ecological focus areas

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Land use intensification is resulting in the loss of semi-natural grasslands and their associated flora and fauna in Europe. Agri-environmental schemes seek to mitigate the trend of biodiversity loss by subsidizing the restoration of grassland. However, little is known about the colonization of newly created ecological compensation areas by insects, especially over periods of more than 1-2 years. We investigated the development of two types of newly established grassland strips over six years in an agricultural landscape in Austria: newly established grasslands (NG) were created within crop fields with a diverse, regionally adapted seed mixture in 2016 and compared to subsidized grasslands (SG; EFAs, CAP cycle 2015). Permanent semi-natural grasslands (old grassland OG) were used as reference habitat. We wanted to find out how individual numbers, species numbers and assemblages of wildbees, syrphids, butterflies, grasshoppers and heteropteran bugs develop in the different grassland types over six years and how ecological traits affect the colonization patterns. Over the six-year period, newly established grasslands with diverse plant communities (NG) showed sustained insect diversity and high conservation value, outperforming plant species-poor SGs in promoting insect species. Therefore, we suggest that diverse seed mixtures could enhance the effectiveness of EFAs and could make re-sowing within the first six years after establishment unneccessary. Further, we found no evidence of a successional change in insect species assemblages in grassland strips (NG, SG), however wildbee, butterfly and grasshopper species composition differences between grassland strips and permanent grasslands were decreasing over time. Both grassland strips showed higher fluctuations in individual numbers and higher species rank change over the years compared to permanent grasslands.

Paddy rice: A win-win for biodiversity and agriculture

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Wetland biodiversity in Switzerland is continuously declining in connection with the loss of about 90% of wetlands due to land-use change. In addition, Switzerland's average annual temperatures increased by 2.5°C compared to pre-industrial times, forcing agriculture to rethink the standard cropping practices in the light of climate change. Introducing better-suited crops for warmer temperatures, like paddy rice, could be beneficial to meet the upcoming challenges due to climatic extremes, ensure food production, and promote wetland biodiversity at the same time. Since 2017 a group of farmers, with scientific support from the Swiss Federal Research Institute for Agriculture, have been pioneering ecological paddy rice production in lowland parts north of the Swiss Alps. Biodiversity surveys showed a variety of wetland fauna and flora, among other endangered species, use paddy rice as habitat. Therefore, paddy fields have a considerable potential as biodiversity promotion areas for endangered amphibians like the natterjack- and yellow-bellied toads (Epidalae calamita and Bombinia variegata) or dragonflies like the white-tailed skimmer (Orthetrum albisytlum) or the spotted darter (Sympetrum depressiusculum). Further, the effect of paddy rice fields for bats is discussed. Since paddy rice is a new crop to this geographical location, not much is known yet about the effect of crop management practices, such as the application of fertilizers, timing of flooding or the use of heavy machines, on the species that are attracted to these fields. Therefore, the ongoing research is evaluating the opportunities and limitations of biodiversity promotion through cultivating paddy rice in Switzerland and the presentation will show its preliminary results.

The potential of natural regeneration for restoring biodiversity in agricultural landscapes. The case of farmer-managed natural regeneration in Kenya

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Farmer-managed natural regeneration (FMNR) is an agroforestry practice where farmers combine naturally regenerating trees with agricultural production. It has received a lot of attention as a cheap and effective way to restore degraded farmland, particularly in Africa. However, we currently do not know what regenerates and to what extent farmers needs may be met. Mechanistic understanding of natural regeneration comes from studies on ecological succession, which control for human influences. How farmers modify successional processes and what the consequences are for ecosystem functionality is unclear.

We systematically compare the recovery of ecosystem properties with field age in actively managed FMNR maize fields and in unmanaged secondary forests in Migori county, Kenya.

FMNR maize fields had much lower tree densities than unmanaged secondary forests, neither system showed directional changes with field age. Basal area increased linearly with field age in both systems, with basal area in FMNR systems reaching about half the values of similar-aged secondary forest. Species richness in FMNR systems is remarkably high, considering the lower tree densities, compared to richness in secondary forests that showed high dominance of a single invasive species (Lantana camara). Differences in species composition between secondary forests and FMNR fields illustrate that farmers promote desired species while removing undesired species. There were also large differences in species composition among FMNR fields, highlighting farmers' individual preferences.

Natural regeneration has great potential to increase tree diversity in agricultural landscapes both at the field level (alpha diversity), and at the landscape level (beta diversity). Although some properties increased predictably with field age, and were similar to secondary succession, mechanistically understanding what species regenerates where is challenged by large individual differences between farmers. Understanding where natural regeneration is sufficient to achieve restoration targets and where additional tree planting is needed is an important step towards effective restoration planning.

Natural regeneration in contrasting land uses. The Case of Farmer Managed Natural Regeneration on grazing fields and crop systems in Kenya

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Farmer Managed Natural Regeneration (FMNR) has attracted global attention in the last 10 years as a low-cost adaptable agroforestry approach where farmers systematically integrate naturally regenerating trees within agricultural systems by means of active selection and management. Despite the reported local success of FMNR across several African countries, there is limited knowledge of how different land uses influence natural regeneration and what the consequences are for on-farm biodiversity.

In this study, we inventorized trees and regeneration across 35 FMNR grazing fields and 30 FMNR crop fields in Kenya to understand the effect of main land uses and farmers preferences on the density, diversity and composition of woody vegetation. Although regeneration diversity and density did not differ between grazing and crop land use systems, tree density and species richness were higher on grazing fields compared to maize fields. Tree densities on maize fields may be kept low to reduce light competition while higher tree density on grazing fields maximizes the availability of fodder from trees which are particularly critical during periods of drought. Species composition differed where grazing fields are dominated by shrub-like vegetation while in maize fields tall trees are promoted. Differences in tree species composition warrant different restoration outcomes on the long term, which deserve to be further investigated.

Understanding the potential of natural regeneration across different land use types enables evaluating the extent to which FMNR is effective to attain restoration targets and identify areas where complementary tree-planting should be included.

Effects of leaving uncut grass refuges on the plant community of extensively managed hay meadows

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Invertebrates inhabiting grasslands benefit from uncut grass refuges, yet their effects on the plant community have not been properly quantified. We experimentally investigated the effects on the vegetation of two different types of refuges. While both consisted in not mowing 10–20% of a meadow area, they differed in their rotation frequency: 1) in within-year rotational refuges (WYRR), the location of the refuge within a meadow was changed at each mowing operation, usually twice a year; 2) in between-years rotational refuges (BYRR), the refuge changed location only between years. A third mowing regime without any refuge was included as control (C) for comparison. The study was conducted in thirty extensively managed meadows across the Swiss lowlands. The vegetation was sampled at two 1-m^2 plots within each of the four strata defined by a stratified random design that accounted for the spatial location of the uncut refuge over the years. There were no overall significant negative effects of WYRR on plant species richness and composition at the meadow scale, although a small negative effect was detected locally (i.e. at the refuge scale) where a WYRR had been implemented more than once in the preceding three years. Leaving BYRR negatively impacted plant species richness (-11%), even reducing the number of indicator plant species by 22% (from 4.45 to 3.47 per 2 m^2), this regardless of when and where refuges were left uncut. A beta-diversity analysis revealed no difference at community level between the two refuge types and control-meadows. Previous studies had evidenced positive effects of uncut refuges on herbivore and pollinator communities, while this study shows that the plant community is not affected as long as the location of the refuge is changed at each mowing operation. We thus recommend this measure for promoting biodiversity in extensively managed grasslands.

Strip cropping with oilseed rape and wheat – Effects on ground beetles (Coleoptera: Carabidae)

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There is increasing awareness for the need to transform agricultural systems to more diversified, wildlife-friendly and sustainable production methods. Strip cropping, a cultivation system where different crops are grown in adjacent strips on the same field, can be a cropping strategy to support biodiversity and associated ecosystem services without setting aside agricultural land. Here, we assess the effect of strip cropping on carabid beetles, which are important biological control agents in arable cropping systems. Abundance and diversity of carabids should be promoted by increased crop diversity, edge density and complexity of habitat conditions in comparison to *pure* arable fields

We used 14 conventionally managed farms in Lower Saxony and Saxony-Anhalt, each providing triplets of fields with one strip cropping field with oilseed rape (OSR) and winter wheat strips, one wheat field and one OSR field as references. Strip cropping fields contained seven alternating strips in working width of machinery (21 – 36 m). Field management was comparable with the reference fields within each farm. Activity density of carabids was quantified using pitfall traps, which were opened for seven days on three sampling periods between April and June in 2022.

The number of carabid individuals depended on the cultivation system, the crop type and the sampling period. We found the highest densities in the wheat reference and the lowest in the OSR reference while strip cropping had intermediate density levels. An interaction between crop type and sampling period showed an increasing activity densities across the year with higher activity density in wheat than in OSR, particularly in the first sampling period in April.

Hence, strip cropping promoted carabid densities in comparison to OSR fields most likely due to increased crop diversity at field level and spillover effects. However, the benefits are rather small when considering the increased number of management operations.

BeeContour- Strip cropping to promote biodiversity in agroecosystems

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Modern agricultural landscapes have become increasingly homogeneous. Innovative crop management techniques are required to strengthen the positive relationship between spatial heterogeneity, biodiversity and the services it provides without compromising production goals. The BeeContour project collaborates with farmers to establish practical strip copping systems, adapting their management techniques and crop choice as well as evaluating socio-economic factors based on operational data. The common requirement in all farms is the inclusion of a flowering crop (oilseed rape in conventional and faba bean in organic farms) and wheat as a control crop in the crop rotation. Both crop types have been sampled for pollinators, ground beetles and predation rates (aphids and weed seeds) in the first year in a replicated field trial at two experimental farms of the Justus Liebig University Giessen. Strip cropping increased the abundance and species diversity in pollinating insects, especially wild bees, compared to conventional cropping systems. In addition, the increase in ground beetle abundance was mirrored by an increase in predation rates. The spatial heterogeneity of strip cropping thus benefits organismal diversity of both flower visitors and ground-dwelling arthropods and enhanced the services they provide.

Potentials and limitations to support pollinators by mixed cropping of maize with common sainfoin (*Onobrychis viciifolia)*

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Diversified cropping systems provide an opportunity for more sustainable and biodiverse agriculture. Increasing within-field diversity by mixed cropping with legumes seems promising to mitigate negative impacts of maize production on the environment. Legumes grown with maize can promote pollinators by providing additional food sources. However, pure crops of legumes might be richer in floral resources than mixed crops and might thus be more efficient in floral resource provision. Further, mixed cropping of legumes and maize can lead to enhanced competition between cropping partners and yield reduction. Yet, little is known about the potential of mixed cropping of maize with sainfoin to support pollinators and how mixed cropping with sainfoin affects maize yields.

In a field experiment, we established plots of pure crops of maize and sainfoin and mixed cropping of maize and sainfoin with different seed rates. We recorded pollinator visits, number of sainfoin inflorescences and flowers, and yields to evaluate which seed rate ratio of maize and sainfoin might simultaneously support pollinators and produce high yields.

Sainfoin as a pure crop and mixed cropping with high seed rates of sainfoin had higher numbers of inflorescences but mean number of flowers per inflorescence did not differ between pure and mixed cropping. Pollinator visits were higher in pure sainfoin and mixed cropping with high seed rates of sainfoin (‹50 %) compared to pure maize and mixed cropping with low sainfoin. Yields were lower in mixed cropping than in pure maize and mixed cropping with low seed rates of sainfoin (›10 %). Sainfoin promotes pollinating insects but as competition in mixed cropping reduces yields and shadowing of the flowering partner crop may reduce accessibility for pollinators a segregating system of maize, and pure sainfoin instead of mixed cropping might be more efficient. However, other aspects such as cover of soil to reduce soil erosion should also be considered.

Strip-Till farming to reduce pesticides and promote beneficial insects and wild forbs on arable land

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Agricultural intensification is considered a main driver of biodiversity loss. To counteract this development, new cultivation practices are required to restore agrobiodiversity and associated ecosystem services on arable land. Therefore, the aim of our project is to develop an innovative cropping system that reduces the use of pesticides and promotes agrobiodiversity in the whole field.

Our study site is located in Bernburg-Strenzfeld, Saxony-Anhalt, with a very dry and warm climate on fertile Chernozem soil. On an area of 5 ha, four arable crops (winter wheat, maize, field bean, winter durum) are cultivated in a strip-till system with row spacing of 50 cm. We tested six different inter-row management variants with four replicates: (i) herbicide treatment, (ii) mechanical weed control, (iii) seeding of crop-specific annual cultivar mixtures with 1 - 3 species, (iv) seeding of crop-specific annual wild forb mixtures with 5 - 10 species, and seeding of perennial wild forb mixtures with (v) 15 and (vi) 25 species.

Following status quo surveys in 2021, we investigated the effects the different inter-row treatments have on flora and fauna starting in 2022. Surveys included vegetation and structural parameters, flowering phenology, and faunal recordings of selected animal species groups (e.g. wild bees, hoverflies, ground beetles) using a variety of methods (e.g. sweep netting, pitfall traps). In addition, the flower visitation by wild bees, hoverflies, lacewings and ladybirds was documented.

In 2022, due to severe drought, species from the seed mixtures were barely able to establish. Thus, differences between inter-row management variants were not significant so far. However, we found significant effects of crop type on e.g. ground beetle species composition.

Because of the improved establishment of sown species in the current growing season of 2023, we expect intercropping with wild forbs to show positive effects on beneficial insects and agrobiodiversity.

Diversification of intensively farmed grassland to benefit pollinators and farmers

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Intensive grassland use caused a strong decline in plant and insect diversity over the past hundred years due to high fertilisation rates, frequent cutting, pesticide use and use of few high performing grass species. Shifting from pure *Lolium* seeding to a diversification of seed mixes for intensively used meadows can produce high yields, lower input-costs, lead to a higher resilience, and an increase in floral resources for pollinating insects. Mixing grass, herb and legume species allows to take advantage of a range of plant properties through biodiversity effects. Five mixes of increasing diversity were created in the BEESPOKE-project and tested in a field trial. They show significantly more floral resources compared to intensively used permanent grasslands in the region. The abundance and species number of wild bees increased greatly in all mixes from the first to the following study years and compared to permanent grassland. Hoverflies did not demonstrate a clear trend towards certain mixes but increased with the presence of *Plantago lanceolata*. The fodder was tested at harvest for its quality and showed great protein and net energy lactation rate values in all five mixes. Furthermore, the most diverse mixes displayed a higher drought tolerance compared to less diverse grass stands. In this study, the diversification of grassland revealed to be promising for both farmers and pollinators.

Integrating flower strips in sugar beet cultivation to enhance biodiversity – lessons learned from 5 years implementation

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Since 2018, annual and perennial flower strips sown in spring and autumn were integrated into sugar beet fields on the Südzucker AG's experimental farm Kirschgartshausen (Baden-Württemberg/ Germany). From 2018 to 2022 the direct effects of the flower strips on biodiversity and on beneficial insects in the flower strips and adjacent sugar beet fields were measured with standardized sweep-net samples (May to September). Further, mid-term effects on insects in the wider area were measured with combi traps. The captured insects were divided into four functional groups: pollinators, natural enemies, pests and other invertebrates.

In the flower strips, 7 times more invertebrate biomass and 3 times more individuals were captured than in sugar beet fields. Pollinators were recorded almost exclusively in the flower strips. Natural enemies were 4 times more abundant in flower strips than in sugar beet fields and were also much more diverse there. In flower strips sown in autumn more natural enemies were recorded than in strips sown in spring. Chalcid wasps, spiders and ladybugs preferred strips sown in autumn. Flower bugs and braconid wasps preferred strips sown in spring. In a split flower strip with parts sown in autumn and spring more natural enemies and less potential pests were recorded than in flower strips sown in spring or autumn. Further, the number of wild bees, braconid wasps, chalcid wasps, lady beetles and spiders increased between 2018 and 2022. Cicadas, the main pest in sugar beet fields, were less abundant in the flower strips than in the sugar beet fields.

Overall, flower strips increase biodiversity. Subdivided perennial flower strips with staggered maintenance that offer habitat and refuge for insects in every season have proven successful.

As a result, Südzucker and IFAB developed a concept to implement biodiversity measures in sugar beet cultivation to produce biodiversity sugar and are currently developing an evaluation system.

A trait-based approach to analyzing Agroecological Living Laboratories

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The use of Agroecological Living Laboratories (ALLs) could drive innovation and rollout of novel tools and ideas in the ongoing transformation towards sustainable agriculture in Europe. Transdisciplinary, user-focused and utilizing real-world settings, the ALL concept can be a useful for the adoption of principles and practices of agroecology. However, the ALL concept is not yet widely established, although a myriad of agroecology-themed initiatives is underway in Europe. To better formulate recommendations and funding schemes for ALLs, we investigated what traits signify past and current European initiatives.
We designed a survey comprising a list of traits based around the initiative's innovation themes, co-design among actors, sustainability aspects, implementation and evaluation. We collected survey answers from 31 agroecological initiatives across 13 European countries. Using multivariate ordination and hierarchical clustering, we analyzed the grouping of the initiatives, and how thematic and organizational traits correlated with funding scheme (public, private or combined) and the initiative's identity as a Living Laboratory (LL) or a non-LL.

Farmers and scientists were the most common actors under all types of funding schemes. Projects with a mix of private and public funding had more types of actors involved. Privately funded projects tended to involve citizens, non-governmental organizations when compared to publicly funded initiatives. Two clusters of ALLs could be distinguished, with social aspects, community supported innovation and food system focus on one hand, and top-down, larger-scale field and crop-focused projects on the other hand.

The trait database developed captures the diversity of agroecological initiatives and pinpoints how they differ with regards to key features of ALLs such as co-development, real-life setting, user involvement, monitoring and evaluation. Further development of databases for ALLs in Europe and their features will aid in designing, establishing and evaluating future initiatives.

Distance functions of carabids in crop fields depend on functional traits, crop type and adjacent habitat: a synthesis

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Natural pest and weed control are essential for agricultural production, but the spatial distribution of natural enemies within crop fields and its drivers are mostly unknown. Using 28 datasets comprising 1,204 study sites across eight European countries, we performed a quantitative synthesis of carabid beetle richness, activity densities and functional traits in relation to field edges (i.e. distance functions). We show for the first time that distance functions of carabids strongly depend on carabid functional traits, crop type and, to a lesser extent, adjacent non-crop habitats. Species richness of both predators and granivores, and the activity densities of small and granivorous species decreased towards field interiors, whereas the densities of large species increased. We found strong distance decays in maize and vegetables whereas richness and densities remained more stable in cereals, oilseed crops and legumes. We conclude that carabid assemblages in agricultural landscapes are shaped by the complex interplay of crop types, adjacent non-crop habitats and further landscape parameters with great potential for targeted

agroecological management. In particular, our synthesis indicates that smaller field sizes (i.e. a higher edge-interior ratio) increases in-field species richness of carabids and thus likely benefits natural pest and weed control, hence contributing to agricultural sustainability.

Rangeland management through bush encroachment control to improve agroecosystems and biodiversity conservation in Southern Africa

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Rangelands in southern Africa have been undergoing a rapid ecological shift in recent decades from savannah and grassland ecosystems to a dominance of woody plants, termed bush encroachment. Bush encroachment alters ecosystem functions, reduces carrying capacity, leads to loss of habitats and biodiversity, and reduces agricultural production. Nearly 50% (~45 million ha) of Namibia's land is infested with bush plant species, but despite this threat, there is a lack of knowledge about the consequences for local biodiversity. This study aims to investigate how different encroaching plant species and management practices affect agricultural production and biodiversity by experimentally applying three thinning intensities (0%, 50%, and 100%) and post-treatment methods (no treatment, manual felling, and shrub/soil treatment with arboricides) to the three plant species (*Senegalia mellifera, Terminalia sericea*, and *Dichrostachys cinerea*). Three plots per plant species were sampled for arthropods on three farms in Namibia in March and April 2023, with two replicates of pitfall traps for ground-active species and pan traps for flying species per plot for five days. In addition, two shrubs per plot were selected for beating sampling for shrub-dwelling species. Our sampling survey before thinning and aftercare provides important baseline data on spiders (Araneae), beetles (Coleoptera), springtails (Collembola), aphids, bugs and cicadas (Hemiptera), bees and wasps (Hymenoptera), and moths and butterflies (Lepidoptera). Improving rangelands through bush control requires optimizing the balance between the costs and the benefits of bush encroachment. Treatment plots will be monitored from 2023 to 2025 during the wet season (Mar-Apr) and the dry season (Sep-Oct) to determine how the experimented thinning intensities and post-treatments optimize biodiversity.

Setting restoration priorities for landscape features: a case study in Brandenburg, Germany

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Conserving biodiversity in agricultural landscapes is highly dependent on landscape features that facilitate connectivity, ecosystem functioning, and ecosystem services. The EU Biodiversity Strategy for 2030 specifically sets the target to “bring at least 10% of agricultural area under high-diversity landscape features”. However, interpreting and implementing this target still remains unclear. We present a two-step approach to implementing the target, utilizing freely accessible geospatial datasets by acknowledging widely-used landscape features classification. We develop a theoretical approach to interpret the target and apply the hybrid hierarchical k-means clustering approach to identify and characterize agricultural landscapes based on spatial patterns.

The resulting landscape clusters are characterized with respect to their landscape feature requirements, enabling prioritizing landscapes for restoration purposes and developing site-specific recommendations for specific landscape feature classes. In the case study area, Brandenburg, Germany, we identified four agricultural landscape clusters, demonstrating the need to understand the complexity of agricultural landscapes beyond landscape features abundance.

The identification and characterization of different agricultural landscapes allow for restoration priorities across landscapes as well as landscape-specific landscape feature recommendations, which can aid in achieving the biodiversity target set by the EU Biodiversity Strategy 2030. This poster emphasizes the importance of understanding and addressing the complexity of agricultural landscapes to conserve biodiversity effectively.

Agricultural landscapes redesign: identifying sustainable spatial allocation for agri-environmental practices

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A redesign of agricultural landscapes is needed in order to halt the decline of farmland biodiversity and biodiversity-related ecosystem services, reduce environmental externalities and increase agriculture's socio-ecological resilience. This redesign should include an increase in agricultural landscapes complexity and a reduction in land use intensity. The implementation of agri-environmental practices (e.g. hedges, field margins, fallow land, reduced tillage, cover crops, etc.) can contribute to both aspects. Multi-objective optimization tools can support the identification of sustainable allocations for such practices, allowing to navigate trade-offs among different considered objectives. We performed a biophysical multi-objective optimization between farmland biodiversity, natural pest control supply (using parasitism of cereal aphids as indicator), water quality regulation and agricultural production. The case study area is the Schwarzer Schöps river basin, located in the East of Germany. Exchanges with an active network of local actors allowed for the identification of locally relevant agro-environmental practices and their possible location of implementation within the river basin. The SWAT+ model is applied to assess crop production and water quality regulation. Indicators of land-use and management (e.g. share of semi-natural habitat, field size, share of reduced tillage) are instead calculated to predict proxies for farmland biodiversity and natural pest control. We analyzed the shape of the Pareto frontier and performed a spatial frequency analysis of the land use maps resultant from each Pareto solution. Our poster will show the impact of adopting agro-environmental practices on biodiversity conservation, natural pest control, water quality and agricultural production within the case study area. It will conclude with an outlook on how the identification of hotspot areas for the implementation of agri-environmental practices can guide, together with local actors' involvement, the redesign of agricultural landscapes toward more sustainable socio-ecological systems.

The European Agroecology Exchange Hub: a virtual space for agroecology stakeholders

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The Agroecology Knowledge Exchange Hub was developed as an online platform for different stakeholders. The main objective of the Hub is to bring together actors involved in agroecology and to provide a space for their shared knowledge, insights and best practices. Besides, the Hub will facilitate exchanges in the Europe-wide network of agroecology organizations thereby linking academic and practitioners. The process of creating Hub includes: discussion of the core elements and structure, technical development and improvement, testing phase, promoting and dissemniation.

"CatchHedge" – an inter- and transdisciplinary project on hedgerows in agricultural landscapes

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Hedgerows have a centuries-long tradition in Germany serving multiple purposes. They are an important linear landscape feature that provides various ecosystem services. However, they were largely lost especially in the last decades, mainly due to agricultural intensification.

To quantify and evaluate the planting of new hedges as a climate protection option, the Thünen Institute started the project "CatcheHedge", which investigates a broad spectrum of aspects with respect to hedgerows, ranging from the legal and economic framework and its improvement potentials to the opportunities of using hedgerows as an agricultural resource and their effects on yield and local water balance. Moreover, the influence of hedges on biodiversity is examined. The effects of different hedge parameters such as structure or woody species composition on the local diversity of animals and plants are comparatively well studied. Little is known though about the optimal number and area of hedges or the effects of spatial arrangement of hedgerows on landscape level for biodiversity. However, this is crucial in terms of providing habitat to different species and of biotope networks. Therefore, we run a field study in which we investigate plant, carabid and spider diversity across Germany.
In addition, a capture-recapture experiment of carabids is scheduled for spring 2024 to assess the barrier effect of hedges. Based on the results of the field trial as well as literature, an optimal hedgerow design is to be developed for two areas of the Thünen Institute. In a last step, the agent-based model "SyrFitSources", which was developed at the Thünen Institute of Biodiversity to simulate population dynamics of the syrphid *Episyrphus balteatus*, is going to be applied to the landscapes examined in the field. As the project has only started a couple of months ago, I would like to present the outline of whole the project with an emphasis on the biodiversity research.

How policy affects farmers and shapes landscapes - concept for an agent-based exploration

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Preserving farmland biodiversity is one objective of the Common Agricultural Policy (CAP) of the European Union. The policy contains instruments that support effective measures for biodiversity such as fallow land, landscape elements, and extensive grassland management. However, uptake of these schemes by farmers has thus far been insufficient. Furthermore, policies target mainly the farm level, whereas effective biodiversity conservation also requires landscape-level approaches.

The CAP4GI project sets out to provide advisory support for the upcoming CAP reform in 2028. One central target is to uncover factors that restrict or facilitate farmers' uptake of biodiversity-friendly schemes. We use case studies in Baden-Württemberg and Thuringia (Germany) employing stakeholder platforms and economic-ecological modelling.

We currently develop the agent/individual-based socio-ecological model Persefone.jl. Centred around the farm landscape, the model will encompass interactions from policy payments and regulations, farmer decisions, landscape composition and configuration, and the dynamic response of animals. We will assess how both farms and biodiversity are influenced by the latest CAP reform, and test alternative payment schemes that may come into place in 2028.

Here we present the conceptual model for the socio-economic part of Persefone.jl. We identify key elements and processes in the CAP, farmers' decision-making processes and management that shape biodiversity landscapes. We consider a) the spatial extent of both negative and positive impacts, b) the extent of direct or indirect impacts by current or reformed CAP regulations and payments, c) the availability of data, d) heterogeneity among farms.

A "Knick" in the landscape – hedge banks as biodiversity enhancing structures in the agricultural landscape of Schleswig-Holstein, Germany

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Agroforestry systems like hedgerows are traditional landscape management systems that intentionally use positive ecological interactions between herbaceous and woody plants. Agricultural hedgerows often persist as last near-natural woody habitat in intensified agriculture landscapes. Northern Germany has special hedge banks called "Knicks", which have undergone surface losses due to streets and the use of machines in modern agriculture in the past 70 years. In the face of climate change, the recovery of hedgerows can support climate protection through binding CO2.

Alongside climate change, biodiversity loss is the second alarming challenge for human society. A decline in species richness has been detected for the wall hedges of Northern Germany, especially for shrubs and herbaceous forest species. However, positive effects on species richness are achieved through structural enrichment of agricultural land through agroforestry. In addition to the scientific perspective, research needs on biodiversity are also addressed from a practical perspective. Therefore, further research with inter-and transdisciplinary perspectives is needed for the implementation agroforestry systems like wall hedges.

This application-orientated research project aims at a multidimensional focus on ecological, economic and social aspects of maintaining, recovering, and implementing "Knicks" in Schleswig-Holstein. With an inter- and transdisciplinary approach including different stakeholders (e.g. scientists, conservationist, farmers, local population and educators) the following research questions are addressed: 1) How can the impact of hedgerows on biodiversity be mapped and evaluated in the everyday practice of organic farms (ecological dimension)? 2) What is the influence of biodiversity-enhancing hedgerows on the economic performance of cropping systems (functional biodiversity) in order to optimize the agroforestry system (economic dimension)? 3) Which type of farming, e.g. farmer cooperatives, offers a feasible livelihood and democratic operations for the agricultural management of hedgerows (social dimension)?

Good neighbours, bad neighbours

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The practice of growing more than one crop species in one plot has a long tradition, like the companion planting of squash, maize and beans in Mexico, but mixed culture systems are virtually not used in modern large-scale agriculture. However, this growing practice can have large benefits like more efficient use of space and nutrients, weed suppression, less herbivory, more natural enemies and a suppression of the spread of diseases. On the other hand, some crops may suppress the growth of each other. A large part of this interaction takes place below-ground and chemical compounds released by the plant are known to play a major role. These root exudates can, for example, solubilize nutrients and make them thus available for neighbouring plants or attract helpful microorganisms and deter herbivores and pathogens. However, they can also have allelopathic effects. In our experiment, we investigate the performance of three crops, cucumber, pea and tomato, that are supposed to be "good neighbours" (cucumber and pea), "bad neighbours" (tomato and cucumber) or more neutral neighbours (tomato and pea) in the greenhouse and in the field. We analyze root exudates as well as roots and shoots by untargeted metabolomics (LC-MS). Using tools for statistics and compound annotation in untargeted metabolomics (MetaboScape, SIRIUS, MetIgel) we seek differences between monocultures and mixed stands and between different species and varieties. We found among others that some species are indeed worse neighbours than others and that some varieties within species are also more harmful than others. With the need for a more efficient agriculture that uses less resources, less fertilizer and less pesticides that can still match the challenges of climate change and bring stable yields, companion planting might contribute to the needed transformation. However, the single systems need careful investigation to give the farmers advice what can be really planted together to be beneficial.

Composition and diversity of bird communities in a South African farmland landscape

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Conversion from low to highly intensive agricultural management implies a direct effect on landscape structure. Simplification of landscapes impacts bird communities by reducing the availability of habitats and resources for a wide range of species. Contrasting, more complex landscapes may have a positive effect on bird communities, increasing species richness and dissimilarities between communities. We expect both species richness and dissimilarities between bird communities increase with degree of complexity of the landscape. At the same time, we expect to see differences in the community composition among habitat types.

We monitored bird diversity on 16 plots in a landscape dominated by sugar cane and macadamia plantations surrounding the Oribi Gorge Nature Reserve in South Africa. Therefore, we deployed in each study plot 16 acoustic recording devices, representing the proportional area of every habitat type in each study plot. Using an automated bird song recognition software, we screened 1536 hours of audio recordings and identified a total of 180 bird species, belonging to 8 trophic niches. Invertivore bird species were most common, followed by omnivores. Bird species diversity varied strongly between sampling locations (41 vs. 93 species) and was highly correlated with landscape complexity, with complex landscapes harbouring the highest bird diversity. Further, bird communities differed distinctly between study plots, as well as between habitat type within each study plot.

Our findings offer valuable perspectives on the bird communities present in South African farmlands. By actively maintaining landscape heterogeneity and encouraging crop diversity, farmers can cultivate environments that are more favourable to bird populations. In turn, this can contribute to the provision of essential ecosystem services, such as effective pest control.

Evolving weed distribution to potential for biodiversity

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Sensing technologies like 3D cameras, multispectral imaging, and artificial intelligence are increasingly utilized in modern weed management to detect and classify weed species for site-specific weed management (SSWM). While weeds can compete with crops, they also offer valuable ecosystem services such as supporting pollinators and providing shelter for insects and animals. Knowing the morphological and functional traits of weed species in a field allows for the selection of SSWM methods that effectively reduce the competitiveness of specific weed species while supporting those with beneficial traits. Trait-based approaches have gained popularity in recent decades. However, the practical application of integrating and interpreting weed functional traits for SSWM remains a gap. This study aims to identify and evaluate weed functional traits related to both provisions of ecosystem services and crop competition to translate this knowledge into maps. A manual weed assessment was conducted in 2022 near Braunschweig (Germany) on a winter wheat field untreated with herbicides, with a grid of 40 sampling points (10 m x 6 m). Plant-specific functional traits relevant for the provision of ecosystem services and agro-ecosystem diversity (e.g. importance for insect families and species, birds, and duration of flowering) and crop competition (e.g. leaf dry matter content, leaf area per leaf dry matter, competition index, and plant height at the vegetative stage) were extracted from published datasets and combined into the two variables 'biodiversity' and 'competition'. Each variable was weighted for each grid point based on the occurrence and density of the occurring weed species. Afterwards, a spatial distribution map was created for each weed species and trait variable using an ordinary kriging interpolation technique. A PCA was performed for each pixel of the grids using the biodiversity and competition variables, allowing to consider the weed community as a whole. As a result, two maps were generated: one showing the areas in the field that provide biodiversity benefits, and the other showing the areas where there is high competition potential due to the present weed composition. The goal is not only to reduce the application of herbicides but also to make a statement about the extent of ecosystem service provided by the weed flora of an agricultural field.

Unveiling the secrets of mason bees: Exploring the role of sexual dialect and flower availability in boosting population sizes within organic farming systems

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Currently there is a consensus that populations of wild bees are decreasing in pesticide polluted environments. Beside the effects on diversity of wild bees there are also sublethal chronical effects. For example, lab studies have shown that pesticide exposure influences precopulatory behavior and changes the chemical volatile composition of compounds with a function in the mating behavior. However, we still do not know if changes in chemical volatiles composition occur in pesticide polluted environments in relation to more sustainable farming systems. Furthermore, bee traits, including size, are known to be a consequence of the availability of local resources for larval provisioning; yet, whether egg laying females are able to recognize these environments and balance investment between offspring production and their sizes, still requires more attention. To shed light on these questions, trap nests were introduced in farming environments with pesticide application (conventional farms) and in organic farms to ensure bees from different environments were directly exposed to the local faming system. Males and females of the mason bee *Osmia bicornis* coming from these environments were counted, sized, and their chemical profiles were compared using gas chromatography. Moreover, the frass content mixed with uneaten pollen were identified and pollen diet was compared. Our results are indicating that there is indeed a potential effect of the farming system on sexual communication since these environments impact specific chemical compounds with a function in the mating behavior. The analyses of larval provision showed that plant diversity is higher in organic farms, where offspring production was higher, and bees were smaller. Our findings provide evidence that females from organic farms optimize maternal investment between offspring production and body size.

Earthworm and Soil Microbial Communities in Flower Strip Mixtures

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o Aims

Incorporation of flower strips is an agricultural measure to increase aboveground biodiversity and ecosystem services. Although soil communities are key components of terrestrial biodiversity and drive important ecosystem services, their abundance, diversity, and composition in flower strips remain largely unexplored. Here, we shed light on earthworms and soil microorganisms in flower strips.

o Methods

We sowed a field margin vegetation as well as two annual and two perennial flower strip mixtures in fully randomized plots of 9×28 m in three different types of soil in Germany. Two years following sowing, we determined earthworm communities using chemical extraction and investigated the soil microbiome using real-time PCR (archaea, bacteria, fungi, and soil-N-cycling genes) and amplicon sequencing (bacteria and fungi).

o Results

Different plant mixtures (i.e. field margin, annual and perennial flower strip mixtures) harbored distinct earthworm and soil microbial communities. Earthworm density and biomass declined or remained unaffected in annual flower strips but increased in perennial flower strips as compared to the field margin vegetation. Arbuscular mycorrhizal fungi showed greater diversity and relative abundance in non-tilled (i.e. field margin and perennial flower strips) than in tilled plant mixtures (i.e. annual flower strips).

o Conclusions

We attribute changes in earthworm and microbial communities mainly to the effect of tillage and plant diversity. Overall, we suggest that perennial flower strips serve as refugia. Future studies should compare soil biota in perennial flower strips to those in adjacent fields and investigate whether the promotion of soil communities spatially extends into adjacent fields (‘spillover’).

“Food-webs” - The changing structure of global-food system networks

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The global food system relies heavily on trade. The networks produced by the individual trade links show patterns that vary across different product groups and are subject to global market dynamics. Using methods from bipartite-network analyses, we show that the variables describing these networks best, fall on two axes: one between maximum modularity and maximum nestedness, and the other between interaction-evenness and web–asymmetry. We show that the staple crops (Cereals, Pulses) have very modular trade-networks, Oil crops are traded in a very asymmetric way, whereas crops like coffee and cocoa exhibit the highest values for nestedness. We also look at the temporal trends in these metrics and link this to market susceptibility.

Two sides of the coin - Field boundary vegetation differs across ecological borders

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Considering biodiversity and its losses in agroecosystems, boundaries play an important role as transition zones and due to edge effects. Arable field boundaries can harbour a large portion of plant species and therefore also taxa of higher trophic levels. While most field boundaries are characterized by ruderal and agro-tolerant plant species, they are still distinguished by their location on the field and adjacent habitats.

Here, we surveyed the vegetation of four different types of arable field boundaries: the crop edge (1) on the arable field and the adjacent permanent vegetation (2), both at outer ("normal") field boundaries (3) and at inner field boundaries (4) that occur, for example, around in-field habitat islands. As habitat islands, we chose kettleholes, because they are a typical landscape feature of our study region, the Uckermark in North-East Germany. Vegetation surveys were conducted in plots directly on each side of the edge.

As expected, permanent vegetation on inner and outer boundaries differs significantly regarding diversity and composition, driven mainly by the habitat type that dominated the boundary. Surprisingly, this was also the case for the crop edges, though the influence of boundary categories was weaker and characteristics of arable crop – its type and development - become more important. Therefore, heterogeneity even at a very local scale can have meaningfully leverage on plant diversity at field scale.

While outer field boundaries have higher diversities and a broader community composition, also inner field boundaries around kettleholes can harbour additional species and can therefore be developed to valuable Add-ons for diversity in agricultural systems.

The absence of landscape heterogeneity at a small scale affects wild bee assemblages and pollination services in mountain apple orchards.

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Many crops (e.g. apples) need insect pollination to set fruit and improve yield. Growers rely on the honeybee *Apis mellifera,* but also wild bees are efficient pollinators and could contribute to pollinating economically relevant crops for free. As landscape heterogeneity generally has a positive effect on bee diversity and fruit production, landscape context is one of the critical factors influencing pollinator presence and service provision. These relationships are mainly observed in lowland areas, but only a few works consider mountain farming systems where the land cover types and land use changes are expected to increase.

We selected 14 apple orchards in the Adige Valley, in South Tyrol (Italy), a mountainous area where (semi-) natural habitats cover more than 80% of the total area, and the valley is characterised by intensive apple production. In this study, we focussed on the scale-dependent effects of landscape heterogeneity on wild bee assemblages and the related pollination service they provide at different distances to the centre of the studied apple orchards (100, 250, 500, 1000 and 2000 m).

With pan-trap catches, observations on the visitation frequency and a pollinator exclusion experiment, we found that (1) landscape heterogeneity positively influenced wild bee abundance and richness on-site at every scale. However, the effect was strongest at a 500 m radius from the field. (2) The multidiversity index calculated on the known species richness of other taxa was positively related to wild bee richness. (3) The visitation rate of wild bees was negatively influenced by crop cover. (4) Pollination success was positively related to semi-natural habitat cover, while honeybee abundance did not affect the wild bee visitation rate or pollination success.

We conclude that maintaining landscape heterogeneity, even on a small scale and in a mountainous region, is critical to sustaining wild bee diversity and potentially benefiting from related ecosystem services.

Monitoring of insects in transforming landscapes – assessing effects of co-designed measures in landscape labs

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Agroecosystem living labs or landscape labs are currently employed in transdisciplinary projects for initiating thorough transformations of agricultural landscapes that go beyond the implementation of individual biodiversity-enhancing measures at local scales. One challenge of those territorial and co-designed approaches is the assessment of success in enhancing biodiversity. The monitoring approach cannot be based on preset parameters of change because quality and quantity of measures as well as their spatial and temporal layout are the result of the co-design process. How can we design monitoring into an almost unknown future?

FInAL (2019-2025) is a transdisciplinary research and demonstration project in three landscape labs (3km x 3km) in Germany, aiming for sustainable transformation of landscapes to facilitate insects. The process is accompanied by annual monitoring of several ecological indicators, i.e. insect taxa and ecosystem functions. Applied sampling methods need to be flexible enough to operate in a changing landscape while the statistical analysis needs to be robust enough to be able to detect change of different effect sizes and geographic scales.

To reflect a transformation that is expressed by small but continuous change over time, we developed and now employ a network of monitoring approaches on the basis of landscapes analyses, power analyses and simulation studies of spatial sampling designs. Wild bees, for example, are assessed four times a year in a systematic centric grid on 18 locations per landscape with pan traps. Together with pitfall traps, they constitute the backbone of our monitoring framework. After four years of sampling, we can evaluate our approach, e. g. by analyzing catch effectiveness, and adapt monitoring, if necessary.

Plant species response at the interface of crop fields to protected grasslands – impact of farm practices

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There is an urgent need to stop the loss of biodiversity and associated ecosystem functions in our agricultural landscapes. The structural heterogeneity of these landscapes is elementarily made up by edges, many of them between habitats of different quality in the sense of biodiversity. If we want to find the most effective conservation measures, we need to understand how common habitats and their land use influence each other. The interface of grasslands and crop fields is so far not much studied, particularly at fine scale, although it is a widespread boundary in Central Europe. Here, we sampled the vegetation continuously on transects from the interior of organically and conventionally farmed arable fields far into adjacent protected semi-natural grasslands in two German landscapes. We found that grasslands adjacent to organic fields had a higher plant diversity - even far into their interior. We could show that the decreasing richness towards the grassland edges continued transitionally into the crop fields, as predicted by theory, and that this response is driven by specialists as well as generalists. Beyond that, and due to the occurrence of additional edge species, the transitional zones at the grassland – crop field interface increased the landscapes gamma diversity. We observed ecological indicator values, particularly for nutrients, to be associated with the species response curves over the transects. To preserve biodiversity, buffer zones at the edges of crop fields with reduced application of fertilizers would enhance the quality of neighboring habitats. Still better, organic farming practices should serve as a standard rather than exception.

Linking Policy and Farmer Behavior: A qualitative study on Cooperative and Agri-Environmental Management in Saxony-Anhalt

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There is increasing evidence that biodiversity in agricultural areas is declining, mostly due to intensification, fragmentation and structural simplification of landscapes caused by the removal of semi-natural vegetation to expand agricultural fields. Agri-environmental policies and management measures to reverse such negative trends mostly focus on specific species, individual actors, isolated plots, and local measures. However, many insect species and associated ecosystem services such as pollination and pest control require coordinated actions at the landscape level. This is due to the interactions between local and landscape factors, and to the dependence of these mobile organisms on year-round availability of resources. Therefore, agri-environmental management requires spatio-temporal coordination in their management and cooperation between the farmers at the landscape scale.

We investigated how farmers' individual agricultural practices and management contribute to the landscape-scale provision of habitat for insects. Using the Behavior Change Wheel, we explored the key drivers and barriers (capabilities, opportunities, motivations) underlying farmers' participation in agri-environmental schemes aimed at promoting insect-related services (namely pollination and biological pest control), at field, farm, and landscape levels in Saxony-Anhalt (Germany).

Our results contribute to formulate recommendations for policy and practice to support the achievement of integrated cross-scale management of insect-friendly agricultural practices.

SESSION 6:

20 Years Jena Experiment

The rationale and history of the Jena Experiment

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The Jena grassland biodiversity experiment was set up in 2002 to investigate the effects of plant diversity on element cycling and trophic interactions. At the time the Jena Experiment was conceived, there was some controversy about the results obtained from earlier biodiversity experiments. The criticisms ranged from poor study design and failure to account for statistical artefacts, to the choice of inappropriate model communities. In addition, there was little focus on physiological and ecosystem ecology in biodiversity experiments, fields where Germany had a strong history. This talk first reviews the motivation and early history of the Jena Experiment. It then considers the role the Jena Experiment has played in the development of ecology in Germany, and some lessons that can be learned for future experiments.

Plant diversity stabilizes soil temperature

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Extreme weather events are occurring more frequently, and research has shown that plant diversity can help mitigate impacts of climate change by increasing plant productivity and ecosystem stability. Although soil temperature and its stability are key determinants of essential ecosystem processes related to water and nutrient uptake as well as soil respiration and microbial activity, no study has yet investigated whether plant diversity can buffer soil temperature fluctuations. Using 18 years of a continuous dataset with a resolution of 1 minute (~795,312,000 individual measurements) from a large-scale grassland biodiversity experiment, we show that plant diversity buffers soil temperature throughout the year. Plant diversity helped to prevent soil heating in hot weather, and cooling in cold weather. Moreover, this effect of plant diversity increased over the 18-year observation period with the aging of experimental communities and was even stronger under extreme conditions, i.e., on hot days or in dry years. Using structural equation modelling, we found that plant diversity stabilized soil temperature by increasing soil organic carbon concentrations and, to a lesser extent, by increasing the plant leaf area index. We suggest that the diversity-induced stabilization of soil temperature may help to mitigate the negative effects of extreme climatic events such as soil carbon release, thus slow global warming.

Biodiversity facets affect community surface temperature via 3D canopy structure in grassland communities

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The surface temperature of a plant community reflects its energy budget and drives growth, yet it is rarely used as a property predicting biodiversity ecosystem-functioning relationships. Diverse communities typically have taller and more densely packed canopies than less diverse communities, which are key elements of their structure, affecting physiological processes and promoting higher primary productivity. However, whether plant diversity can translate into a cooling potential remains unclear and lacks empirical evidence. Here, we assessed how functional identity, functional diversity, and species richness of grassland communities predict plant surface temperature through canopy structure in the Jena Experiment. We estimated canopy structure describing vertical structure (mean height, LAI, and evenness), and the highest allocation of biomass (center of gravity) along height strata. Stands gaps and canopy surface variation were horizontal structures. The thermal camera measured surface temperature and the terrestrial laser scanning estimated structural canopy metrics. SEM models predicted the biodiversity effects on surface temperature during two seasonal peaks of biomass. In May, herb-dominated communities directly promoted lower leaf surface temperatures. However, communities with Grass-dominated communities showed a smaller variation of surface temperatures, positively affected by species richness via an increase in mean height. In August, mean surface temperature decreased with increasing community clumpiness and LAI, while the variation of surface temperature was greater in herb-dominated than in grass-dominated communities. Effective differences in canopy structure appear to be driven by different functional groups (grasses and forbs). Our results show that biodiversity facets influence microclimatic conditions across the growing season and may contribute to sampling and facilitation effects on ecosystem functioning.

Rapid adaptation: a narrative of plant community history and diversity

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The strength of positive biodiversity–ecosystem functioning relationship increases in long-term biodiversity experiments. Different biotic interactions characterize high- and low-diversity communities, the first one with an increased resource-use complementarity, strong competition for light, and positive plant–soil feedbacks, causing higher community performance. Low-diversity communities are characterized by low competition for light (due to low vegetation cover) and negative plant–soil feedbacks. We expected these different environments to exert different selective pressures to which plant species respond adaptively. To measure these responses, we established a phytometer experiment with nine plant species in a 17-year-old biodiversity experiment (the Jena Experiment). The performance of offspring of plants with known selection history in experimental communities of different species richness (“with plant and soil history”) was compared in their origin environment, and in communities with the same species composition, but “without plant history, with soil history”, “without plant and soil history”. Additionally, we compared the performances of individuals grown in their origin environment with the ones of offspring of plants with no selection history. In all actual environments, species responded to increasing species richness with an increase in SLA and a decrease in leaf greenness, leaf nitrogen concentrations, and plant individual biomass, the last having interaction effects between species richness and actual environments. Plant height and SLA had the highest values in the environment “without soil and plant history”, especially in low-diversity communities. Comparison between individuals with or without selection history showed how the first ones had a weaker decrease of biomass production with increasing species richness and a steeper increase in plant height, therefore better responding to the competitive environment caused by increasing plant diversity.

Plant diversity and soil and plant history shape volatile profiles at community and species levels

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In the last decades, numerous laboratory experiments have shown that volatile organic compounds (VOCs) play pivotal roles in plant defense as well as pollination and intra- and interspecific plant communication. Thus, VOCs represent important ecosystem functions in natural communities. The effects of plant and soil community biodiversity and eco-evolutionary history on plant VOC profiles have been poorly understood. The objectives of this study were to investigate a) how plant diversity affects VOC emission at community and species levels and b) whether plant and soil history modify the effect of plant diversity on plant VOCs. Here, we explored plant VOC emission at both community and species (Plantago lanceolata) level across a diversity gradient in a long-term experimental grassland (The Jena Experiment).

Our results show that community-level VOC richness and abundance increase with plant diversity. P. lanceolata VOC emission was not influenced by plant diversity but rather by the diversity of the VOCs emitted by the surrounding plant community. P. lanceolata individuals in plant communities emitting a low VOC diversity emitted higher VOC diversity themselves, compared to individuals in the midst of high VOC diversity. Furthermore, we found that plant and soil history influence the effect of plant diversity on VOC diversity in P. lanceolata. Individuals with soil and plant history decreased their VOC diversity with increasing plant diversity, while individuals without history had a weaker relationship with plant diversity but emitted higher VOC diversity compared to individuals with soil and plant history. Our findings emphasize the importance of diversity and soil and plant history in driving VOC-mediated biodiversity and ecosystem functioning relationships.

Long-term plant diversity-consumer relationships in the Jena Experiment

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Consumers are essential parts of ecosystems because they provide ecosystem functions that transfer matter and energy (plant carbon) from primary producers (plants) to higher trophic levels and can affect plant community assembly and diversity (top-down effects). At the same time, strong bottom-up effects occur when changes in the plant community (quantity and quality of resources) shape the consumer community. Measuring the plant diversity-consumer relationships in the Jena Experiment since 2010, we showed that plant diversity has multi-fold impacts on higher trophic levels and their associated functions. Overall, higher plant species richness supported more diverse and complex arthropod communities (species richness, abundance, and functional composition) and levels of herbivory (consumption of living plants or plant parts) and predation (the killing and consumption of live prey animals by higher trophic level consumers). While these patterns were consistent across multiple years, we also documented large variability within and between years and shifts in these relationships over time. For example, the strength of diversity effects on herbivory rates has increased from 2010 to 2021. So far, temporal changes in biodiversity-ecosystem-functioning relationships have been observed mainly for producers. Using long-term data from a biodiversity experiment, we show that such changes also occur in plant diversity-consumer relationships with consequences for multitrophic ecosystem functioning and whole-ecosystem energy flows.

Plant diversity effects on above-belowground phenology

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It is often argued that biodiversity enhances ecosystem functioning when species with complementary niches allow biological communities to capture resources more efficiently or by the presence of one dominant species. Yet, the role of community phenology as a measure of temporal niche breadth has rarely been explored. Moreover, plant phenology is typically assessed aboveground, and less is known about the phenology of belowground processes, and how biological diversity may influence the coupling of aboveground-belowground activity. We measured plant (plant height and greenness) and soil (root growth and detritivore feeding activity) processes as proxies of biological activity every two weeks for one year in an experimental grassland ranging in plant diversity from monocultures to 60-species mixtures. We then tested how plant diversity and climatic factors predict the phenology of aboveground-belowground activity and how this may contribute to the phenological coupling of above- and belowground compartments during spring, summer, and winter in terrestrial ecosystems. In the growing season, peak plant height preceded greenness. Root production started right after leaf senescence and continued throughout the winter. Detritivores were active throughout the year but with high variability, with peaks in summer and late fall. The magnitude and/or direction of the plant diversity effects on plant and soil activity changed throughout the year, but mostly showed enhancing effects on individual activities. Because these effects did not kick in simultaneously for the different processes, the aboveground-belowground coupling increased and decreased with increasing diversity, depending on the combination of processes. By providing fine-resolution within-year data, we show fundamental differences in the phenological patterns of shoots, roots, and soil fauna activity, stressing the role of plant diversity in modulating plant-soil interdependence and ecosystem functioning.

Causal inference in soil-plant-climate systems

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The connection between plant diversity and stability has been well-documented in various studies, yet the exact mechanisms responsible for this relationship still need to be determined. We previously suggested that a significant factor contributing to the observed stability increase could be the influence of plant diversity on soil temperature and its fluctuations. Soil temperature plays a crucial role in numerous ecosystem processes. Alterations of its dynamics may therefore serve as a foundation for several observed effects. To comprehend the mechanism connecting plant diversity and soil temperature stability, we aim to uncover the underlying dynamics of this system, utilizing data from the Jena experiment gathered over nearly two decades. We contrast the outcomes of Structural Equation Modeling (SEM), based on expert opinions, with those of Causal Inference techniques that do not presume any potential relationships. While the findings are generally in agreement, we also note differences between the methods, which challenges the frequent use of SEMs as the only tool to uncover structural relationships in ecological data.

Plant diversity effects on soil microbial communities

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Experiments manipulating aspects of biodiversity and observing the effects on ecosystem functioning have provided ample evidence for positive diversity-productivity and -stability relationships. Concerns over potential cascading effects are acute, particularly in slow, complex systems like soils. From its inception, the Jena Experiment has had a strong and rather unique focus on belowground effects of plant species and functional group diversity. Its soils were repeatedly monitored for effects on microbial biomass and activity, establishing the importance of both plant diversity and functional groups, as well as dynamic changes. The experiment's soil was also among the first plant diversity experiments to be characterized in terms of the compositions of various soil microbial communities.

This talk first briefly reviews the findings of microbial community analyses in the Jena Experiment, which differ in terms of whether effects on microbial diversity and community composition are found, also within microbial groups. Most published studies analyzed specific microbial groups in conjunction with specific soil parameters, choosing to include covariates appropriate to their experimental design and question. Technological approaches differed. Sampling for the studies was conducted at different times, both with respect to season and years since establishment. Therefore, the main part of the talk will focus on data generated in the current phase of the Jena Experiment at a single time point, at which we can assume that the plant communities were established, and using similar technological and bioinformatics approaches. This analysis highlights contrasting effects of plant diversity on functionally contrasting soil microbial groups, such as eukaryotic plant mutualists and pathogens. Finally, the talk will touch on evidence for soil microbial feedback on ecosystem functioning collected before and during the current phase of the Jena Experiment.

Nitrogen fertilization weakens tree diversity effect but enhances soil microbial diversity effect on productivity in a tree diversity experiment

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Biodiversity increases ecosystem functions such as productivity. Whether and how above- and belowground biodiversity simultaneously contribute to ecosystem productivity remains to be elucidated, especially under global changes. Here, we conducted a manipulation experiment by planting 76,500 trees in plots with varying tree species richness (ranging from 1 to 16 species) under both control and nitrogen fertilization treatments. We found that increased species richness positively influences productivity through proportional increases in both complementary and selection effects after four years. Functional diversity and identity directly and strongly contributed to increases in productivity, while tree species richness indirectly linked to productivity via soil bacterial diversity. Nitrogen fertilization diminishes the relationship between tree species richness and productivity by promoting productivity in monocultures, leading to proportional decreases in complementary and selection effects. Importantly, nitrogen fertilization reduces the direct effect of functional diversity and weakens the effect of functional identity on productivity. Furthermore, nitrogen fertilization shifts the weak positive links between productivity and soil bacterial diversity towards a strong positive relationship with soil symbiotic fungal diversity. These findings suggest that nitrogen fertilization weakens aboveground biodiversity-productivity relationships and strengthens belowground biodiversity-productivity relationships in subtropical plantations.

Plant Diversity, Plant History, and Soil History Effects on Community Composition of Cercozoa, Oomycota, and Bacteria

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The “Jena Experiment” is a long-term field experiment established in 2002 and consisting of experimental plots with varying plant communities ranging from 1 to 60 species. In 2016, a sub-experiment, the “ΔBEF Experiment” (DELTa-BEF; short for DEterminants of Long-Term Biodiversity Effects on Ecosystem Functioning) was set up. On all plots of the Jena Experiment, three subplots with differing soil and plant history were established. Bulk soil was sampled in 2021. We investigated by amplicon sequencing how plant species richness and the history treatments influenced the diversity of Bacteria and two protistan taxa, Cercozoa (Rhizaria), and Oomycota (Stramenopila). These two protistan groups are functionally diverse and include a wide range of plant parasites. Our results showed that plant diversity and the history treatments had a significant effect on the diversity and composition of those microbial communities. We observed that bacterial alpha diversity increased with plant diversity. In contrast, the alpha diversity of Oomycota decreased, and the alpha diversity of Cercozoa was similar across all plant diversity levels. However, the alpha diversity of Phytomyxea (subset of Cercozoa, plant parasites) also increased with plant diversity, potentially indicating “pathogen dilution” along the plant diversity gradient. Our results indicate that not all microbial groups react equally to plant diversity. Community compositions of all three microbial groups were driven by the plant diversity gradient and by the history treatments, while the soil history effects were much stronger than plant history effects.

Plant diversity increases microbial resistance and resilience to drought

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Higher plant diversity is thought to facilitate root niche partitioning, resulting in greater root densities and a more active rhizosphere. The ability of microorganisms to resist drying and recover after a drought, in turn, might depend on the microbial access to rhizosphere carbon resources. Yet, the influence of plant diversity on the microbial responses to drought cycles remain unknown. We hypothesized that the microbial ability to resist drought and recover following drought would increase with higher plant diversity. To test this, we investigated how microbial communities maintained their growth during dry conditions (resistance) and how fast growth rates recovered after rewetting (resilience). We used soil samples from the main experiment at the Jena Experiment (1-60 grassland plant species) and two different soil depths (0-10 cm and 10-30 cm). We found that both the microbial resistance and resilience to drought increased with higher plant diversity. In addition, surface soils were more resistant to drought than soils from deeper soil layers. This suggests that microbial communities cope progressively better with drought as the plant diversity increases. Our findings reveal that grasslands with higher diversity can reduce the amount of carbon released during drought cycles by shifting the microbial use of carbon from respiration to growth.

Long-term plant diversity effects on the temporal stability of ecosystem multifunctionality

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It is well known that biodiversity enhances and stabilizes the functioning of ecosystems, and that these positive biodiversity effects increase over time via complementarity and adjustment processes among plants and higher trophic levels. However, this knowledge is almost exclusively based on the analysis of single ecosystem functions, e.g., analysis using biomass production or soil microbial activity as a response, while there is a lack of studies using a multifunctional approach. In this study, we addressed this knowledge gap by testing the effect of plant diversity (1–60 species) on ecosystem multifunctionality over a five-year period, its temporal stability, as well as multifunctional resistance and resilience to a two-year drought event, in a long-term grassland biodiversity experiment (Jena Experiment). Taking advantage of the split-plot design (i.e., ΔBEF Experiment), we further tested whether a shared history of plants and soil has an influence on the studied relationships. We calculated ecosystem multifunctionality based on functions related to plants (aboveground biomass, height, invasion resistance, leaf area index) and higher trophic levels (soil microbial activity [Cmic, BAS], aboveground herbivory and predation). Our results showed that plant diversity increased ecosystem multifunctionality and its temporal stability. Moreover, we found that plant diversity fostered the resistance against drought. Plant communities with shared history showed a stronger plant diversity–multifunctionality relationship, and a higher temporal stability of ecosystem multifunctionality than plant communities without shared histories. Our study highlights the importance of diverse and long-established grasslands for ecosystem multifunctionality, ecosystem functioning, and thus human well-being.

The multiple-mechanisms hypothesis of biodiversity–stability relationships

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Long-term research in the Jena Experiment provided novel empirical evidence that ecological and evolutionary processes are intertwined in determining biodiversity–ecosystem functioning (BEF) relationships. These insights are likely to have implications for ecosystem stability.
We hypothesize that multifunctional stability is highest in high-diversity plant communities and that biodiversity–stability relationships increase over time, due to a variety of forms of ecological complementarity. We introduce the multiple-mechanisms hypothesis of biodiversity–stability relationships, suggesting that it is not individual mechanisms that drive long-term biodiversity effects on ecosystem functioning and stability, but it is a multitude of intertwined processes that produce increasingly positive ecosystem effects. Important mechanisms include: low-diversity plant communities are dominated by accumulating plant-antagonists over time; low-diversity plant communities use resources less efficiently than high-diversity plant communities, with the latter having more closed nutrient cycles; high-diversity plant communities support a greater diversity and activity of beneficial interaction partners across trophic levels; high-diversity plant communities diversify in their traits within and across species to optimize temporal (intra- and interannual) and spatial complementarity; high-diversity plant communities have higher top-down control of aboveground herbivores by predators. In line with the observation that different species play unique roles in ecosystems when considering multiple ecosystem functions, years, locations, and environmental change scenarios, the dominance of different mechanisms in contributing to the higher performance and stability of high-diversity plant communities might differ across ecosystem functions, locations, and environmental conditions, indicating a “complementarity of different mechanisms”.

The role of biodiversity–ecosystem functioning experiments: open questions and future tasks

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Terrestrial and aquatic ecosystems contain a large number of species and provide a large number of ecosystem services, in particular transformation of solar energy and carbon dioxide into biomass, fueling element cycles, soil formation, climate control and more. The role of biodiversity–ecosystem functioning experiments is to test what would happen if the number of species within an ecosystem would be reduced—more drastically than experienced up to now but predicted under some scenarios for the future. The Jena Experiment and others have shown that such species loss strongly reduces ecosystem functioning and ecosystem stability and that this effect increases over time. The well-functioning and stability of species-rich ecosystems seem to mainly be due to reduced competition and beneficial interactions between species with complementary niches and/or at different trophic levels. However, it is still unclear what makes interactions beneficial (e.g., which trait differences), how such interactions are shaped by community-assembly and evolutionary processes, and which forces may counteract the emergence of positive biodiversity effects in ecosystems. The challenge for future experiments is to find out new designs that could address these open questions. More direct manipulations of specific interactions, either in simplified model systems or by removal in more complicated systems, may be one approach. Incorporating genetic analysis underpinning interactions from the within-species up to the between-trophic-group level promises to overcome limitations of trait-based approaches. It may be particularly rewarding to develop biodiverse agricultural systems with desirable functioning, because in this case some of the forces counteracting positive biodiversity effects such as invasion by “selfish” genotypes or species can be prevented.

Plant diversity enhances belowground multitrophic functioning in the long term

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The relationship of plant diversity and several ecosystem functions strengthens over time. This suggests that the restructuring of biotic interactions in the process of a community's assembly and the associated changes in function differ between species rich and species poor communities. An important component of these changes is the feedback between plant and soil community history. In this study we examine the interactive effects of plant richness and community history on the trophic functions of the soil fauna community. We hypothesized that disrupting the relationship between soil and plant community history will diminish any positive effect of plant richness on the multitrophic functions of the soil food-web. We tested this hypothesis on a long-term grassland biodiversity experiment. Using a split-plot design and sequentially removing elements of community history (without plant history, without plant or soil history) we compared the diversity-functioning relationship in our treatment subplots to controls with ~20 years of plot specific community history. We found that indeed, the relationship between plant richness and belowground multitrophic functionality is stronger in communities with shared plant and soil community history. Our results partly accord and partly contrast what has been shown for aboveground diversity and multitrophic functioning relationships.

Plant and soil history modulate plant diversity effects on leaf litter decomposition

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Leaf litter decomposition is a crucial process in terrestrial ecosystems. Across environmental conditions, litter decomposition is mainly driven by litter quality, such as leaf nutrients and phenolics, plant species richness, and the local soil biota community. Both the plant community and the soil biota community affect each other and can change and co-adapt over time. However, how this shared history affects litter decomposition remains unknown. Here, we investigated the effects of plant and soil history on leaf litter decomposition and assessed the role of plant species richness in this process.

We measured litter decomposability and litter quality of six temperate grassland plant species. In 96 Ecotron subunits, we grew plants in communities of increasing plant diversity (1-6 plant species), crossed with plant and soil history treatments. Plant history was established using two seed sources: seeds harvested from plants grown in a long-term biodiversity experiment (Jena Experiment) for 12 years or seed material without selection history in the biodiversity experiment. Soil history was established by using either the soil from the same experimental plots or from bare ground plots. We measured leaf carbon, nitrogen, phenolics, and soil microbial respiration as predictors of litter decomposability.

Our results show how plant and soil history affect leaf litter decomposition and to what extent plant species richness interacts with plant and soil history to determine litter decomposability. Furthermore, we assessed leaf phenolics and demonstrate the importance of litter quality in predicting litter decomposability.

Our findings underscore the importance of considering plant and soil history in predicting leaf litter decomposition and thus nutrient cycles. Understanding the factors that influence leaf litter decomposition can help to better predict and manage ecological processes in terrestrial ecosystems.

ECOSENSE - Multi-scale quantification and modelling of spatio-temporal dynamics of ecosystem processes by smart autonomous sensor networks

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Recurrent stresses, such as heat waves and droughts, increasingly endanger European forests, with potentially cascading effects on their carbon sink capacity and drought resilience. Knowledge on the impact on the multitude of processes driving soil-plant-atmosphere interactions within complex systems is widely lacking and uncertainty about future changes extremely high. Forecasting forest response to climate change will require an improved process understanding of carbon and water cycling across various temporal and spatial scales, covering the atmosphere, biosphere, pedosphere and hydrosphere. Many processes occur at small scales and high spatial heterogeneity and their interactions and feedback loops can be key players to amplify or dampen a system's response to stress. Currently, we are lacking the appropriate measuring, data and modelling tools allowing for comprehensive, real time quantification of relevant processes at high spatio-temporal coverage. Climate impacts are highly unpredictable, and future research will require novel mobile, easy deployable, and cost-efficient approaches. Our interdisciplinary project **ECOSENSE** will investigate all relevant scales in a next generation ecosystem research assessment. Our vision is to detect and forecast critical changes in ecosystem functioning based on the understanding of hierarchical process interaction. **ECOSENSE** will develop, implement, and test a new versatile, distributed, cost-effective, autonomous, intelligent sensor network based on novel microsensors tailored to the specific needs in harsh forests. They will measure the spatio-temporal dynamics of ecosystem states and fluxes in a minimally invasive way. Data will be transferred in real-time into a sophisticated database which can be explored for process analysis, deep learning approaches, and enhanced simulation models for now- and forecasting applications. Our novel **ECOSENSE** Toolkit will open new horizons for rapid assessment in vast and remote ecosystems.

SESSION 7:

Cross-Boundary BEF Effects

Principles and pathways for cross-boundary effects of biodiversity on ecosystem functioning

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The biodiversity–ecosystem functioning concept states that properties of and processes in ecosystems are markedly influenced by species richness and other facets of biodiversity. However, biodiversity–ecosystem functioning studies have been largely restricted to single ecosystems, ignoring the importance of functional links—such as the exchange of matter, energy and organisms—between coupled systems. Here we outline three different pathways of cross-boundary biodiversity effects on ecosystem processes, focusing on terrestrial-aquatic linkages to illustrate the case. Pathway 1 describes cases where biodiversity of 'donor' ecosystems directly affects the functioning of 'recipient' ecosystems. Pathway 2 illustrates cases where biodiversity of 'donor' communities affects the functioning of 'recipient' ecosystems indirectly, by influencing biodiversity of the 'recipient' communities. Pathway 3 describes cases where biodiversity of 'donor' ecosystems affects 'recipient'-ecosystem functioning indirectly through effects on 'donor'- ecosystem processes that propagate across system boundaries.

This cross-boundary perspective of biodiversity–ecosystem functioning relationships presents a promising frontier for biodiversity and ecosystem science, with repercussions for the conservation, restoration and management of biodiversity and ecosystems from local to landscape scales.

Response of Terrestrial Food Webs to Changes in Aquatic Subsidies

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Aquatic and terrestrial ecosystems are functionally linked through reciprocal flow of resources (subsidies). Aquatic subsidies are high-quality food sources for terrestrial predators owing to their high content of long-chain poly-unsaturated fatty acids (PUFAs). However, subsidy flows from aquatic to terrestrial systems and the role of subsidy quality has been comparatively less studied. We generated theories on how changes in the quality (long-chain PUFA) of aquatic emergent insects affect the stocks and functions of terrestrial ecosystems. Aquatic subsidies can directly enter a recipient ecosystem through terrestrial predator consumption or through recycling in the terrestrial nutrient pool. Both pathways can cause multiple indirect and potentially conflicting effects. We derived a series of models to predict the relative and interactive effects between consumption and recycling aquatic subsidy coupling pathways on the stocks and functions of terrestrial ecosystems. Our analysis showed that the functioning of the terrestrial ecosystem increased with the quality of aquatic emergent insects. The recycling of nutrients within the terrestrial ecosystem increased more strongly than its production per unit aquatic emergent insects' quality increase. This implies a threshold where an increase in aquatic emergent insects' quality led to stronger effects of subsidies on recycling relative to the production of the recipient ecosystem. Aquatic subsidies coupling pathways also had differential effects on the terrestrial ecosystem as recycling coupling pathway always led to equal or higher terrestrial ecosystem stocks and functions, whereas consumption couplings had alternating positive and negative effects depending on the trophic level and characteristic of a trophic cascade. We argue that terrestrial ecosystems are highly sensitive to changes in the quality of aquatic emergent insects and related changes can cause complex feedbacks within the terrestrial ecosystem.

Effects of mining activities on fish communities and food web dynamics in a lowland river

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Fish communities of streams and rivers might substantially be subsidized by terrestrial insects that fall into the water. Although such animal-mediated fluxes are increasingly recognized, little is known on how anthropogenic perturbations may influence the strength of such exchanges. Intense land-use, such as lignite mining may impact a river ecosystem due to the flocculation of iron (III) oxides, and thus altering food web dynamics.

We compared sections of the River Spree in North-East Germany that were greatly influenced by iron oxides with sections located below a dam where passive remediation technologies are applied. We studied abundances and species composition of macroinvertebrate and fish assemblages as well as the growth of juvenile piscivorous pike Esox lucius. Terrestrial contributions to the diet of the three most abundant fish species was compared using an estimate of short-term (i.e., metabarcoding of the gut content) as well as longer-term (i.e., hydrogen stable isotopes) resource use.

Compared to locations below the dam, the abundance of benthic macroinvertebrates at locations of high iron concentrations above the dam was significantly reduced. Similarly, catch per unit effort of all fishes was significantly higher in locations below the dam compared to locations above the dam and juveniles of piscivorous pike were significantly smaller in size in sections of high iron concentrations. We could demonstrate that two of the three most abundant fish species, perch Perca fluviatilis, and bleak Alburnus alburnus, received higher contributions of terrestrial insects to their diet at locations of high iron concentration.

Lotic food webs above and below the dam greatly differed in the overall structure with respect to the energy available for the highest tropic levels and the contribution of terrestrial insects to the diet of omnivorous fish.

Therefore, human-induced environmental perturbation such as river damming and mining activities represent strong pressures that can alter the flow of energy between aquatic and terrestrial systems, indicating a broad impact on the landscape level.

Generalization of density-dependent ecosystem function in dominant aquatic macroinvertebrates

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Past BEF research in aquatic systems often focussed on community richness and relative abundances of species, yet rarely considered the density of focal species and possible intraspecific interactions. Intraspecific density variation, however, is ubiquitous in nature with expected consequences for density-dependent interactions. We experimentally investigated how leaf litter processing by freshwater amphipods varies along a large population density gradient and in a competition setting. Results from 252 mesocosms in the laboratory and 97 mesocosms in a natural stream show that per-capita leaf processing rates are strongly depending on population density in monocultures (density-ecosystem function relationship; DEF). The interspecific competition setting confirmed the DEF relationship and highlighted the functional redundancy of the studied species. The density-dependent processing rates possibly arose due to both intra- and interspecific interference competition. The wide range of densities allowed identifying a flattening in processing rates at well-defined breakpoints. We interpreted those as minimal metabolic requirement at which bare survival overruled any other process such as interference competition. Our work clearly corroborated and generalized nonlinear density-dependent processing rates in freshwater macroinvertebrates that are purely relying on terrestrial allochthonous resource inputs.

How cross-ecosystem spatial flows between habitats of contrasting functioning could relax the limitations to production at local and meta-ecosystem scales

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Species at the basis of food webs are possibly limited by different elements in aquatic and terrestrial ecosystems. If spatial flows from the neighboring habitat bring those limiting elements, we can expect them to enhance productivity in aquatic-terrestrial meta-ecosystems through spatial complementarity. We studied this hypothesis in a stoichiometric model and a meta-ecosystem experiment. The model allowed us to identify the conditions on basal species needs and on flow levels for such spatial complementarity to emerge; the results also highlight that out of those conditions, spatial flows could also have negative impact on metaecosystem productivity. In the experiment, we manipulated the presence and the nature of the spatial flows (top consumer excretion versus detritus flow) connecting one net autotrophic ecosystem and one net heterotrophic ecosystem. We found an overall positive effect of spatial flows on ecosystem productivity emerging over time, which differently affected some parts of the system depending on the nature of the flow. We discuss the mechanisms at play through the change in stoichiometry induced by the spatial flows. Our results stress the importance of accounting for flow quality, in addition to flow quantity, when analyzing the contribution of spatial flows to ecosystem functioning.

Water-filled tree holes and other aquatic microecosystems as models for cross-boundary BEF effects

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Water-filled tree holes and other small aquatic ecosystems can host a variety of organisms, from bacteria and protists to insect larvae. These systems may function as relatively isolated aquatic microecosystems within larger terrestrial ecosystems. However, they do have specific linkages with the "outside world". For example, they depend on detritus entering the aquatic systems as resources for the inhabiting organisms. Adult insects emerge from the water and may act as subsidies and providers of ecosystem functions to the surrounding terrestrial areas. In addition, terrestrial species may use the water bodies for a variety of reasons, including feeding. Thus, water-filled tree holes can serve as model systems for cross-system interactions. I will present results from several studies of natural tree holes but also anthropogenic systems such as water-filled tires. For example, I will show that forest management reduces forest structural complexity and detritus amount in tree holes and that this affects the inhabiting insect richness and abundance. Species richness and abundance of aquatic insects can then influence the decomposition of detritus, one of the central ecosystem functions in the aquatic systems. In a different project, we used emergence traps to record the emergence of adult insects from aquatic microecosystems in cities. Some of these emerging insects serve as pollinators and may increase this ecosystem service in the surrounding gardens and parks. However, depending on the emerging species, there are also disservices, such as an increased production of mosquitoes. Especially non-native species of mosquitos act as vectors of diseases and might have particularly negative effects on humans and livestock. These results show that waterfilled tree holes and other aquatic microecosystems are not only interesting and important habitats but can also be used as model systems to study cross-boundary BEF effects and the environmental changes that affect them.

Interactive effects of temperature and functional composition over freshwater ecosystem structure and functioning

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Global warming is likely to alter the composition and quality of leaf litter – a key external subsidy to freshwater ecosystems. Although warming and detritus functional diversity and quality act in concert in ecosystems, these factors are often studied separately. Here, we used a cross-boundary aquatic system (tank bromeliads) to understand the interactive effects of warming and resources attributes (functional diversity and quality) on food web structure and ecosystem function. Contrary to our expectations, an increase in the quality and functional diversity of detritus actually magnified the negative effect of warming on macroinvertebrate body mass. There were also major changes in network structure, with a more connected food web as temperature increased. Finally, total energy flux was greater as detritus quality and temperature increased, in contrast to ambient temperatures, where energy flux reduced with increased resource quality. We suggest that reduction in body size imposed by warming is the mechanism by which energy becomes more demanded, and that quality of resources, temperature and network connectance is determinant for its acquisition rate. Meanwhile, higher functional diversity supported higher abundances of every trophic group, indicating that reproduction and or colonization are strongly driven by resource trait variability. We conclude that in warmer climates, quality of resources becomes an important determinant of energy flux and body size, while functional diversity might be more important for habitat selection and reproduction regardless of temperature in detrital based communities.

SESSION 8:

From Functional Diversity to Health

From functional diversity to human well-being: a conceptual framework for agroecosystem sustainability.

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Agricultural intensification contributes to global food security and well-being. However, ongoing land-use change and intensification seriously affect the abundance, diversity and distribution of species thereby threatening the functioning of ecosystems worldwide. Despite the accumulating evidence that the current agricultural model is unsustainable, we are far from understanding the consequences of diversity loss for functioning and ecosystem service supply and the potential long-term threats to food security and human well-being, particularly health. In this regard, there is growing evidence that traditional taxonomic definitions of biodiversity are not sufficient to understand the relationships between biodiversity and ecosystem functioning. Functional diversity approaches, based on ecological properties ("traits") of species offer a more tractable link between community composition and ecosystem functioning. We propose a conceptual framework to understand the relationships between functional diversity and human well-being that also considers agroecosystem health. With this, we aim to highlight the potential effects of land-use change and ecological intensification on the functional diversity of plant and animal communities, and the resulting consequences for ecosystem services and ultimately human health. We included proximate and ultimate causes of issues related to human health as the latter can be directly traced back to ecosystem functions. The resulting conceptual model has been developed for researchers and policy makers. With this conceptual model we highlight the need for a holistic approach to understand diversity impacts on human well-being.

From biodiversity to health: quantifying the impact of diverse ecosystems on human well-being

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Ample evidence suggests positive effects of species diversity on ecosystem functioning and services in natural and agricultural landscapes. Less obvious and even contested are the effects of such diversity on human well-being. This state of art partly stems from methodological difficulties to evaluate and quantify these effects and imprecise conceptual frameworks.

Here we propose a conceptual framework that links different aspects of diversity, particularly species and genetic richness, to ecosystem functioning, ecosystem services and disservices, and different aspects of well-being. We review current approaches for the study of diversity – well-being relationships and identify shortcomings and principle obstacles, mainly stemming from theoretical premises that are too imprecise. We discuss five basic methodological approaches to link diversity to well-being: matrix models, indirect inference, Price partitioning, structural equation modelling, and environmental inference. We call for a stricter terminology with respect to the different aspects of functioning, multifunctionality and well-being and highlight the need to evaluate each step in the different pathways from diversity to well-being. A full understanding of ecological constraints on human well-being requires consideration of trade-offs in diversity effects, of contrasting perceptions of well-being, and of ecosystem disservices. We also call for appropriate long-term socio-ecological research platforms to gather relevant data about ecosystem functioning and well-being across space and time.

Landscape configuration, organic management, and withinfield position drive functional diversity of spiders and carabids

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Agricultural management intensity and landscape heterogeneity are drivers of biodiversity loss in agricultural landscapes. We focused on carabids and spiders, and we assessed the effect of small- vs. large-scale agricultural landscapes, organic farming, and within-field position on functional diversity of spiders and carabids. We sampled pairs of organic and conventional winter wheat fields in small-scale agricultural landscapes (former West Germany) and in neighbouring large-scale agricultural landscapes (former East Germany) in transects at field edges, field interiors, and field centres. The gradient from field edges towards the centres played an important role: spider body size decreased; ballooning ability increased, and hunting strategy switched from active hunters to more web-builders. Higher trait diversity of spiders in field edges suggested higher biocontrol potential in small-scale agriculture. In contrast, carabid feeding switched from herbivores to carnivores, presumably due to higher pest densities inside crop fields. Furthermore, small-scale agricultural landscapes and organic management supported larger, i.e., less dispersive carabids. In our research, spiders were more sensitive to edge effects and less sensitive to management and landscape composition than carabids. Smaller fields and longer edges, as well as organic management increase carabid functional diversity, which may increase resilience to environmental change. Since many spider species are confined to field edges, the effect of within field position on functional diversity is more important in small-scale agricultural landscapes with more edge habitat than in large-scale agricultural landscapes. Our findings suggest that European Union policy should acknowledge the high benefits of small-scale agriculture for the functional role of major predators such as spiders and carabid beetles, as the benefits are equal to those from a conversion to organic agriculture

Opposing relationships between biological control potential and functional diversity versus community weighted mean body size of ground beetles in European agroecosystems

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Land use intensification is frequently associated with a decline in functional diversity undermining ecosystem service provisioning. How traits of species influence ecosystem processes is still poorly understood. The mass ratio hypothesis proposes that primarily trait values of dominant species in a community relate to ecosystem processes. Alternatively, variation in trait values across species in a community may drive ecosystem processes. We quantified effects of local and landscape-level land-use intensity on two functional diversity metrics for ground beetles and then evaluated to which extent the community-weighted mean body size (CWM) and functional diversity (FD) affect pest control and crop yield. In addition, we assessed how the land-use responses and the effects of different species on pest control and yield vary with their traits. We included data from 160 farms across six European countries in structural equation models and evaluated the relative importance of various ground beetle traits using fourth corner models. Local and landscape-level land-use had no significant effect on CWM body size or FD, but local land-use intensity strongly increased crop yield. CWM body size affected pest control and yield negatively, whereas FD had a positive effect on aphid removal, but not on yield. Our trait specific analyses revealed that the response of different taxa as well as their effect on pest control and yield was more strongly influenced by body size compared to other traits. Our results suggest that biodiversity is already strongly diminished in arable fields and that ongoing intensification will not further affect the functional diversity of ground beetles. Body size was the most important response as well as effect trait in our analyses. The negative effect of CWM body size on pest control is likely due to stronger intraguild interference in communities with larger ground beetles. Although pest control was positively affected by FD, this effect did not cause an increase in crop yields.

Which forest characteristics safeguard humans from heat stress? Combining methods from forest ecology, human biometeorology and environmental psychology

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As climate warming and urbanisation progress, a growing share of the global population will be exposed to hazardous heat levels. Forests can mitigate this and support plenty of additional health co-benefits such as improved mental well-being. Yet, which forest types are coolest and how thermal and mental wellbeing interact is underexplored. I will present two complementary studies: one focused on forests and one on humans.

The first study used 14 months of data from 131 forest stands (BE, DE, FR, PL) and revealed that forests can reduce human-perceived temperatures by well over 10°C, causing a six-fold reduction in dangerous heat stress days. Moreover, the cooling capacity strongly depended on stand structure metrics, followed by the species composition. Tree diversity had no direct influence.

The second study involved 223 participants which were exposed to ecologically contrasting peri-urban forests (AT, BE, DE). Forests were perceived as being much cooler than non-forest baselines and strongly enhanced overall comfort. Surprisingly, participants were almost three times as likely to feel warmer at the controls for the same thermal conditions, which suggests confounding psychological effects. This is corroborated by significantly improvements in multiple mental wellbeing indicators. Furthermore, our data revealed a positive association implying that forests may foster a synergy where the enhanced thermal wellbeing improves mental wellbeing, and vice-versa.

In sum, results show that the great heat mitigation potential can be strongly enhanced via targeted forest management, and may benefit from a 'surplus' subjective cooling from forest-induced mental wellbeing.

Functional diversity and human health: focus on organic crops

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Current intensive food systems do not provide nutritious and safe foods for the world's population, they also largely contribute to the depletion of natural resources and biodiversity decline. Organic food systems by not relying on synthetic fertilisers and pesticides, could, through functional diversity, be associated with human health benefits. We previously proposed (de La Riva et al. 2023), a causal pathway through which functional diversity could affect health, via various ecosystem services (e.g. pest control, or nutrient cycling), and ultimately human health. In our presentation, we will explore how organic systems, could influence the quality of crops, and indirectly human health through functional diversity in Europe. For instance, organic agriculture can indirectly contribute to human health through conservation biological control which strongly limits pesticide use. The lower pesticide contamination in crops has been translated into humans, since individuals eating regularly organic produce have less pesticide metabolites in their urines. Regular organic food consumption and lower exposure to pesticide mixture have also been associated with lower chronic diseases risk in several epidemiological studies. Fertilisation under organic management relies on manure, crop rotation and the introduction of legumes. The non-use of mineral N, P and KCL fertilisers in organic farming could explain the greater content of antioxidants (including certain polyphenols) - which have been associated with lower metabolic disease risk, in organic crops compared to conventional crops, as well as the lower N and Cd content. In addition, chemicals could also reduce the content of nutritious compounds in crops. We will briefly compare conventional and organic food crops in terms of nutritional quality and safety, based on the available evidence and we will detail studies, in particular cohort studies, that have investigated the effects of organic food consumption on human health.

Functional diversity and human health: focus on landscape

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The main determinants of human health include lifestyle in the broad sense of the term, including diet. Next determinants are environmental conditions, genetic background and the quality of health services. Poor diet is at the forefront of factors detrimental to health (Murray et al. 2020). The primary goal of a good diet is dietary diversity, as highlighted by the current FAO guidelines (Gonzales Fischer & Garnett 2016). It is emphasised that dietary energy supply can be met without diversity, but micronutrient supply cannot be met without diversity. Functional diversity in agriculture is higher in organic farming than in conventional farming and means an abundance of local species and varieties of crops and animals. This ensures diversity on the plate and a healthy diet. A heterogeneous agricultural landscape provides human well-being not only through the diversity of food raw materials, but also through the enhancement of psychological well-being (savannah concept – Moura et al. 2017) and the treatment of the landscape (silence, greenery, essential oils of plants, transcendental experiences of nature observation – Marselle et al. 2021), the creation of opportunities for sports and recreation in nature. Landscape heterogeneity also provides other ecosystem services - it increases the attractiveness of the landscape (Hahn et al. 2017) and attracts tourists, which increases farmers' incomes, and it diminishes the occurrence of pests and diseases, which reduces farmers' expenditure on synthetic plant protection products (Thomine et al. 2022). There are also human hazards - wildlife, zoonotic diseases and allergens. However, functional diversity in agricultural landscapes brings benefits that far outweigh the problems listed.

SESSION 9:

Ecosystem Health: From Theory to Practice

Challenges and opportunities within data integration for ecosystem health assessment

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The increasing demand to understand ecosystem health at local, regional, and national scales requires integrating together data from different sources, including both traditional and novel sources of ecological data. Integrating together data from different sources requires more sophisticated data analysis methodologies, along with an understanding of the biological systems that are represented. Here I will present a series of case studies demonstrating how integration of data using novel statistical methodologies can in some cases prove highly informative for ecosystem health assessment, while in others leave us with more questions than answers. Challenges include identifying and accounting for varying biases within different data sources, modelling at the appropriate scale for both the data source and the question of interest, and usefully summarising the variety of ecosystem properties of interest into a few dimensions of ecosystem health. However, evaluation of different data sources ranging from traditional field surveys to more novel data sources such as citizen science data and DNA-based methodologies can lead to new insights into the dynamics and drivers of ecosystem health at different spatial and temporal scales even where full data integration is implausible.

The functional integrity of bird communities worldwide

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Human-driven environmental change is increasingly impacting nature's capacity to provide contributions to people, jeopardising wellbeing now and in the future. Goals and targets have been adopted globally to arrest biodiversity loss with biodiversity indicators being important tools to monitor progress. However, few indicators have yet been developed that estimate ecological communities ability to resiliently perform functions, despite continued function being crucial for the reliable flow of nature's contribution to people. Here, we combine a comprehensive dataset of the functional traits of the world's birds with models of how global bird communities are reorganised by land-use change and other anthropogenic pressures to prototype a functional diversity-based biodiversity indicator – the Functional Integrity Index (FII). FII estimates the proportion of functional trait space retained in ecological communities compared to those expected in the absence of modelled pressures. We estimate that, by 2020, the average functional integrity of bird communities worldwide had declined to only 63.62%, having been in continuous decline for at least 20 years. FII varies among geographic regions and among biomes highlighting the need for context-dependent interventions to restore and maintain ecosystem multifunctionality. We discuss ways FII could be developed to help provide rapid feedback on efforts to 'bend the curve' of biodiversity loss.

Role of terrestrial vertebrates in the assessment of ecological integrity: a systematic review

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Natural systems are dynamic and complex entities that are subject to pressures for change, so generating indicators to identify the ecological health or Ecological Integrity (EI) of these systems is a matter of urgency. EI assessments are tools to identify the state of an ecosystem through biotic or abiotic indicators. Few EI indicators include fauna as a key element in the assessments even though it is a relevant element in the functioning of ecosystems. We conducted a systematic literature review to know the state of the art on the use of indicators related to terrestrial vertebrates used in the evaluation of EI. Forty-seven publications related to the use of terrestrial vertebrates as an EI indicator were identified, with a high representation of works carried out in North America (United States, Canada, and Mexico). The most worked ecosystems are forests, followed by wetlands and grasslands. The vertebrate group most frequently used as an indicator was birds, followed by mammals and amphibians. Species composition was the most frequently evaluated element of EI, and community metrics stand out as the most frequently used when looking for the effect of the EI of an ecosystem on a faunal group. The index of biological integrity (IBI) and indices derived from it were the most frequently used to identify the state of integrity of a group of vertebrates. Few studies develop a conceptual model that explains the relationship between fauna and integrity. EI assessments are a valuable tool for identifying the state of a system, but it is necessary to complement them with faunal indicators that include various taxonomic groups to identify changes at different levels. It is important to generate biological hypotheses of relationships between measurable variables at the faunal level and the scaling of these to the concept of EI, as well as the integration of non-linear relationships between EI values and faunal metrics such as richness, diversity, or occurrence

Mathematical biases in the calculation of the Living Planet Index lead to overestimation of vertebrate population decline

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The Living Planet Index (LPI) measures the overall population trend of vertebrate species over recent decades and has been repeatedly used to assess the changing state of global biodiversity. The LPI indicates that vertebrate populations have decreased by almost 70% over the last 50 years. This is in striking contrast with current studies based on the same population data that show that increasing and decreasing populations are balanced on average. We examined the methodological pipeline of calculating the LPI to search for the source of this discrepancy. We found that the calculation of the LPI is biased by several mathematical issues which impose an imbalance between detected increasing and decreasing trends and overestimate population declines. Rather than indicating that vertebrate populations do not substantially change, our findings imply that population time series used in the Living Planet Database are not suitable for a proper evaluation of current biodiversity changes.

National long term biodiversity monitoring sites to analyze the Anthropocene degradation in mexican ecosystems and ecosystem services: SiPeCaM, the first phase.

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Fauna is a key component of ecosystem health, composition and functioning. It may also be indicative of proximity to human health and long-term responses to degradation. This means that their presence is not only indicative of biodiversity status and the ongoing crisis, but also provides ecosystem services to humans (e.g. through pollination, pest control, control of emerging diseases, decomposition, etc.). The main objective for the establishment of Permanent Biodiversity Monitoring Sites (SiPeCaM) in Mexico is to detect differences in parameters (composition, abundance, activity, occurrence of ectoparasites in small rodents) associated with the defaunation processes due to anthropogenic impacts or degradation, by measuring Ecosystem Integrity (IE). For these reasons the sampling design was built around plots (modules), that incorporate a set of sites which represent different natural treatments in order to capture local variability. On one hand we have control sites with proven high IE values, which represent the condition of an ecosystem with little or no anthropogenic impact (pristine module); and on the other hand sites with average integrity values (degraded module); that represent two distinct levels of degradation. This is achieved through a standard "matched pairs design" in which as pristine as possible and degraded modules are contrasted, controlling by ecosystem. Sites monitoring were carried out by local communities. Different taxonomic groups will be covered by means of two passive biodiversity monitoring tools: medium and large mammals, with trap cameras, and bats, birds, amphibians, insects as well as soundscapes by means of recorders. In addition small mammals and ectoparasites, by Sherman traps. These findings will also allow the issuance of conservation recommendations on the monitoring of specific parameters sensitive to degradation that may establish in some way an early warning about the state of different ecosystems.

Estimating the ecosystem integrity of Mexican sandy coastal shores using machine learning techniques

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In 2021, the United Nations Statistical Commission adopted the Environmental-Economic Accounting-Ecosystem Accounting System. This new statistical framework aims to make it easier for countries to measure the natural capital at their disposal and understand nature's contributions to our well-being and the importance of protecting and sustainably managing it. The SEEA EA comprises three accounts: extent, condition, and ecosystem services. The condition account provides a structured approach to recording and aggregating data describing the quality of the ecosystem measured in terms of its biotic and abiotic characteristics. So far, most accounting systems have been implemented for terrestrial ecosystems. In Mexico, as in most countries, a conceptual and methodological framework for assessing the condition of coastal and marine areas still needs to be developed. Due to their location, coastal zones are of great ecological, economic, and social importance and provide relevant ecosystem services (e.g., protection against hurricane impact, scenic beauty, and recreation). Under the framework proposed by the SEEA EA, assessing their condition would allow for more structured management of these ecosystems and evidence-based public policy design and evaluation. The characteristics of coastal zones make this assessment a major challenge under the SEEA EA framework. It is challenging to incorporate the abiotic and biotic conditions of coastal zones due to their high dynamism, resulting from being an interface between the terrestrial and marine systems. This work analyzed the condition of sandy coasts at a national level. To do so, we used methodologies and concepts atypical in the field of environmental accounts and integrated biotic and abiotic indicators into an index of ecosystem integrity, through a causal model under a data-driven Interpretive Artificial Intelligence (IAI) approach, in contrast to the dominant approaches based on expert judgment alone.

Is it possible to operationalise global gridded land-use data to assess ecosystem health?

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Ecosystem health has initially been regarded as being similar to human/animal health by various authors (Schaeffer et al. 1988; Rapport 1989) and has therefore been heavily criticized (Suter II 1993). While Costanza (1992) has suggested a model/framework for approaching the problem of "operationalizing" the understanding of ecosystem health – based on the definition:

› An ecological system is healthy and free from "distress syndrome" if it is stable and sustainable - that is, if it is active and maintains its organization and autonomy over time and is resilient to stress. Ecosystem health is thus closely linked to the idea of sustainability, which is seen to be a comprehensive, multiscale, dynamic measure of system resilience, organization and vigor. (Costanza 1992)

Suter II (1993) states that

› "Ecosystems are not organisms, so they do not behave like organisms and do not have properties of organisms such as health"

and criticizes, among other perspectives, the Costanza model. Despite this criticism, Lu and Li (2003) have tested (a modified version of) the model and found that more diverse vegetation plots have a higher "health index", showing that and discussing how the model can be operationalized. Here, I want to build on this and suggest a way to operationalize landscape scale concepts (Landis 2017) to assess ecosystem health. I present the global LUCKINet dataset (currently under development), where agricultural commodities are mapped globally for the last 25 years at a 1km² spatial resolution as sub-pixel proportion. I discuss which are readily available means and still open questions to assess ecosystem health based on the spatial and temporal extent of agricultural management, the most important driving force of biodiversity change and in the focus of sustainability efforts.

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Are fragmented forests healthy? Investigation of the impact of the configuration and composition of agricultural landscapes on forest health.

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Healthy forests are essential for maintaining biodiversity and providing ecosystem services. Fragmentation of forested lands due to land use change affects and potentially worsens the health of forests. In the European agricultural landscape, forest patches are a common sight. Assessing their state and health is a necessary step for achieving the biodiversity and sustainability goals set by the CAP and the EU diversity strategy 2030, among others.

Remote sensing has been widely used in forest studies, where indices for monitoring spectral responses, water stress, biomass growth or structural diversity are already well established. However, these indices only assess part of the ecosystem, which should be analysed comprehensively to understand its combined value for biodiversity. Furthermore, a combination of active and passive sensors to derive indices of the overall ecosystem has yet to be used to study the health of forests in fragmented agricultural landscapes. By building yearly profiles of these indices, we analyse changes in forest health driven by the configuration and composition of agricultural landscapes, which can co-inform strategic actions and optimized management plans and enable regular and low-cost monitoring not only in remote regions.

SESSION 10:

Animal Chemical Ecology

Evolution of fruit-animal chemical communication

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Fruits have evolved to be attractive to seed dispersers, and fruit traits evolved in response to selection pressures by frugivores. Fruit scent has evolved as a signal for frugivores, signaling ripeness and potentially fruit quality. However, it is still unclear how and what parts of fruit scent have evolved as signals for frugivores and what information they contain. Unlike most chemical classes, aliphatic esters are found to be concentrated in species that communicate with seed dispersers via chemical cues and only in ripe fruits. Some evidence and theoretical basis have indicated a positive correlation with sugar content. This means that there might be a link between chemical signals and where chemical coevolution is expected for fruit dispersed in lemurs. Our research aims to identify whether aliphatic esters are indeed an honest signal for fruit quality and test whether it is an adaptation acquired by plants. We test this hypothesis on a model system of up to 20 fig species (Ficus spp; MORACEAE) growing in Madagascar. With collections of fruit and leaf, we intend to (1) establish an ecological network, (2) reconstruct phylogeny, (3) identify the link between chemical signal and reward by using thermo desorption gas chromatography-mass spectrometry (TD-GCMS) and high-performance liquid chromatography (HPLC) to test whether it is the unique link between species and dispersal ecology, and (4) to sequence alcohol acyltransferase (AAT) to check if the selection regimes corresponding to the dispersal mode.

Specificity of plant metabolite modification in adults of the turnip sawfly

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Plant metabolites are able to shape the behaviour of many other organisms and have a profound impact on the functioning of ecosystems. Adults of the turnip sawfly Athalia rosae (Hymenoptera: Tenthredinidae) take up nectar from flowers for nutrition. In addition, they visit the plant Ajuga reptans (Lamiaceae) and sequester specific terpenoids, known as clerodanoids, from the plants for pharmacophagy. Compounds derived from these clerodanoids improve their sexual attractiveness and defence against predators, influencing thus the individual's social and ecological niche. However, until now it was unknown to which compounds the plant clerodanoids are metabolised, where they are stored and how specific the uptake is. Therefore, we performed feeding assays and a metabolomics approach to characterize and localize these relevant compounds. Comparison of different treatments revealed two focal peaks, which were specific to C+ samples of A. rosae but neither occurred in C- samples nor in leaves. Thus, plant metabolites taken up from A. reptans leaves are likely further metabolised and seem to be clerodanoid-derived. Separate analyses of the thorax versus abdomen and of short body washings revealed that these compounds were present in both body parts but also on the surface of the adults, where they could be readily detected by mating partners or predators. To test the specificity of uptake, additional feeding assays and chemical analyses were performed with larvae of A. rosae, which do not feed on A. reptans , as well as a food-generalist, Spodoptera exigua (Lepidoptera: Noctuidae), by applying leaf extracts of A. reptans on their host plants. Intriguingly, larvae of A. rosae were capable of metabolising these clerodanoid-derived compounds in small quantities, while the two focal peaks were absent in S. exigua larvae. Overall, our findings provide novel insights into the specificity of pharmacophagy in interactions across taxa.

The smell of birds

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Birds produce odours, but the function of these odours is still poorly understood. Recent studies found that avian body odours can be used for intraspecific communication, including mate choice and parent-offspring recognition. Avian body odours may also have a role in limiting detection by predators via olfactory crypsis. In this presentation, I will first present results from a comparative analysis on the function of bird odours. Second, I will present results from experiments on olfactory parent recognition in the laboratory and in the wild. In doing so, I aim to summarize recent advances in the rapidly growing field of avian chemical ecology.

Wildlife exposure to currently used pesticides and their potential effects: a silent threat?

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Following the scientific and public awareness on the adverse impacts of legacy pesticides on wildlife over the last century, PPP regulation has been continuously strengthened. The problem was considered resolved with the most persistent and toxic compounds being banned, environmental risk assessment being required before marketing, and cautious practices being mandatory for the farmers. But the most recent evidences highlight an opposite trend, showing biodiversity erosion and pervasive contamination, and raising societal debates about the use of PPP and its consequences on human and environmental health. This is the case for instance for neonicotinoid insecticides and glyphosate-based herbicides. Pollution is now recognized as a major threat to biodiversity conservation, and plant protection products (PPP) are increasingly pointed out as a major driver of biodiversity decline, especially in agricultural ecosystems. We will present our latest results issued from different recent research programs, and in particular, those about the exposure of soil and non-target fauna (earthworms, carabids and small mammals) to currently-used pesticides. We found a ubiquitous contamination of both soils and biota in arable landscapes by glyphosate and by mixtures of insecticides, herbicides and fungicides. Our findings about risks and potential effects on soil fauna in contaminated agricultural soils will be presented. We will show that this soil contamination reaches toxic thresholds and ecotoxic impacts on non-target invertebrates over agricultural landscapes even in semi-natural habitats. Finally, an overview of the newest insights and gaps in knowledge from the literature as reviewed by a scientific French national expert panel will be provided.

Does herbicide exposure in oil palm plantations affect wild southern pig-tailed macaques?

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Agricultural expansion into natural habitat harms global biodiversity, especially when unsustainable practices are used in the cultivation of cash crops, such as oil palm. Wildlife populations living in these disturbed areas face multiple threats, e.g., conflicts with humans, increased predation risk and exposure to various pesticides, but how these factors impact health and fitness in wildlife is not understood. Therefore, we studied a population of wild macaques (Macaca nemestrina) inhabiting a rainforest and oil palm plantation habitat matrix in Peninsular Malaysia. While foraging in the plantation for oil palm fruits and rats daily, these macaques are exposed to herbicides used there. Long-term demographic data (2014-2023) show an exceptional high infant mortality (57% of offspring died before aged one), likely contributing to declining populations in this endangered species. Infant survival analysis suggests a clear link between the length of maternal interbirth intervals and infant survival probabilities. Specifically, the risk of infant death is significantly elevated for infants born after prolonged interbirth intervals, as well as for infants of first-time mothers. Thus, we suspect that herbicides, that may accumulate in macaques' bodies over time and be passed on from mothers to foetuses during pregnancy, could affect infant survival. Using chemical analyses, we now aim to detect herbicides and their degradation products in the plantation environment (i.e., soil, water) and macaques' food (i.e., fruits and rats), and their evoked changes in macaques' body odour. Our study will reveal direct implications of pesticide exposure for macaque health by linking individual pesticide loads to various measures of health, including coat quality and body weight, parasite loads, and disease symptoms. Overall, our work stresses the importance to reduce pesticide use in agricultural landscapes to protect biodiversity against the adverse effects of chemical pollution.

Chemical communication in callitrichids (South American primates): insights from captive and wild populations

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Animals use chemical signals during territorial and resource marking, as well as during social interactions. Odorants may be direct by-products of essential biochemical pathways, derived from the diet and the environment, and/or produced by commensal bacteria. Accordingly, animals in captivity, which are subjected to artificial diets and environments, may produce a different range of chemicals than found in their wild counterparts, yet few studies have directly compared chemosignaling in wild and captive conspecifics. Here we analysed scent samples collected from wild (n = 8) and captive (n = 5) tamarins bearded emperor tamarin, Saguinus imperator subgrisescens, by headspace solid-phase microextraction–gas chromatography-mass spectrometry. Wild tamarin samples contained over twice the number of identified compounds as those collected from captive tamarins; wild and captive scent samples also showed a marked overall difference in their chemical composition. Our results, although based on small sample sizes, suggest that captivity alters primate chemosignaling, with potential implications for captive husbandry practices, including conservation breeding programs of rare species.

Keywords: chemosignalling, primates, gas chromatography-mass spectrometry, zoo animals

Geographic distribution of terpenoid chemotypes in *Tanacetum vulgare* mediates associated insect communities

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Many plants produce a high number of specialized metabolites that mediate plant-environment interactions. Common tansy (*Tanacetum vulgare*) contains highly diverse leaf terpenoid profiles. Previous studies have demonstrated that depending on terpenoid composition, tansy differ in their morphological traits and associated insect community. However, little is known about how tansy chemical composition and associated insect communities is distributed geographically. We investigated the spatial distribution of terpenoid composition in tansy leaves and how they affect associated insect communities across Germany. We sampled tansy leaves from 26 sites in a North-South transect in Germany, and collected data on plant morphological traits, specialized aphids (*Metopeurum fuscoviride*), their tending ants, and parasitoids. Plant terpenoid profiles clustered into four distinct monoterpenoid (MT) and sesquiterpenoid (ST) 'chemotypes' that were not linked. While ST chemotypes were relatively evenly distributed across the transect, MT chemotypes dominated by β-thujone and camphor occurred more often in the South while the chrysanthenyl acetate and mixed chemotypes occurred more in the North. Aphid and ant presence was higher on plants from the MT β-thujone chemotype than expected by chance. Aphid abundance was marginally affected by plant height. Moreover, ant occurrence was influenced by the average annual temperature of the sampled sites, with higher ant presence in sites with higher temperatures. We found geographic differences in the distribution of tansy terpenoid profiles, and showed that associated insects were influenced by plant chemistry, plant morphology, and abiotic factors. Our work implies that geographic variation in plant chemistry can be an important local driver of insect assemblages, and may partly explain geographic variation in tansy insect communities. Our findings highlight the importance of understanding abiotic and biotic drivers of insect communities.

Effect of intraspecific variation in fruit traits on animal sensory ecology

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Many plants rely on animal seed dispersal and evolved to provide frugivores with fleshy fruits. Fruit traits mediate much of this interaction, and animal sensory behaviour responds to variation among plant species. While much is known about interspecific variation in fruit traits, little is known about how animal sensory behaviour responds to intraspecific variation. This is despite the fact that fruit quality varies substantially within species, and that fruit selection within rather than among species would require more acute sensory behaviour. The objective of the project is to assess how wild animals adjust their sensory behaviour to intraspecific variation in fruit traits. We use wild lemurs (*Eulemur rubriventer*) in Ranomafana National Park (Madagascar) and their forage plants to test the hypothesis that lemurs emphasize sensory trajectories that are most informative about fruit quality (sugar content), which may vary among plant species. To this end, we record the sensory behaviour of a lemur group and measure the scent, colour, and size of the fruits to define the trait that correlates most strongly with the sugar content and to compare this to the sensory behaviour of lemurs.

SESSION 11:

Unravelling Plant Chemodiversity

Individual chemotype and plot chemodiversity affect plant performance and herbivory in *Solanum dulcamara*

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Chemodiversity of saponin defense compounds such as steroidal glycosides (SGs) is well described in Solanum dulcamara. However, the ecological and evolutionary mechanisms maintaining the genetic polymorphism(s) leading to variations in the degree of unsaturation of SGs remain unknown. Do individual leaf chemotype and plot chemodiversity affect plant performance and herbivory in Solanum dulcamara? To answer this question, siblings from a F1 hybrid population segregating for unsaturated (U) and saturated (S) SGs were chemotyped and selected. 80 four-plant plots were designed whereby plot chemodiversity was manipulated. Individuals were repeatedly phenotyped for plant performance parameters from May until October 2021. We found that U chemotypes had higher* stem length and seed germination ratios compared to S chemotypes. Additionally, moderate evidence* exists for the interaction between chemotype and chemodiversity for the number of berries on a plant. In contrast, S chemotypes showed higher* mean seed count in six selected berries compared to U chemotypes. We have strong evidence^ for the effect of chemodiversity on damage by specialists and generalists, and for the effect of chemotype on damage by generalists, but not specialists. Moreover, weak evidence& for the interaction between chemotype and chemodiversity on damage by generalists, but not specialists was found. Our results indicate that the number of berries on a plant and the damage caused by chewing generalist are not only a function of an individual's intrinsic chemical traits, but also that of its' neighbors. Additionally, the number of berries produced was maximized in the most chemodiverse plot. In conclusion, we found that both individual chemotype and plot chemodiversity, as well as their interaction, affect plant performance parameters and herbivory in Solanum dulcamara.

Sex and position in the canopy determine the chemodiversity of the leaves in old-growth black poplar (*Populus nigra*) trees

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The crowns of mature trees can reach enormous heights and diameters, resulting in strong heterogeneity of abiotic and biotic conditions within the canopy. To date not much is known about the effects of seasonality and vertical stratification within canopies on leaf chemodiversity. The question of whether there is further sexual dimorphism in chemical traits in dioecious tree species is also poorly understood. This study aimed to investigate the spatiotemporal trajectories of leaf chemistry in adult male and female black poplar (Populus nigra) trees growing in a natural floodplain forest in Northeastern Germany. Leaves from nine trees from five different canopy heights were harvested and analyzed by targeted and non-targeted LC-MS/MS analysis. Our data show that both sex, position within the canopy, and season influence the chemical composition and diversity of black poplar leaves. Our study highlights the importance of vertical stratification and sex for chemodiversity in the leaves of trees

Synthetic agrochemicals vs. chemical ecology: Species interactions in agro-ecosystems.

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Agricultural practices intensified during the past decades which lead to an increase in agrochemical use, including synthetic pesticides. Consequently, a large proportion of arable land is polluted by agrochemicals and pesticide residues are ubiquitous.

Glyphosate is the active ingredient in most widely used herbicides causing an agrochemical pollution in habitats across the globe. Glyphosate disrupts the plants shikimate pathway, which is the basis for several metabolite groups involved in mediating species interactions such as phytohormones, phenylpropanoids and volatiles. Insects and microorganisms are vital partners of crop plants in agricultural ecosystems. They fulfill essential ecosystem services, such as pollination and pest control.

We studied the effect of soil with a history of glyphosate-based herbicide use on a grass-mutualistic fungus and on hormone levels of different plants and showed that shikimate-deriving phytohormones were inhibited in oat which correlated with a decrease in plant damage by insect herbivores. In potato leaves the levels of several stress-related hormones were induced by glyphosate residues in soil. Strawberry plants were differentially affected by glyphosate residues in soil depending on plant genotype; the herbivore-susceptible genotype remained unaffected by glyphosate residues in soil, while the herbivore-resistant genotype showed altered phenylpropanoid concentrations in leaves and fruit. Further, our results demonstrate a reduction of fungal-conferred plant defense to their grass host mediated by glyphosate residues in soil, which caused an increase in herbivore infestation.

We conclude that herbicide-polluted soil has multifaceted consequences by modulating the hormonal equilibrium of plants and reducing microbe-mediated plant protection with cascading effects on trophic interactions. Thus, glyphosate residues may interfere with trophic interactions affecting the ecology and evolution of species in agricultural environments.

Diversity of metabolite profiles of *Eruca sativa* and *Sinapis alba* – a source for breeding pollen beetle-resistant oilseed rape

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Our study shows that chemical diversity in crucifers can help to understand the mechanism of plant resistance to insect pests of oilseed rape (Brassica napus). The pollen beetle (Brassicogethes aeneus) is one of the major pests of oilseed rape causing significant yield losses. Since it is becoming increasingly resistant to pyrethroids, alternative control strategies are needed in the context of integrated pest management. We studied the natural variation in brassicaceous plant species and initiated the intergeneric transfer of resistance to adult pollen beetles into oilseed rape. Such resistance has not been found in oilseed rape and B. napus resyntheses, but could be demonstrated for Eruca sativa and Sinapis alba (Austel et al. 2021). The feeding response of the pollen beetle to five E. sativa and 15 S. alba accessions was dependent on host accessions and the beetles´ sex. To identify potential chemical resistance markers, we compared semi-polar metabolite fraction profiles of resistant and susceptible accessions of E. sativa and S. alba using a non-targeted approach. Discriminating metabolites were positively or negatively correlated with the beetles feeding behaviour. The diversity of metabolites within a species was lower in S. alba than in E. sativa. However, in both cases the most important discriminating metabolites were derivatives of glucosinolates, amino acids and small phenolic compounds. To transfer this potential resistance to oilseed rape, we generated intergeneric hybrids with resistant accessions of E. sativa and S. alba and three spring oilseed rape cultivars using an embryo rescue approach. Intergeneric hybrids were backcrossed to the third back cross generation. Beetles' feeding behaviour was screened in no-choice assays on all generations of these hybrids. The metabolome of the generated hybrids will be analysed further for the presence of chemical resistance markers from the parental material.

Biodiversity effects on *Quercus petraea* litter metabolome and volatiles composition in a BEF experiment

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Plants produce a variety of metabolites that together are called the metabolome These compounds can mediate the resistance to herbivores and pathogens, the colonization by beneficial root microbes and many other interactions. It is known that the composition of the metabolome of plants can change due to these interactions and also due to the plant diversity level in their surrounding community. What is not usually considered is that these leaves will then senesce and form the litter layer bellow the trees. In that way, changes in the metabolome of leaves could later reflect on the composition of the litter metabolome and also on the volatiles it emits. We hypothesize that the litter volatiles could attract specific types of invertebrate decomposers according to its composition and through litter leaching the litter metabolome will also get in contact with the soil, which may end up reflecting on the soil nutrient cycle. To test this hypothesis, we aim to study the metabolome and the volatiles from the litter of *Quercus petraea* in a biodiversity-ecosystem functioning (BEF) experiment in order to assess the effects of plot diversity on their composition. We analyzed the volatiles from the litter through solid-phase microextraction followed by gas chromatography-mass spectrometry (SPME-GC-MS) and they consisted mostly of sesquiterpenoids and fatty acyls.

Dealing with the boundaries - the impact of nutrient imbalance on the chemical defense and diversity and of *Plantago lanceolata*

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The nutrient composition of soil plays a crucial role in shaping plant growth, development, and overall health. However, inequity in nutrient availability within soil ecosystems can significantly impact the synthesis and abundance of secondary metabolites in plants, which are essential for plants to defend against herbivores, pathogens, and other biotic stresses. Plants often face a critical dilemma when essential nutrients, such as phosphate, potassium, ammonium and nitrate, become limited, as they must allocate limited resources between defense and growth.

In this study we aim to explore the relationship between nutrient inequity in soil and its consequential effects on the production and effectiveness of chemical defense compounds in *plantago lanceolata*.

We want to present the findings of a study that utilized the iDiv Ecotrons to investigate the impact of resource inequity and the presence or absence of mycorrhizal associations on the metabolome, species-specific chemical defense compounds (glycoiridoids), and chemodiversity in plantago.

The ecology of the alga *Fucus vesiculosus* – physiological variation in different habitats

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Unlike animals, many plants and marine macroalgae cannot easily change their location when the environmental conditions change. Therefore, such organisms show considerable physiological adaptation to persist in different habitats and cope with unfavorable circumstances. For instance, the brown alga *Fucus vesiculosus* is a very successful, keystone marine species largely distributed over the coasts of the North Sea, the Western Baltic Sea and the Atlantic Ocean. We were very curious to find out how this alga succeeds in colonising such different habitats.

In our approach, we want to explore which physiological traits enable this species to thrive in different surroundings. The use of mass spectrometry (MS) to acquire profiles of small-molecular weight metabolites, "Ecometabolomics", is a very successful method to explore physiological differences on the molecular level. Therefore, we selected gas chromatography coupled to MS to investigate the metabolic profile of *Fucus vesiculosus* grown in different parts of Europe. After thorough method development for sampling and sample preparation, we finally applied our protocol to *Fucus vesiculosus* individuals harvested off the island of Helgoland (North Sea), the Keret Archipelago (White Sea), and the coast of the Baltic Sea near Kiel.

GC-MS metabolite profiling allows the semiquantitative evaluation of various carbohydrates, organic acids, fatty acids, amino acids and secondary metabolites. In agreement with published data, algal extracts contained carbohydrates as the most abundant analytes but with different relative intensity. Based on this data, we describe distinct metabolic traits of *Fucus vesiculosus* attributed to the three habitats occuring in the metabolome of three different tissues (apices, blades and receptacles). Moreover, we discuss the metabolic variability observed under other conditions such as the season or the influence of harvesting time. The findings of our work evaluate the potential contribution of specific metabolic traits of *Fucus vesiculosus* to its physiological flexibility towards environmental conditions.

Effects of intraspecific plant chemodiversity on the attraction and occurrence of aphids

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Few plant species express an extraordinarily high intraspecific diversity in phytochemicals (= chemodiversity) which can provide better resistance against herbivory. One of these plant species, *Tanacetum vulgare*, shows a high variation in its leaf terpene composition and thus forms so-called chemotypes. However, little is known to which extent the resistance of a plant individual against herbivores is comprised of its own, individual chemodiversity or of associational resistance provided by chemodiversity of neighbouring conspecifics. To investigate this matter, we planted 60 plots with five *T. vulgare* plants per plot in a common garden, in which all *T. vulgare* individuals per plot either had the same (homogenous) or a different chemotype (heterogenous). Weekly, the presence of winged individuals and the number of winged and unwinged individuals of specialised aphid species were counted for each plant. Additionally, leaves were re-chemotyped and terpenoid diversity quantified on individual plant (α-chemodiversity) and plot (γ-chemodiversity) level at the timepoint of peak aphid abundance. Chemodiversity did not affect aphid attraction, i.e. presence of winged aphids, but aphid fitness, i.e. their total count. For two out of five chemotypes we found lower counts of *Uroleucon tanaceti* in heterogenous plots as well as a negative correlation between plot-level abundance and γ-chemodiversity. These findings support the associational resistance hypothesis. The probability of presence of *Macrosiphoniella tanacetaria* differed between plot-types on one chemotype and the individual plant-level abundance correlated positively with α-chemodiversity. In contrast, *Metopeurum fuscoviride* was not affected by chemodiversity on any level. Our results clearly show that plant-herbivore interactions are shaped by the chemodiversity of individual plants as well as their neighbouring conspecifics. Furthermore, these effects are specific to aphid species and their winged vs unwinged morphs.

The evolution of chemodiversity - From verbal to quantitative models

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Plants harbour an astonishing degree of chemodiversity, i.e., diversity of specialized metabolites, at different scales. For instance, individual plants can produce a large number of different specialized metabolites and individuals in a population can differ in their metabolite composition. Given the ecological and economic importance of plant chemodiversity, it is important to understand how it arises and is maintained over evolutionary time. For other dimensions of biodiversity, i.e., species diversity and genetic diversity, quantitative models, that is, mathematical models and computer simulations, have long played an important role in addressing such questions. Here we review models and hypotheses for the evolution of plant chemodiversity and, in particular, explore what quantitative models have been proposed so far and what gaps there are in quantitative modeling of chemodiversity. We explore how quantitative chemodiversity models can be classified, their ingredients, i.e., the biological processes that are assumed to shape chemodiversity, and the scales at which the model explains or claims to explain chemodiversity. And, importantly, we elucidate the extent to which these models have been formalized as a mathematical or simulation model. From this, a mixed picture emerges. We identify a small number of quantitative models for the evolutionary dynamics of plant chemodiversity. In addition we find a number of models that use equations to derive an optimal defense, but are not dynamic. Many influential models, however, have remained verbal so far. Therefore we outline our vision for future model building for the evolution of plant chemodiversity, giving a flexible framework for the creation of individual-based models that address the different scales of chemodiversity and the different ingredients that bring this chemodiversity about.

Intraspecific chemical variation of *Tanacetum vulgare* at plant and plot level affects plant growth and reproductive traits in field plant communities

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Intraspecific plant chemodiversity plays a fundamental role in interactions between plants and their interaction partners. Individuals of a plant species can be clustered into chemotypes by dominant chemical compounds or their chemical composition. Intraspecific stands of plant communities can vary in the number and type of plant chemotypes that grow in them (i.e., chemotype richness). However, it is not yet fully understood how chemotypic diversity at the stand-level affects ecosystem functioning. Further research is needed to determine the relationship between chemotype richness and ecosystem functioning within plant communities. Here we describe a biodiversity experiment in which we manipulated intraspecific plant chemodiversity at the plot level using six different chemotypes of common tansy (*Tanacetum vulgare* L., Asteraceae). We tested the effects of chemotype identity and plot-level chemotype richness (1-6) on plant growth and reproductive traits under field conditions. We found that plant chemotypes differed in growth and reproductive traits, both at the plant and plot levels, and that reproductive plant traits and plot-level trait means were affected by tansy chemodiversity. The plot-level trait means were influenced by the presence or absence of certain chemotypes in a plot. The community's headspace terpenoid blend minimally reflected plot-level leaf terpenoid compound blends. Although tradeoffs between chemodiversity and growth and reproductive traits were observed, the links between chemodiversity and traits expressed themselves in the early establishment but dissolved over time, suggesting that different chemotypes adopt different growth strategies, which may facilitate their establishment in nature. This long-term field experiment will allow for further investigation of the consequences of intraspecific chemodiversity for plant-insect interactions and insect community assembly.

SESSION 12:

Microbiomes of the Future

A meta-analysis of the effects of bacterial and fungal species on plant traits

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Bacterial and fungal microbiomes associated with plants produce a range of bioactive natural products that can significantly affect the plant's phenotype. Inoculating plants with one or multiple bacterial and fungal species can positively affect specific plant traits. Currently, we lack a comprehensive synthesis on the generality of these effects under different experimental approaches and the relative importance of different microbial taxa. We provide such a synthesis to better understand the role of microorganisms in plant health and productivity. We performed a meta-analysis to determine whether inoculation of plants with one or multiple bacterial and fungal species could improve quantitative phenotypic traits (e.g., shoot and root biomass, plant height, flower and fruit numbers). In detail, we reviewed 61 papers covering 27 different plant genera, 25 plant traits, and 46 different bacterial and fungal genera. Overall, inoculation of plants with bacterial species increased root fresh weight, nodule, and leaf numbers, whereas fungal inoculation increased shoot dry weight, fruit number, and weight. Our meta-analysis provides insight into how microbial inoculation affects various plant traits, depending on factors such as plant species, the method of inoculation, the experimental setting, and the duration of the experiment. These insights may contribute to an effective identification of microbial candidate strains to improve plant growth and functioning as well as to choose conditions to maximize the microbial effect.

The inherited microbiome in natural and agroecosystems

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Different part of the plant harbor distinct microbial community and their role has been extensively studies in the last decade. Yet, information about the seed microbiome has only recently started.

The relative stability of the plant microbiome across generations has only been recently brought to attention. Seeds play a unique role by linking one generation to the next, thereby ensuring the continuous transmission of endophytes. The seed microbiome can, consequently, be viewed either as the apex of what was achieved during the dynamic assembly in the mother plant, or as the starting point of what will be established in the developing seedling. It is important to clearly define and differentiate between microbial inheritance, vertical transmission, and horizontal acquisition of the plant microbiome to avoid any confusion usually encountered in growing fields about the meaning of the used term terminology. If microbial inheritance is considered from an ecological or evolutionary perspective, it will have a major consequence on understanding the outcomes of plant mating systems e.g. outcrossing and autogamy, which would be of high significance, opening a new venue for breeding strategies.

Maize plant facing a dry and a moist year: root-soil-microbiome interactions in the field

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A better understanding of plant-soil interactions is mandatory to tackle the problems in crop production that are caused by increased frequency and intensity of drought events. Plants modify soil microbiome composition by drought-triggered alterations in the extent and quality of root exudation, and these altered microbial communities play out in plant drought tolerance. We joined the field experiment of the Priority Program 2089 “Rhizosphere Spatiotemporal Organization” to better understand how the feedback processes between the roots and the soil are affected by drought. Maize root gene expression and rhizosphere microbial community composition were investigated during a “dry year” 2022 and a “moist year” 2021, at the time of rapid growth of maize plants, the 9-leaf stage. In the “dry year” as compared to the “moist” year, we observed higher transcript levels of genes for dehydrins and heat shock proteins as well as increased malondialdehyde levels, suggesting a stress response, and higher level of terpene synthase expression, indicating changes in secondary metabolism. These changes were accompanied by altered microbial community composition, with increased levels of Actinobacteria and Chloroflexi, but lower numbers of Proteobacteria and Crenarcheota, and modification of the community composition of ACC deaminase carrying bacteria that promote plant drought tolerance. On-going research deals with the drought responses in a greenhouse experiment that can be interrelated with the results of the field experiment, and future work includes the comparisons of the obtained results to multiple samplings in a year of the same field experiment to improve the temporal resolution of the analysis.

Influence of prolonged water limitation: understanding how Scots pines and soil microbes interact and influence biogeochemical processes

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In parallel to the widespread reduction in tree growth and increased mortality, which have been documented as a response to drought, the impact of water limitation on the soil microbiome can drive prominent effects on the cycling of carbon and nitrogen.

Therefore, we set up a mesocosm experiment featuring Scots pine saplings and natural forest soil, to follow changes in plant development and alterations in the composition of the soil microbiome during prolonged episodes of water limitation. The mesocosms were maintained at three soil moisture levels – control, intermediate, and severe water deficit (40% and 75% reduction compared to control, respectively) – over two years. DNA metabarcoding of prokaryotic and fungal ribosomal markers was used to evaluate changes in the soil microbiome on a seasonal basis. By adopting isotope labelling techniques, we further studied how the parallel responses of the saplings and the soil microbial communities influenced the dynamics of carbon and nitrogen in the mesocosms.

Our results indicated that the Scots pine saplings reduced their growth with more intense water limitation despite initially partitioning more biomass to the roots. The saplings maintained (or even increased) their carbon allocation to roots and soil fungi under increasing water limitation. Yet, water limitation induced progressive changes in soil microbial community composition and promoted the proliferation of desiccation-tolerant and oligotrophic taxa. The abundance of saprotrophic groups increased alongside an accumulation of dead plant tissues. We also observed that water limitation negatively affected soil microbial taxa involved in nutrient cycling, influencing the nitrogen acquisition of the saplings.

Overall, prolonged episodes of water limitation strongly impaired the development of the Scots pine saplings and continuously altered the structure of microbial communities, unbalancing the cycling of carbon and nitrogen at the plant-soil interface.

The effects of drought and nutrient addition on soil microbial communties

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Soil microbial communities play a critical role in maintaining ecosystem functions, but they are increasingly threatened by global changes. Prolonged droughts and excessive nutrient enrichment have emerged as particularly worrisome disturbances for these communities. These disruptions raise concerns regarding their impact on the composition, diversity, and functional services provided by soil communities, including decomposition, nutrient cycling, and carbon sequestration. To investigate this, we conducted a five-year field experiment as part of the International Drought-Network, focusing on the effects of drought and nutrient addition (NPK) on soil communities (bacteria and eukaryotes) in a grassland. To assess the abundance, alpha and beta diversity of soil microorganisms, we employed amplicon sequencing analysis of 16S and 18S ribosomal RNA. Additionally, we measured soil basal respiration, microbial biomass, soil water content, and considered available data on plant biomass. Surprisingly, we discovered that drought did not significantly impact microbial activity and biomass. However, nutrient addition had a substantial effect, significantly increasing microbial respiration while leaving microbial biomass unchanged. We also found that both drought and nutrient addition strongly influenced beta diversity and led to changes in eukaryotic abundances. Moreover, the composition of soil communities gradually shifted over the course of the five-year period. The combined influence of drought and nutrient enrichment resulted in the most notable decline in soil bacterial diversity, indicating a synergistic effect of both factors. Therefore, gaining a deeper understanding of the drivers behind soil microbial communities and their associated soil functioning is crucial for making well-informed policy decisions that safeguard soils for future generations.

Towards management of soil and root-associated microbiomes in agroecosystems

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Soil microorganisms are key players of soil and plant health. Harnessing this potential for microbiome-based solutions might contribute to reduce agrochemical inputs and improve agricultural sustainability. At first, this requires a better understanding of factors shaping the soil and rhizosphere microbiome in agroecosystems. By using long-term field experiments located in different climatic regions, we could show that not only soil (e.g. soil type) and plant (e.g. developmental stage, cultivar) characteristics but also agricultural practices (e.g. tillage, fertilization) affect the structure and functionality of soil and root-associated microbiomes. This highlights the potential of agricultural practices to steer the soil microbiome into a more beneficial state supporting soil and plant health. For instance, we observed in field experiments in Uruguay that soils under long-term conservation practices such as pasture, reduced tillage and organic fertilization exhibited a distinct microbiome, which differed from conventionally managed soils and likely contributed to the improvement of soil structure and plant yields.

Another option to manage microbiomes is to add plant-beneficial microorganisms by inoculation. I will present examples from greenhouse and field trials, where we inoculated microorganisms as single strains or as consortia. The efficacies in terms of promoting plant performance were not only dependent on the strain but also on (a)biotic stress conditions. Interestingly, the inoculation with plant-beneficial microorganisms resulted in a modulation of the indigenous rhizosphere microbiome which varied e.g. based on the agricultural history of the soil and likely contributed to the inoculants' efficacy.

These interdisciplinary studies under close-to-practice conditions provide important insights into a better understanding of options and the ecology of microbiome management, paving the way towards microbiome-based agricultural solutions in the future.

Ecological forces dictate microbial community assembly processes in bioreactor systems

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Microbial communities are indispensable for future biotechnology to produce valuable platform chemicals and reduce the exploitation of fossil resources. Yet, the stability of microbial communities in classical continuous reactor setups is best brief or non-existent. The population ecology of microbial communities is still poorly understood and their notorious instability makes them impossible to control. Much of the instability is caused by the stochastic assembly of microorganisms, especially in highly diverse microbiomes where structural and hence functional changes occur rapidly due to the short generation time of their members. Usually, to maintain organismic proportions in communities, their niches are deterministically reinforced, but stochasticity strongly counteracts this.

Looped mass transfer was found to be a means of stabilizing microbial communities over long periods of time via increasing the mass transfer rate RC. Mass transfer i) reduced local and temporal variations, and the stochastic behavior was reduced. All microbiomes showed high constancy and increasing resistance as well as unaffected functions at high mass transfer rates. Mass transfer ii) synchronized structures of the microbiomes by the mechanism of homogeneous dispersal, resulting in the lowest inter-community β-diversity at the highest mass transfer. Persistence of particular SCs was highest at high mass transfer. High turnover of community structures was observed only when no mass transfer occurred. An increase in mass transfer iii) increased cell numbers, thereby decreasing netgrowth rates μ’. Subcommunities that showed no growth μ›SCx=0 in one locality were rescued by growth at another locality and by their redistribution via the loop design.

The rescue effect, known from metacommunity theory, was the main stabilizing mechanism leading to synchrony and survival of subcommunities, despite differences in cell physiological properties, including growth rates. This study fills a long-standing gap and enables continuous and proportionally equal growth of community members using an unprecedented operational design that addresses an acute need in healthcare and biotechnology industries.

The role of phyllosphere fungal guilds on plant recruitment

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The interest on the microbial ecosystems inhabiting the phyllosphere is rapidly increasing due to their possible effects on vegetation dynamics. In the context of plant-fungi interactions, studies linking the effect of phyllosphere fungi with the recruitment process are lacking. Partition of abundance-based dissimilarity in two components: i) balanced abundance variation and ii) abundance gradient, can be useful to identify which aspects of variation in fungal assemblages between pairs of plant species contribute to the frequency of canopy-recruit interactions. We analyzed the influence of phyllosphere fungal communities on plant recruitment in 46 plant species from two Mediterranean-mixed forests. We used sequencing data and incidence data of leaf-interacting fungi with a functional classification and explored their role on the plant-hosts recruitment dynamics. We found there is a negative probability of canopy-recruit interactions when both canopy and recruit present similar abundance of fungal pathogens in the leaves. On the other hand, we found there is higher probability of recruitment when both canopy and recruit species share the dominance of the same epiphytic fungi, indicating that epiphytes can be acting as potential mutualists for the plant host.

Drought tolerant synthetic bacterial community from barley rhizosphere

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The rhizosphere is a narrow zone surrounding the plant root that is colonized by many soil microorganisms collectively known as the rhizosphere microbiome (RM). Composed in part of so-called Plant Growth Promoting Rhizobacteria the RMs are host-specific and play a key role in helping the plant adapt to its environment by enhancing plant stress tolerance, producing phytohormones, and assisting in nutrient acquisition. The transfer of RMs or individual rhizosphere bacteria from stressed hosts to non-stressed hosts has been shown to confer stress tolerance upon exposure of these plants to stress. This can be done through the application of SynComs (Synthetic Communities), artificially constructed communities of select well-characterized bacterial strains who collectively confer stress tolerance to the host.

Here we present a SynCom for barley (*Hordeum vulgare*) derived from the RM of drought-stressed barley hosts. Composed of sixteen isolates, this SynCom contains eight strains that display ACC deaminase activity, which lowers the ethylene level of the host plant, increasing its resilience against different environmental stresses. Six strains also appear to produce the plant hormone auxin, important for root growth. When applied individually to barley seeds and seedlings, a slight increase in leaf weight was observed. However, none of the strains showed significant enhancement on germination or plant growth. There also appears to be no antagonistic activity between the SynCom members in pairwise antagonism assays. Characterization of the individual strains has provided evidence of PGPR traits and consequently the next step is to investigate the effects that the constructed SynCom has on barley when grown under drought stress, and if they trigger systemic immunity in barley. Genome analysis of the SynCom members is underway, and the future work concerns SynCom assembly and performance under drought and heat stress.

Successful management of the rhizosphere microbiome using a beneficial consortium depends on growing season and tillage practice

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Soil microorganisms are key players of soil and plant health. Harnessing this potential for microbiome-based applications could contribute to reduce agrochemical inputs and therefore improve agricultural sustainability. One potential option to manage the microbiome is the inoculation with beneficial microorganisms, which may restore crop productivity, promote plant growth or improve stress resilience. However, microbial inoculants often suffer from low or varying efficacy under field conditions. In order to better understand the underlying reasons, we conducted a field inoculation experiment in two consecutive vegetation periods. The long-term field experiment in Bernburg/Germany served as study site, which allows to compare the influence of different management practices (mould-board plough vs. cultivator tillage) as well as fertilization intensities (full N-fertilization including pesticides vs. 50% reduced N-fertilization without fungicides) on inoculant performance. We drench-inoculated maize, grown in the differently managed soils, at two early plant developmental stages with a beneficial consortium (*Pseudomonas* sp., *Bacillus* sp., *Trichoderma* sp.). Control plants received only water. Sampling was carried out five weeks after the second inoculation. Bacterial plating showed that the inoculants successfully colonized the roots independent of the year. However, their efficacy was influenced by the conditions during the growing season. In 2020 with early drought, the inoculation significantly increased shoot biomass while this was not observed in 2021 with average rainfall. Also, the modulation effect on the indigenous rhizosphere microbiome (alpha- and beta-diversity) depended on the year as well as on the tillage practice. The integrative analysis of soil, plant and microbial data will allow to obtain further insights into inoculation-dependent root-microbiome interactions as well as the ecology of rhizosphere microbiome management under field conditions.

Climate effects on plant microbiome and plant-climate interactions in a dominant grass *Festuca rubra*

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Plant associated microbiota plays a key role in plant adaptations to changing climatic conditions. Yet, our understanding of variation of plant-microbiota associations along climatic gradients is limited. We studied root and rhizosphere associated microbiota (prokaryotes and fungi) associated with a dominant grass, Festuca rubra, along climatic gradients in western Norway. Subsequently, we explored the effect of interaction of plant and soil biota from a specific climate and cultivation climate on plant performance. We found large overlap in composition of fungi in root and rhizosphere, while prokaryotes were largely different among the two compartments. Variation of fungal communities in both compartments was driven mainly by temperature, while prokaryotes were driven mainly by temperature in rhizosphere and exclusively by precipitation in the root. Effects of climate were partly mediated by their effects on plant community composition and on soil chemistry, but some of the effects were also direct, possibly mediated by their effects on Festuca physiology. Temperature decreased relative habitat specialisation of both prokaryote and fungal rhizosphere community and also of fungal community in roots. In contrast, specialization of prokaryote communities in roots increased with precipitation. Increasing temperature also increased robustness of microbial networks. Overall, the results indicate that changing climatic conditions have strong effects on plant-associated microbiota. Under future warmer and drier climates, communities of microbiota are expected to be less specialised. Microbial communities associated with Festuca rubra in colder climates are less robust and thus seem more vulnerable to any perturbation. Exposing soil biota to novel climate lead to less negative feedback towards the plant, increasing its performance. Festuca is thus expected to profit from the climate change as judged from its plant-soil interactions.

PhytOakmeter - Using clonal oak phytometers to unravel acclimation and adaptation mechanisms of long-lived forest tree holobionts to ecological variations and climate change

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Climate change and the loss of global species pose significant threats to human well-being in the coming decades. Despite more than two centuries of organized forestry and research in temperate forests, there are still gaps in our understanding of fundamental aspects such as the phenotypic plasticity of forest trees, the interplay between trees and their microbiomes, and how these interactions contribute to acclimation and adaptation processes in trees and their holobiont partners. To address these knowledge gaps, the DFG-SNSF Research Unit PhytOakmeter focuses on investigating the tree holobiont, with a specific emphasis on *Quercus robur*. One advantage of working with *Q. robur* is the availability of the DF159 clone, which can be easily propagated in large numbers in vitro. This allows us to exclude genetic variability in the host tree and specifically examine the role of holobiont partners in the oak holobiont's acclimation and adaptation processes. In the initial phase of our Research Unit, our subprojects (SP1 – SP7) will utilize three experimental platforms involving the DF159 clone. These platforms include conducting controlled experiments in Ecotrons to expose the holobiont to moderate droughts and above- and below-ground herbivory, exposing oak clonal saplings to the microclimatic variations within the canopy of mature trees, and analyzing clonal oak saplings released across Germany and Europe to understand acclimation and adaptation mechanisms under various environmental conditions. The overarching goal of PhytOakmeter is to unravel the patterns and mechanisms of acclimation and adaptation to drought and herbivory in a tree holobiont. Additionally, we aim to establish significant experimental resources to develop a novel tree model for forest evolutionary ecological research. This involves creating a tree model system with comprehensive -omics resources to investigate acclimation and adaptation patterns from a holobiont perspective in forest trees. We will also conduct mesocosm experiments that range from fully controlled environments to partially natural conditions, as well as establish a phytometer monitoring platform using a model tree to observe responses under a wide range of environmental conditions, including extreme sites.

SESSION 14:

Microbial Eukaryotes in the -Omics Era

Biodiversity, function and traits of microbial Eukaryotes

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Ecologists summarize the different supergroups of microbial Eukaryotes (Amoebozoa, Opisthokonta, Archaeplastida, Cryptista, Excavata, Stramenopiles, Alveolate, Rhizaria) under the term "Protists". Most ecologists have only a vague idea of the astonishing diversity and the spectacular life forms among microbial Eukaryotes. Although unicellular microbial Eukaryotes emerged by vastly divergent routes of evolution with size ranges differing between a few micrometers to meter-size, cover all trophic levels, are often the most important consumers in food webs, and contain among the most devastating parasites and pathogens of animals and plants - "Protists" in the ecological literature - are still treated as if they were a homogeneous taxonomic clade. By covering a variety of vastly divergent evolutionary lineages, by showing examples of the variety of clades and their multiple functional roles in ecosystems, I will highlight their multiple functions in terrestrial ecosystems and why it is so problematic to assign traits to the astonishing diversity of microbial Eukaryotes.

Protists genomics for ecology and biodiversity

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All the eukaryotes other than animals, plants and fungi are protists. They are in most of the cases unicellular and microscopic organisms. Protists are morphologically and functionally diverse, they are present in almost all the earth environments and have a relevant role on planetary health and on the biogeochemical cycles. Furthermore, protists represent most of the eukaryotic genomic diversity and are key to understand the origin and evolution of eukaryotes. Despite their importance, protists are much less studied than the rest of the eukaryotes. That is also true regarding the generation of genomes. Protists genomics presents multiple challenges and limitations, especially when most of the methodologies have been conceived with multicellular organisms in mind. In order to obtain protists reference genomes, we need to rethink the approaches we use, even the concept of reference genomes itself. In this talk we will present our efforts generating high quality protist reference genomes and developing alternative methods to overcome some of the challenges that we face to obtain protists genomes.

Biotic interactions explain seasonal dynamics of the alpine soil microbiome

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The soil alpine microbiome is dependent on season and elevation, yet there is limited understanding of how complex communities are differentially shaped by abiotic and biotic factors. Here we investigated the spring-to-summer dynamics of soil microbiomes in alpine grasslands, focussing on soil food web interactions. To this end, we conducted a survey along altitudinal transects in three mountains in the Alps, in spring at snowmelt and in the following summer, recorded vegetation and topographic, climatic and edaphic parameters for 158 soil samples. By using metatranscriptomics, we simultaneously assessed prokaryotic and eukaryotic communities, further classified by nutrition guilds. Our results show: (i) that biotic interactions could explain more variation of the microbial communities than topographic and edaphic variables, more for consumers than for preys, and this effect was stronger in summer than in spring; (ii) a seasonal dynamic in biotic interactions: the consumers' pressure on preys increases from spring to summer, resulting in a higher diversity and evenness of preys. In alpine grasslands, consumers effectively contribute to maintain the diverse soil bacterial and fungal community essential for ecosystem functioning. We will also show how metatranscriptomics ourperform the more classical PCR-based methods in getting a more complete view of the soil microbiome

Microeukaryotes: Diversity, Traits, and Function

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Despite their importance in ecosystems, microeukaryotes (protists) have been understudied in comparison to prokaryotes, in part due to the biases inherent in molecular techniques. In this presentation, I will summarize several recent studies in which we used various meta-omics techniques and microscopy-based methods to investigate the functioning and interactions of the whole wastewater microbiome, including prokaryotes, fungi, protists, and microscopic metazoa. We found that microeukaryotic predators shape the community composition of prokaryotes, and thus are essential for efficient wastewater treatment. Interestingly, microeukaryotic gut parasites are highly active in wastewater but are effectively reduced during denitrification, likely partially due to microbial predation.

This presentation will highlight that the now-available tools finally enable us to study microbial eukaryotes comprehensively and consider their ecological functions.

Deep molecular characterization of microorganisms´ diversity and community composition in the tree canopies using a metatranscriptomics approach

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More than 3 trillion trees exist worldwide whose canopies form numerous diverse and dynamic habitats. Previous metabarcoding approaches revealed highly abundant and specialized community compositions of heterotrophic protists. However, metabarcoding approaches are limited in detecting the whole microbial diversity due to the lack of suitable barcoding primers. To investigate the entire microbial community composition and diversity in tree canopies, we sampled the bark of three different tree species - Quercus robur, Tilia cordata, and Acer pseudoplatanus - of the Leipzig floodplain forest with the Leipzig Canopy Crane facility. Using shotgun metatranscriptomic (RNA) sequencing data we were able to assess the mainly active microbial community composed of 645 prokaryotes, 114 algae, 558 fungi, 154 heterotrophic protists, and 16 microscopic metazoa genera respectively. We found tree-species dependent differences between alpha and beta diversity in the canopy, and putative trophic interactions within. Among our findings, we report a high relative abundance of myxomycetes and the importance of algae for the food web composition.

First Galápagos Macroalgae Genetic Database through DNA barcoding of algae specimens from marine iguanas foraging grounds

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The Galápagos Islands are a critical site for scientific research, given their unique biodiversity, high endemism of flora and fauna and their ecological significance. Algae present in this island-ecosystem are particularly important because of their dynamic ecology and their role in sustaining unique endemic species like marine iguanas, which feed almost exclusively on marine macroalgae and have shown dietary patterns that may be influenced by local algal diversity. Yet algae from this region have not been studied in detail and their taxonomic identification has mostly relied on morphological analyses, which present numerous challenges. In this study, we aim to obtain an overview of the macroalgae species that exist in the habitat range of marine iguanas by establishing a DNA barcoding method applicable to both, to the identification of species from macroalgae tissue but also from samples that contain fragmented or degraded algal DNA such as environmental samples and faeces. This provide us with the possibility to further apply this approach in diet analyses of a unique herbivore species, the marine iguanas. Using barcodes from the ribulose-1,5-bisphosphate carboxy-lase/oxygenase (rbcL) and the nuclear ribosomal gene 18S, we analysed 177 marine macroalgae specimens collected in eleven islands of the Galápagos Archipelago and we identified 135 red algae, 29 green algae, and 13 brown algae specimens. Our findings not only provide the first DNA reference library of macroalgae in the Galápagos, but also report 24 new records of red macroalgae species and 4 new records of green algae in the region. Our study showcases the value of DNA barcoding as an effective approach for identifying algae species and contribute to the availability of knowledge regarding macroalgae in the Galápagos, crucial to assess their diversity and status throughout the Archipelago to ensure comparative patterns in the future.

SESSION 15:

Landscape-Scale Biodiversity Conservation

Local- and landscape measures for the conservation of plant and butterfly communities in permanent grasslands do not depend on the conservation goal.

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Permanent grasslands ecosystems are threatened across Europe. Multitrophic interactions and specific characteristics of species need to be considered to improve conservation measures and effectively protect biodiversity across taxonomic borders. To understand how environmental factors, local land-use intensity (LUI) and landscape-level factors affect butterfly and plant communities, we modelled the effect of these potential drivers on ten scores calculated in 89 grasslands sites of the DFG biodiversity exploratories in two regions of Germany. We included ten scores grouped in four major categories: traditional conservation scores (n of red list species and threat-level of those species); regional distribution characteristics (n of species with narrow distribution range); trophic interactions (sum of plant-butterfly interactions, number of unique interactions, average number of co-occurrences); and pollination potential (community-weighted mean number of crops that a local butterfly community could pollinate). Both, LUI and region (Alb/Schorfheide) had a strong negative effect, the slope of the grassland site and the proportion of the landscape covered by semi-natural habitats had a strong positive effect on the scores. Those results were consistent among all score categories except for pollination scores, which was negatively affected by the slope of the site. Interaction scores were all positively affected by semi-natural habitats in the surrounding landscape, showing the need to consider landscape composition in conservation schemes to protect trophic interactions. Correlation analyses between all scores generally showed positive correlations indicating a high potential for synergies. Only pollination scores were negatively correlated to other scores, showing potential trade-offs between different conservation goals. Independent of the conservation goal, measures should be designed at the regional level considering site and landscape-level elements.

Effects of habitat fragmentation on grassland bird communities in the Global North and South

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Land-use change and associated habitat fragmentation are the main causes of global terrestrial biodiversity decline. Our research focused on the effects of habitat fragment size (small vs. large) and habitat type (forest plantations vs. natural grasslands) on bird communities in forests steppes of the Pannonian Basin (Global North) and mist-belt grasslands of South Africa. Before the bird surveys, we selected 9 small and 9 large grassland fragments using GIS (the South African sites were an order of magnitude larger than the Hungarian ones), and we paired nearby exotic pine plantations with them. We detected 43 bird species during the Hungarian survey, while in South Africa 127 species. In Hungary, landscape variables (fragments size, habitat type and their interaction) had no significant effect on species richness and abundance, but the trait analysis indicated that pine plantations contained more carnivorous birds compared to grasslands, mostly woodpeckers. However, species composition differed significantly by fragment size and habitat type. In the South African region, pine forests had only 12 species, while large natural habitats were significantly richer and had higher bird abundance. In terms of functional traits, plantations contained significantly more cavity and other tree-nesting species. Overall, our research showed that small-scale and heterogenous plantations can support diverse bird communities in Hungarian forest steppes (~land sharing), whereas in Southern African landscapes, the large-scale homogeneous habitat matrix had much poorer bird communities due to they forced back to natural habitats (~land sparing).

Landscape dependencies in the effectiveness of sown wildflower areas in promoting multi-diversity

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Sown wildflower areas in agroecosystems are a common measure for biodiversity conservation in agricultural landscapes. However, little research has been done to determine what factors influence their effectiveness in promoting biodiversity. The quantity of semi-natural habitat and the degree of habitat fragmentation may influence which animal species can colonise and/or utilise sown wildflower areas.

Here, we go well beyond the set of species commonly used in evaluations of sown wildflower area effectiveness for biodiversity conservation. Using a combination of traditional specialist species identification and DNA metabarcoding of samples we collected species richness data of wild bees, ichneumon and braconid wasps, syrphid, tachinid and dolichopodid flies and coccinellid beetles from combined flight traps (yellow pan traps with crossed window panes), and of carabid and staphylinid beetles and arachnids from pitfall traps as well as of orthopteran, bats and birds with Audiomoth bioacoustic recorders. Sampling occurred during the summers of 2021 and 2022 at 41 sown wildflower areas across Schleswig Holstein, northern Germany.

This multi-diversity data has been tested against high-resolution spatial data on the quantity and diversity of semi natural habitats and modelling of habitat fragmentation, and on-site botanical surveys to assess wildflower community composition. To enable not only insights into the landscape dependencies in the effectiveness of sown wildflower areas in promoting biodiversity but also of resource quality, during the summer of 2022, we applied a recent eDNA method for detecting insects visiting wildflower heads. Our results will foster the efficient design, placement and programming of sown wildflower areas as integral parts of multifunctional agroecosystems.

Keywords: landscape ecology, eDNA, biodiversity and ecosystem services, bioacoustics, sown wildflower areas.

Impact of local and landscape scale effects on the occurrence of the Common hamster (*Cricetus cricetus*) in structurally simple agricultural landscapes

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European landscapes are dominated by agricultural land, with many species depending on these agriculturally used habitats. However, during the last decades agriculture has rapidly been intensified, resulting in strong decline of species diversity. The causes of this biodiversity loss are scale-dependent. Thus, at the landscape scale, factors such as habitat loss and the increase in the amount of cultivated areas and at the local scale an increasing use of pesticides and fertilizers, as well as an intensive and early tillage have a negative impact on biodiversity. One species that is particularly affected by agricultural intensification, is the Common hamster (Cricetus cricetus). While there are studies on the impacts of local and landscape scale effects on hamster occurrence in structurally complex landscapes studies in largely simple or cleared landscapes are missing. Here, we investigated the occurrence of the endangered common hamster in relation to local (vegetation cover and density, field size, field vole infestation, predator densities, etc.) and landscape parameters (landscape composition and configuration) in the largely simple landscapes of Saxony-Anhalt. First results show that hamster protection measures to support the common hamster, such as delayed or modified harvesting of cereals, strongly enhance hamster densities, whereas an increase in field vole densities did not affect the occurrence of the common hamster. At the landscape scale, there was a trend towards a negative effect of an increasing amount of agriculture areas around surrounding study fields on hamster occurrence, whereas the distance to the forest and to settlements did not affect hamster occurrence in our largely simple or even cleared agricultural landscape. In conclusion we could show that in simple agricultural landscapes, local field management and vegetation cover are more important for the conservation of the common hamster than landscape-scale effects.

Bird and tree conservation may depend on the magnitude of shifting baseline syndrome

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As environmental change is accelerating, conservation and land management aim to alleviate its negative effects by restoring ecosystems to historical conditions, i.e. baselines. But the psychological phenomenon called Shifting Baselines Syndrome (SBS) potentially poses an important and widely understudied barrier to conservation because people use their own life experiences to assess change and make decisions. The main goal of this study is to test for the existence and identify the drivers of SBS amongst different groups of actors (conservationists, land managers and the general public with outdoor affinity) in order to better inform future management and conservation practices. We used tree and bird population changes since the 1920s in the Black Forest region of Germany as a pilot case because trees and birds play pivotal roles in the ecosystem and the lives and well-being of local population. Our results highlight the extent to which different segments of society are affected by SBS. Although SBS may be an important component of adapting to change, it may also cause humans to unintentionally contribute to environmental degradation without even realizing it. This is why successful conservation and restoration practices at the landscape level rely on understanding and accounting for the Shifting Baseline Syndrome.

A glimpse into the past: how does the historical landscape matrix explain current population genetic structures?

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One of the most important, however often neglected determinants of the population genetic structure is landscape history. Today, most population genetic studies at the landscape scale quantify the historical gene flow, which integrates the functional connectivity of the landscape over an unknown time. It may reflect the past rather than the present-day landscape structure because it takes some generations of time (time lag) to reach an equilibrium between the population genetic structure and corresponding functional connectivity.

The typical agricultural landscape found in central Europe has been established for centuries. The number and distribution of land-use types, i.e., landscape matrix, have changed ever since. The population genetic structure of forest herbs living in isolated small forest patches that are embedded in this agricultural matrix is highly influenced by gene flow, both historical and current.

Here, we reconstructed the landscape matrix of three regions in four different time points (the 50s, the 80s, the 2000s, and after 2010), using historical maps and aerial photographs. We then used these historical landscape matrixes to explain the population genetic structure of two forest herb species with different generation times.

We expected that (i) historical landscape matrixes can explain more variance of the population genetic pattern than the current landscape matrix (ii) the time lag of the species with a longer generation time is larger than that of the species with a shorter generation time.

Co-designing insect-friendly agricultural landscapes – Challenges for collaborations at the landscape level

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Although numerous agri-environmental programmes have existed for decades, they are not effective to halt biodiversity loss. One reason is that so far many measures have been designed and implemented for field or farm level lacking a landscape perspective. Natural processes primarily run and manifest in landscapes, they can reinforce or compensate for local impacts. This should be taken into account in respective approaches. By applying a landscape lab approach the FInAL project promotes the long-term transformation towards more insect-friendly landscapes under real-world settings. We implemented an adaptive co-design process in three German landscape labs, which involves different scientists, landscape coordinators, and practitioners. The sequence of co-design workshops and field trips aim at 1) discussing transformation pathways, 2) co-designing measures, 3) participatory mapping, and 4) monitoring and reflection. Here, we focus on landscape actors' perception of measures at landscape level. We analyse interviews, a survey, workshop minutes, and field notes from participatory observations. At the project start, a few practitioners already saw the need for agroecological transformation and better cooperation at the landscape level. Many farmers showed interests in such a landscape approach but were sceptical about their practicability. During the four-year project period, measures at the landscape level (e.g. networking of riparian strips) were co-designed and partly implemented. However, the farmers perceive that the collaboration between themselves has not considerably increased. The reasons for this could be socio-cultural impacts of current practices as well as economic and political-institutional constraints (e.g. the need to keep an eye on the profitability of one's own business). Thus, still joint efforts are needed to encourage such collaborations by creating inspiring examples, showing ecological effects at the landscape level, and fostering actors' ecological literacy. Continuous reflection is required to explore co-learning in this on-going co-design process.

The *Grassworks* Project: What leads to success in grassland restoration in Germany – an ecological and sociopolitical and economic perspective.

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We have a large body of knowledge about what leads to success ecologically when we aim to restore species-rich grasslands and yet grassland restoration is not a key focus in our landscapes despite its importance for biodiversity and resilience. In our inter- and transdisciplinary project we analyze ecological, social-ecological and socioeconomic facets of already restored sites in three regions in Germany (a total of 120 restored, 30 negative and 30 positive control sites) as well as taking the surrounding landscape configuration into. Our three **model regions** in North, Central and South Germany vary in their economic, social-ecological and socioeconomic contextual conditions. In a second main approach, we are aiming to help transform the way grasslands are valued and the extent to which they are restored with which perhaps different multifunctional goals, **by working in co-creation of live grassland restoration measures across the regions** in question. Our real world laboratories with local stakeholders have the goal to restore together and in so doing leverage more potential for a true transformation of the way we see and value and restore such high species-rich grasslands. The presentation will highlight various aspects of the project in its second year.

Implementing co-design processes: Results from a European perspective paper and a local case study in Saxony, Germany

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Current literature indicates that co-design is widely seen as an opportunity to bring together diverse landscape-level stakeholders and improve the coordination and success of landscape-level biodiversity conservation efforts. However, there is a lack of practical experience and knowledge about what exactly the challenges and pitfalls can be and how to implement co-design processes in detail. In 2022, we conducted interviews with four researchers from European co-design projects and two representatives from agricultural organizations to gain practical insights about co-design efforts. Thereby, we identified the main benefits and challenges of co-design and compiled a list of specific recommendations for different stages of the co-design process, which I would like to present here.

Moreover, we used the results to initiate our own co-design process in a case study area in Saxony, Germany, which focuses on the implementation of four different conservation measures in grass- and cropland, the monitoring of plants, birds, grasshoppers and birds on these fields, as well as the analyses of social acceptance and economic-ecological effectiveness of these measures. We further use the co-design process to discuss with local farmers and other stakeholders the coordinated development of conservation measures that work together at the landscape level and thus have a greater impact on biodiversity than measures taken by individual farms. Here, I would like to present the first results of our co-design process and, in particular, first results on how the planting of hedgerows could be coordinated to increase landscape-scale bird diversity.

Applying a collaborative and participatory landscape planning approach to enhance biodiversity in agroecosystems

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The CLEAR (Collaborative Landscape Planning for Enhanced Agrobiodiversity and Resilience) project identifies integrative, collaborative landscape-level planning as a promising approach to facilitate targeted adoption of diversified agro-ecological practices. The overarching goal of our project is to develop and apply an interdisciplinary methodological framework for data- and stakeholder-based identification and evaluation of agricultural management practices enhancing agrobiodiversity.

We explore this through four landscape-scale regional case-studies in France, Germany, Poland and the UK. In a first step, we evaluate promising diversification practices across different EU contexts, focusing on enhancing agrobiodiversity from field to landscape scales. This is done through a multi-step approach that blends participatory methods, modeling approaches and the collection of ground-truthed data. This approach identifies and validates agrobiodiversity indicators selected to facilitate performance assessments of evaluated farming practices on agrobiodiversity and related agroecosystem services (e.g., carbon storage, yields). This process prioritizes stakeholder participation to contextualize the selection of priority indicators and practices and to explore broader visions, opportunities and limitations associated with the enhancement of agrobiodiversity. Results will feed into the design of novel collaborative and result-based agro-environmental schemes. In a second step, we plan to apply participatory methods to develop future land-use scenarios in each study region. Resulting scenarios will then be quantitatively assessed through spatially explicit modeling to illustrate potential trade-offs and synergies associated with upscaling of priority measures.

Ultimately, we present a novel, interdisciplinary research framework that incentivizes collaborative landscape-level planning to create multifunctional and resilient agricultural landscapes that reconcile agrobiodiversity conservation and food security in the context of global change.

Promoting bee biodiversity through landscape-level multi-stakeholder collaboration

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The last few decades, conservation efforts have increased rapidly and significantly but have nevertheless failed to halt the decline of biodiversity. This is in part due to the fact that conservation is currently implemented in isolation from other activities in the landscape that adversely affect biodiversity and that may counteract positive effects of conservation actions. Landscape-scale approaches in which multiple stake-holders collaborate to implement and integrate biodiversity-friendly management on farmland and in public space and protected areas may therefore be needed to bend the negative biodiversity curve upwards. While this has been proposed before, to date hardly any studies exist that show whether this works. Here we present an example from the Netherlands that aims to promote pollinators in a 30 km^2 area using a collaborative approach implemented by 11 stakeholders. Each of the stakeholders implements bee-friendly management that aims to improve the spatio-temporal availability of floral resources on part of their land. Base-line date of bees and flowers were collected in 2018-2019 and effects of bee-friendly management have been being monitored since 2020. We present preliminary effects for the period 2018-2022 of these conservation actions and discuss both the benefits and the challenges of collaborative conservation approaches.

Tailoring of policies to agricultural landscapes where they are most effective

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Implementing the same agricultural and biodiversity policies uniformly in different regions can undermine their effectiveness due to the pronounced variability in relationships between agriculture and farmland biodiversity. Tailoring policies and associated agri-environment measures to match the characteristics of specific agricultural landscapes is a prerequisite to increase the policies' limited effectiveness. Here, we present a concept to tailor policies so that they best contribute to the transformative vision of conserving and restoring farmland biodiversity. It rests on the current interplay between agricultural production and farmland biodiversity to which we fitted transformative pathways based on agroecological principles. For example, in intensively used, simplified agricultural landscapes, crop diversification, erosion control and ecological intensification reducing synthetic fertiliser and pesticide input are best suited measures to enhance farmland biodiversity and agricultural production. In contrast in extensively used agricultural landscapes that still contain rich (semi-)natural landscape components, conservation of rare and endangered species and habitats and high-nature value farming with associated value chains are particularly effective measures. Our concept helps to evaluate if and under which conditions existing agri-environment measures are most effective to realise the transformative vision. If provides a synthesis framework to discuss solutions developed and tested in stakeholder-centred initiatives such as on-farm experimentation or living laboratories at landscape scale experimenting on real farms with farmers and other food system actors. This will provide the necessary spatially-explicit insights suited to inform the co-design and implementation of policy measures.

Living Labs for biodiversity conservation in the Netherlands: scaling up from successes in the past

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Biodiversity conservation requires a landscape-scale approach. Ecological communities in habitat with appropriate conditions can only thrive if they are sufficiently large, are inter-connected and are not exposed to nutrient and pesticide pollution. In the riverine farmland area of the Ooijpolder near Nijmegen (NL), landscape complexity has been restored over the last 15 years by installing hedges, flowerstrips, ponds and dry-wet gradients. This has been realized by a concerted effort between nature conservation organisations, farmers, governmental institutions and private parties, resulting in 30-year contracts with farmers for the maintenance of the natural areas on their properties. In an interdisciplinary research project (Living Lab Ooijpolder), we are investigating the ecological effects of this restoration effort, why farmers agreed to contribute, and the process by which the arrangements were realized. Our research is retrospective as well as prospective. Together with the farmers, we are exploring how farm activities can further improve biodiversity for example by developing herb-rich pastures. The research activities are set up in a trans-disciplinary way, in close interaction with farmers and others, learning from their economic constraints and their visions on the future of their own farm and the landscape. So far, we see that landscape complexity has improved plant and insect diversity, as well as that farmers have become to appreciate the results of their efforts as improving the inherent natural value of the landscape. The Ooijpolder case shows how a dialogue based on mutual respect and a constructive input from all parties can make significant steps towards landscape restoration. From interactive research on the ecological (soil, plant, insects), social, governance, economic and legal processes involved, we hope to decipher the key values for success that can be transferred to other regions.

Farmland biodiversity conservation at the landscape scale - Synergies between ecology, economy and governance

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Globally, biodiversity is declining rapidly and these declines threaten not only the functioning and stability of natural ecosystems but also agricultural production. These detrimental trends occurred despite efforts to promote biodiversity through voluntary agri-environment schemes (AES) in which farmers are paid for implementing environmentally friendly measures. Main criticisms of current AES include a mismatch of the local implementation scale and the species' landscape scale habitat requirements. Currently most AES have no landscape heterogeneity targets and single farmers decide where to implement which AES.

Due to these shortcomings, landscape scale implementation through cooperation of multiple farmers and other stakeholders based on clear targets considering local and landscape scale factors has been identified as one of the main potential tools to substantially improve the ecological effectiveness of AES. However, successful implementation of collaborative schemes strongly depends on their social and economic impacts. The achievement of ecological targets in landscape scale AES requires collaboration among farmers and therefore depends substantially on the functioning of social networks as well as the economic outcomes. We identified synergies between ecological, social and economic benefits that may arise when AES are implemented at the landscape scale.

However, many important questions regarding the implementation of AES remain unknown, including: i) How many AES are necessary within a landscape, ii) How can farmers collaborate? and iii) Which are the economic consequences? Considering the ecological effects and economic consequences, the project KOOPERATIV will develop and implement a participatory and cooperative approach for AES at the landscape level. KOOPERATIV aims at informing future CAP policies to substantially increase the effectiveness of AES and halt the decline of farmland biodiversity.

Collaborative action in agri-environmental conservation – review of European initiatives

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Agri-environmental measures (AEM) are important to promote biodiversity in agricultural landscapes. They incentivize farmers to adopt management techniques that create habitats for beneficial insects and target species of nature conservation. To support their conservation, different habitat types - e.g. for nesting, foraging, and overwintering - are necessary within the respective mobility range of target species. However, AEM mostly focus on isolated measures at the field or farm level, neglecting spatial coordination at the landscape scale.

So far, the Netherlands are the only EU Member State that has introduced a countrywide and systematic collaboration for agri-environmental action to address this challenge. However, different European countries promote collective action of farmers within their national CAP-funding schemes, and several federal states in Germany are currently testing collaborative AEM in model projects. To understand the approaches of collaborative governance in different European countries, our research focuses on a systematical analysis of the design and organization of relevant initiatives. Therefore, we aim to analyze which European countries support collaborative action, how initiatives are organized and with what success landscape-scale AEM are being implemented.

We contacted 25 EU National CAP Networks to gather information. First results indicate that a common prerequisite in agri-environmental cooperatives is a nature conservation plan oriented towards target species or the conservation of typical habitats of local agricultural landscapes. Beyond that, coordination structures are required when it comes to measure implementation at the landscape level. Institutional framework conditions vary among the cooperatives. Based on insights into governance structures, funding regimes, goal-setting and stakeholder composition, our contribution will shed light on relevant aspects for configuring collaborative AEM at the landscape scale.

InterRest – Effects of local and landscape restoration on interactions and ecosystem functions of semi-natural grasslands

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Calcareous grasslands are a special heritage of traditional land use in European cultural landscapes and one of the most species-rich habitat types. They harbour many rare and highly endangered species, but are nowadays often threatened, mainly by abandonment, and restoration measures are urgently needed. However, transnational approaches are missing and evaluations focus usually only on certain taxa or species richness and usually ignore their interactions, functions and the landscape context. Especially species interactions are important indicators of restoration success as they are often more sensitive to environmental changes and may impact vital functions that are necessary to stabilize ecosystems.

In this project, we will compare restored and unrestored calcareous grasslands in three countries (Germany, Spain and Estonia) and investigate interaction networks at different trophic levels: (1) plant-soil, (2) plant-pollinator and (3) bird-food resource interactions. We hypothesize that local restoration measures will lead to more complex and stable interactions leading to improved ecosystem functions including pollination and predation. Moreover, we will investigate how agri-environment schemes at the landscape scale can contribute to the local restoration effects. We expect that agri-environment schemes increase the connectivity of calcareous grasslands, especially in isolated sites with no other calcareous grasslands in the surrounding.

Moreover, we will analyse the social contexts of the restoration programs and identify key actors who are necessary to achieve local and landscape restoration goals. Importantly, we will investigate how social interdependencies impact biological interactions as indirect drivers. To synthesize the results of this project, we will use metanetwork, multifunctional and social-ecological network approaches, e.g. to identify conservation priorities and possible trade-offs.

Plant-pollinator interactions in functional grassland networks (FuncNet) – Zoom in on genetics, performance, fitness, and demography of an insect-pollinated grassland plant

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Loss of the area and connectivity of biodiversity hotspots in Europe, i.e. semi-natural grasslands, threatens flora, fauna and their interactions, which are essential for balanced ecosystem functions and services such as pollination. Maintaining functional habitat networks, including target and non-target habitats, for inter-habitat exchange of species, individuals and genes is crucial for the conservation of biodiversity at the gene and species level and facilitates the resilience and adaptability to climate and environmental change of both flora and fauna. Within the Biodiversa+ project "FuncNet" (Improving the Functional Connectivity of Grassland Networks for Plant-Pollinator Interactions), we will contribute to a more detailed assessment of the functioning of plant-pollinator interactions in landscapes with connected and fragmented semi-natural grasslands. We will investigate the structural and functional connectivity in those landscapes, including analyses of current and historic landscape data and grassland-scale pollinator meta-networks. Besides, we will examine the genetic diversity and structure, gene flow patterns, individual performance, fitness and demographic patterns of *Primula veris*, a wild, insect-pollinated grassland plant species, and align those data with species-specific pollinator movements to characterize effects on gene flow and the distribution of genetic material in the landscape. Molecular methods such as ddRADseq and targeted sequencing will be used to extract putatively neutral and adaptive genetic regions. The project includes study areas in five countries (Estonia, Sweden, Czech Republic, Belgium, Germany) where semi-natural grasslands were historically widespread but have declined dramatically due to land use change. Finally, the overarching aim is to discuss and develop strategies, in tight interaction with local land users and stakeholders, to sustainably conserve and facilitate biodiversity at its various levels.

Synergies between biodiversity conservation and multifunctionality in permanent grasslands

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Permanent grasslands can be highly biodiverse and multifunctional ecosystems. Biodiversity conservation in grasslands is often based on agri-environmental schemes (AES), prescribing extensive management. Future AES will aim at sustaining and increasing non-production ecosystem services (ES), such as carbon storage and cultural services. Potentially, but not necessarily, financially supporting grassland multifunctionality (MF) can result in a synergy with biodiversity conservation. Because it is laborious and unrealistic to measure many ES, an open question restricting the implementation of AES for grassland MF is, how to effectively approximate and monitor MF. To address this question, we measured plant diversity and 30 ES indicators in 88 grasslands along a land-use intensity gradient in Switzerland. We i) explore relationships between plant diversity, single ES and MF, ii) discuss potential indicators to inform future AES about grassland MF, and iii) highlight synergies between biodiversity conservation and grassland MF. Results show three distinct bundles of grassland ES. The first bundle (i.e., “extensive bundle”) in positively related to plant diversity and consists of several ES linked to reduced environmental impacts, high aesthetic value and fungal diversity. This bundle (including plant diversity) is strongly negatively related to the second bundle, which is composed of productivity, soil nutrient availability as well as weed and herbivory control (i.e., “production bundle”). A third, widely uncorrelated bundle consists of only few ES such as soil carbon stock and microbial biomass (i.e., “soil carbon bundle”). Plant diversity was found to be the indicator most closely related to MF calculated without provisioning ES, indicating that result-based payments for plant diversity might also support grassland MF and vice versa. In addition, the third ES bundle could make a useful contribution to indicating grassland MF beyond plant diversity and its correlates.

How much area are we talking about? - Some data on arable land in protected areas

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At the global UN Biodiversity Conference (COP 15) in Montreal last December, all participating countries, including Germany, agreed that 30% of the landscape and oceans should become protected areas. In Germany, 179,668 km² of the terrestrial land area was within a protected area defined under the Federal Nature Conservation Act in 2022. This amounts to about 50% of the total terrestrial land area of Germany. Despite this large area under protection, biodiversity loss continues.

A look at the Federal Nature Conservation Act shows that biodiversity conservation is not the highest priority in every type of protected area. However, sufficient prioritization of biodiversity conservation does not occur even in the most strictly protected area types, such as Nature Reserve and Special Areas of Conservation (SAC), because orderly forestry and agriculture may take place here.

In the context of the cultivation of arable land, the resulting problem situation becomes clear. In Germany, about 440 km² of arable land is located in nature reserves, and about 1280 km² of arable land is located in SACs, accounting for 0.36% and 1.04% of Germany's total arable land, respectively. It can be assumed that this land is predominantly farmed conventionally. For example, only around 70 km² of arable land in nature reserves and only around 160 km² in SAC are farmed organically. Protected area ordinances often make hardly any specifications for agricultural use. In addition, protected areas are surrounded by a large amount of arable land. Within a radius of 2 km around the nature reserves there is about 31% of the total arable land in Germany, around the SAC it is 51%.

These figures clearly show the need for action. Studies have shown that insects in nature reserves are contaminated by pesticides. The fertilization of arable land also affects the composition of vegetation in adjacent biotopes that are worthy of protection. All types of species-rich arable biotopes are now critically endangered or threatened with extinction according to the Red List. With regard to arable land, protected area planning must therefore be improved.

Investigating the link of wild bees and their pollination service and landscape ecosystem types in a systematic literature review

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Meta-analyses with a global focus reported a substantial link between wild bee occurrence, pollination service and the landscape composition and use. However, the smaller scale which means the relevance of single landscape elements for wild bees and pollination service has been less considered in meta-analyses. To better understand wild bee – landscape interactions happening on a smaller scale, a systematic literature review was conducted that was combined with a meta-analysis and which only focused on Germany and its neighboring countries.

For Germany, around 50 studies were identified that were published between 2012 and 2022. A preliminary evaluation of the literature showed that almost all studies investigated the link between wild bee occurrence/pollination service and landscape only in agricultural ecosystems and often with a focus on how wild bee presence interacts with crop fields. The studies were mostly conducted in highly intensively agricultural areas in Germany such as Lower Saxony and Saxony-Anhalt. Studies dealing with forest, wetlands, heathland, quarries and other ecosystems (except from urban ecosystems) were extremely rare or not existing for Germany. Expanding the literature review to Germanys neighboring countries, it was found that here ecosystems outside the agricultural focus, such as forests ecosystems, roadsides and wetlands were more intensively studied when it comes to interactions of wild bees and landscape features. This preliminary analysis already reveals that German wild bee research could put its focus more on ecosystems outside the agricultural area. This could help to better communicate to decision-makers why such non-agricultural ecosystems should be preserved because these habitats provide wild bee habitat and therefore pollination service.

The results from the systematic review could help to objectively validate an expert-based assessment from the Joint Research Center (Zulian et al. 2013) where wild bee experts estimated the benefit of different land cover and land use types (CORINE land cover) for wild bees on the EU-level. This part will be addressed in upcoming research.

SESSION 16:

Conservation of Forest Biodiversity

Natural disturbance regimes as a guide for forest biodiversity management and conservation in Europe

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In Europe, there has long been interest in natural dynamics silviculture (NDS) to provide a full spectrum of seral habitats and structural conditions required by forest biodiversity, including species that are poorly represented in intensively managed forests. However, adoption of NDS has been limited by incomplete understanding of the ranges of variability in disturbance regimes, including frequencies, spatial attributes, and severities. Addressing this constraint in European forest management, we adapted a “comparability index” (CI) that was first developed in the US to compare natural disturbances and forest management effects. We extended the original concept that included spatial and temporal axes by adding disturbance severity (i.e. tree survivorship or retention) as a third dimension. We populated the model by compiling published data on disturbance dynamics for four major forest types (i.e. spruce, beech, oak, and pine-dominated). Data on silvicultural systems by country and forest type were obtained through an expert-based process employing standardized estimation protocol. The data for both natural and harvest disturbances were visualized in three-dimensional plots indicating ranges for frequency, size, and severity. We developed an algorithim to calculate the index values for bivariate comparisons. The results indicated that natural disturbances are highly variable in size, frequency, and residual structure, but European forest management fails to encompass this complexity. The CI showed the highest congruence between uneven-aged silvicultural systems and key natural disturbance attributes. Even so, uneven-aged practices emulate only a portion of the complexity associated with natural disturbance effects. The remaining silvicultural systems perform poorly in terms of retention, especially, as compared to tree survivorship after natural disturbances. Our results and the CI will help European forest managers to expand their portfolio of silvicultural systems to sustain and conserve forest biodiversity, while providing a broad array of ecosystem services.

How "close-to-nature" are forest disturbance regimes in managed forests in Germany?

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Close-to-nature forestry is considered our best option to address the societal demands towards forests while simultaneously safeguarding forest biodiversity and ecosystem functioning. However, close-to-nature forestry in Central Europe has largely focused on stand-level processes while ignoring landscape-scale phenomena such as disturbances. What hinders a current modulation of management after natural disturbance regimes is a lack of quantitative information on disturbances under unmanaged conditions.

At the same time, forest disturbances will amplify in the future under climate change. A central premise of management is that disturbances can be reduced through risk management, yet whether and to what degree unmanaged forests differ in their natural disturbance impacts from managed forests remains unclear.

To tackle this knowledge gap, we investigate disturbance regimes for managed and corresponding unmanaged forests across Germany. We integrate a Landsat derived forest disturbance map, tracking the disturbances of the last decades, with climate and environmental data and compare them between managed and unmanaged forests across different ecoregions.

In order to account for diversity in forest types, management practices and climates, we structurally match Germany-wide unmanaged forest sites (management ceased at least 35 years ago), with multiple comparable managed forest sites. The matching includes site condition (including climate), elevation and forest type to isolate the effect of management. We ask two questions: (i) are the canopy openings in managed forests within the recent range of natural variability derived from unmanaged forests, and (ii) are natural disturbance impacts higher in managed or unmanaged forests?

The findings bear significant implications for biodiversity conservation, as they explore whether forest management impacts the frequency and size of canopy openings, thereby influencing forest biodiversity in a crucial manner. Furthermore, assessing disturbance impacts in relationship to different management addresses the question of potential co-benefits between climate-adapted forest management and biodiversity conservation.

Unraveling the influence of exotic vs. native forests on ecosystem functionality through soil co-occurrence networks

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Profound land use changes and socio-economic transformations have affected European forests over the last century and to disentangle their effects on communities and biodiversity is key for future conservation strategies and sustainable practices. In Portugal, a country where wild spaces cover the majority of the territory, forests represent the main land use type (36%) and their condition and extent relies widely on human activities. For example, forest plantations of ***Pinus pinaster*** promoted intense land use changes from agricultural to forest land until their peak in the 1980s, and more recently a rise of exotic Eucalyptus plantations from their inclusion in 1960s until now, where they occupy 26% of the forest land use. In forest ecosystems, habitat conditions as shade, type of canopy and litter, and micro habitat qualities as soil properties like pH, Organic Matter or availability of nutrients are determined by tree species while multiple ecosystem services are also dependent on the soil community composition and diversity, which can be used as indicators of ecosystem health. Here we study the soil community composition of the northern region of Portugal through a comprehensive sampling across exotic and native forests to disentangle the multiple drivers, including anthropogenic and natural factors, that affect ecosystem services in soils. We use 16S and 18S soil amplicon sequencing to assess bacterial and eukaryotic community composition and apply co-occurrence network properties to reveal how community resilience and resistance are influenced by forest type. In an area that is naturally affected by big gradients in climate, soil and socio-economic variables we aim to unravel the site dependent effects from forest type and determine the potential measures that could be implemented to increase local ecosystem functionality in highly anthropogenic ecosystems.

Enhancing structural complexity in production forests: impacts on soil biodiversity and functions

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Production forests are managed to optimize timber production, resulting in even-aged stands with few canopy gaps and little deadwood. These homogenous forests lead to low biodiversity and multifunctionality that is well investigated at the alpha diversity level, while studies at larger spatial scales are scarce. The objective of the DFG Research Unit BETA-FOR is to test at a management-relevant scale, whether the enhancement of structural complexity of several adjacent patches at the alpha level (50 x 50 m patches) can lead to increased biodiversity and multifunctionality at the landscape level across 11 German forests. To accomplish this, different silvicultural interventions were implemented in spatial proximity, uniquely manipulating light availability and deadwood occurrence. These areas with increased structural complexity are compared to homogenous control areas. Since soils provide a habitat for many species that drive important ecosystem functions, we examined the BETA-FOR approach for soil functions (soil respiration, microbial biomass, respiratory quotient, water-stable soil aggregates, enzymes), soil biodiversity (soil nematodes), and abiotic variables (soil pH, CN, soil texture). First results indicate that the effects of enhanced structural complexity on soil functions are context dependent: in some forests, soil respiration decreases and microbial biomass increases in structurally complex areas. A higher variation in microbial respiration was found between treatment patches than between control patches, which indicates higher variability of microbial activity. Preliminary analysis show that within the patches, enhanced structural complexity leads to a higher diversity of microsites, meaning that within one patch, light and deadwood availability varies more than on control patches.

Temporal development of tree-related microhabitats in temperate European forests

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Tree-related microhabitats (TreMs) have been promoted as indicators of forest biodiversity and to guide conservation practices. Ensuring a rich and diverse supply of these structures in the long term is crucial for the viability of forest-dwelling species communities, yet challenging in the absence of information regarding their dynamics.

Based on an original dataset describing TreMs on 11,569 trees, we provide the first insights into the highly dynamic temporal development of TreMs on living habitat trees from temperate European forests. To illustrate how, and what drives changes in TreM abundance and richness over a period of 3 to 12 years, we estimated the rates of TreM persistence and loss events at tree-level using survival analysis methods. Consequently, **persistence** was characterised by consistency and increment events (when TreM numbers maintained or increased); while **loss** events were defined by a reduction in TreM numbers or their disappearance. Cox proportional hazards models were fitted for ten distinct TreM groups.

The magnitude and frequency of temporal changes in TreMs varied between coniferous and broadleaved trees and among TreM groups. For most TreMs and event types, changes occurred more frequently on broadleaved trees than on conifers. The latter experienced earlier and higher magnitude events. Most trees experienced losses of TreMs such as exposed sap- and heartwood, epiphytes, twig tangles, fresh exudates (on conifers) or crown deadwood, perennial fungi, exposed sapwood (on broadleaved trees). While loss events were predominant in nearly all TreM groups, overall TreM abundance and richness were persistent at the tree level, irrespective of species. Large trees were prone to experience persistence in their overall TreM abundance and richness. Increasing diameters resulted in higher persistence rates in seven TreM groups and concomitantly lower loss rates in four of them.

We suggest that selection of habitat trees based on TreMs should take in consideration the likelihood of those TreMs being lost over time, to ensure long-term provisioning of habitat for the TreM associated species.

Tree-related microhabitats in beech forests with different managment

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Beech forests play an important role in creation of shelters for various plant and animal species. Moreover, beech trees can bear different tree-related microhabitats (TreMs), which by itself creates a diverse microhabitats and temporary living conditions for many organisms. Several studies showed that TreMs can be used as an indicator or a predictor of biodiversity, which is why it's important to know more about TreMs and their drivers. TreM diversity is related to a different factors, from which we underlined forest management, tree species, DBH and elevation. In this study we described TreM diversity in managed and unmanaged beech forests, covering the most geographical range of beech distribution in parts of Europe and West Asia.

Analyzing the data, we found out that the TreM composition was more connected to the "host" tree species and elevation, not to a management or DBH. And the TreMs coverage increased via number of trees and DBH, but was higher in managed forests. We also assessed the diversity of rare and dominant TreM types and found that it was higher in unmanaged forests and was increasing with elevation. These findings shows the drivers for TreMs in beech forests and can be used for future studies, which will allow researchers and forest managers to take TreMs into account for biodiversity conservation.

Effects of spongy moth outbreak and insecticide treatment on caterpillar and parasitoid networks across subsequent years

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Massive insect outbreaks in forests, like the infrequent eruption of the spongy moth Lymantria dispar, pose a major challenge in the management of natural ecosystems. Parasitoid hymenopterans and dipterans are important antagonists of such phytophagous insects, however, due to restricted taxonomic knowledge, they are often neglected in studies regarding biodiversity and species interaction. In a large-scale experiment, the effect of spongy moth host population dynamics (high and low densities) and forestry insecticide (tebufenozide and control treatment) on host-parasitoid network and community structures were studied over three consecutive years. Combined methods of taxonomy, barcoding and metabarcoding were used to identify caterpillars and parasitoids inside caterpillars as well as adult parasitoids after canopy fogging from oak trees. The network analyses revealed a high level of host-parasitoid interaction complexity which remains stable over the years. However, the application of insecticide resulted in a decreased network complexity, which is probably due to the reduction of the caterpillar density. Moreover, non-metric multidimensional scaling based on distance matrices showed strong effects of years and insecticide application on caterpillar and parasitoid communities. Altered community structures indicate sensitivity to environmental fluctuations, which in turn may be reflected in changes of species interactions. Overall, the study highlights the importance of including so-called "dark taxa" in ecological studies to understand important ecosystem functions and to expand our knowledge of forest biodiversity.

Response of ground beetle (Carabidae) assemblages to retention structures, roe deer and landscape factors in SW Germany

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Degradation and fragmentation of forest habitats due to timber production has led to declines in forest-specialized organisms, such as predatory ground beetles (Carabidae). The recent implementation of retention forestry practices contributes to structural enrichment of managed forests, which may benefit forest-specialized ground beetles. However, little is known about the effects of retention measures in Central European forests managed under single-tree selection systems. In that region, intense browsing by deer may also play a large role in driving composition of carabid assemblages, and forest fragmentation can lead to replacement of forest-specialized by more generalist carabid species, but it is still unclear how these effects interact with the effect of retention measures. With this study we aimed to determine to what degree retention structures benefit ground beetles, in relation to the effects of roe deer abundance, landscape composition and other stand-level structural features not targeted by retention. We have measured relative abundance and community composition of carabid beetles in 66 1-ha forest plots, using pitfall traps, and obtained relative abundance of deer from camera-trapping. We expect to find that carabid assemblages are more strongly determined by the share of broadleaf trees and by canopy closure, which are not directly targeted by retention, than by other factors. Nevertheless, the abundance and diversity of brachypterous and large-bodied species should increase with forest maturity and dead wood volume, which are associated with retention measures. Total ground beetle richness and diversity, on the other hand, should increase with the amount of non-forest land in the landscape and with abundance of deer, with this effect being driven by smaller-sized and macropterous species.

Linking forest structure to multi-taxon species diversity

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Retention forestry is a forest management practice aimed at ameliorating post-harvest forest structures and at preserving, maintaining and ultimately enriching biodiversity in managed forests. The goal of our work was to assess the effect of retention forestry across different taxonomic groups in a multiple-use forest system in the Black Forest in southeast Germany.

We defined biodiversity, as diversity (shannon index, beta) and abundance of six taxonomic groups, and investigated their response to forest structures, such as old and dead trees, vegetation heterogeneity and spatial configuration of the surrounding landscape. We found that while there are several significant effects (both positive and negative) of forest structure on several species groups at different response levels (Such as: SSCI on bats (+), coniferous share on bees (+), ...), there is no general pattern and the effect size is lower than expected. In addition, there was no clear trend visible whether mean conditions, heterogeneity, local or landscape descriptors of forest structure are more relevant for biodiversity. Our results suggest that biodiversity responses to forest structure are group specific, and that no single factor can be managed to maximize a uniform response of biodiversity. Furthermore, biodiversity responses are scale specific - both spatially and temporally. If the management goal is to maximize landscape species richness, then a cross-scale management approach which fosters forest patches with different characteristics are promising to be applied in conservation.

What's social about forest biodiversity conservation?

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Successfully implementing forest conservation measures is not only dependent on a proper understanding of ecological processes. Recently, the importance of socio-cultural drivers in determining how forests are being managed for biodiversity conservation has been increasingly recognized. Understanding conservation as a social-ecological endeavour entailed a shift from a focus on 'pristine' ecosystems and species to the analyses of interactions between human and natural systems, including managed landscapes such as forests. Yet, despite this increasing awareness of social dimensions within forest management, the dominant focus behind conservation research continues to be on the acquisition of rational and scientific knowledge to inform management. Especially in landscapes managed for multiple purposes, the lack of appreciation for the complexities of social-ecological systems often results in resistance by land owners and/or managers, as their individual relations and imaginations towards the land they manage are often disregarded. Neglecting social dimensions within forest biodiversity conservation thus continues to build barriers for implementation. Consequently, conservation programs are in need of integrating evidence-based measures while at the same time taking into account a diversity of values and interests present in the relevant groups of actors.

Drawing on empirical research and experiences in the multi- and interdisciplinary setting of the RTG ConFoBi, we highlight the importance and diversity of social science research in the field of forest biodiversity conservation. One focus of our research is analysing the value-driven processes shaping the implementation of forest biodiversity conservation, how these values are reflected in the production of scientific knowledge and manifest in certain dominant discourses on nature conservation. Another focus is showing how social processes on an individual, organisational and institutional level influence the success of forest biodiversity conservation initiatives.

Experimental canopy opening: The impact on multi-taxa biodiversity in European deciduous and mixed forests

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European forest ecosystems experience decline in biodiversity associated with homogenization of forest structure and predominance of closed-canopy stands. Several projects studying the effect of artificial canopy opening on different taxa in managed or protected forests have been established across Europe recently. We collected multi-taxa data from 13 such projects to analyse the response of diversity to two major types of interventions: thinning (spatially dispersed cutting) and gap creation (spatially aggregated cutting). We evaluated the relative change in alpha diversity and community dissimilarity by pair-wise comparisons - between plots where interventions were carried out and their closest reference (control) plots, using samples from 1st to 6th season after cutting. The results suggest that increased openness in intervention plots had positive effect on diversity of vascular plants and saproxylic beetles, but negative effect on diversity of birds. Response of bryophytes, fungi, or moths was different based on the intervention type - thinning or gap creation. The most studied groups across the experiments were vascular plants and epigeic beetles. For vascular plants, the community dissimilarity to control plots increased with thinning intensity (percentage of trees cut), but was unaffected when related to size of gaps. Alpha diversity, although being higher in intervention plots, did not increase with thinning intensity or with gap size. For epigeic beetles, community dissimilarity also increased with thinning intensity but not with gaps size and alpha diversity showed variable response, sometimes positive, sometimes negative, suggesting that their communities may by more affected by locally specific conditions than by intervention per se. Our study shows positive effect of artificial canopy opening on forest biodiversity. However, further continent-wide studies are neccessary to assess the role of increased light conditions in patterns of less studied taxa.

Effects of forest management on the key fungal decomposer *Fomes fomentarius* in European Beech forests – Lessons from a large-scale experiment

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Fomes fomentarius is a key, abundant fungus in European Beech forests and is important for nutrient cycles and food web dynamics. Forest management can be tailored to balance the extraction of wood with retaining dead wood in forests – key to sustaining F. fomentarius and numerous saproxylic organisms. To determine the influence of dead wood type (logs, snags, stumps) and microclimate (open vs. closed canopy) on the presence and abundance of F. fomentarius on the stand- and object-scale, we designed an experiment in which we added coarse woody debris to stands in a random block design in the Bavarian Forest. We observed that stands with stumps both under open and closed canopies were less frequently occupied by F. fomentarius than dead wood on other stand types. The lower abundance of F. fomentarius on stumps under an open canopy was significant. The higher average abundance of F. fomentarius on stands with snags under a closed canopy was also significant. This study shows that the abundance of F. fomentarius can be promoted when an intact canopy is maintained and where snags are left or introduced in the forest. This outcome could be explained by microclimate and dead wood type preferences of F. fomentarius.

The effects of amount and spatial distribution of dead wood on saproxylic diversity in a central European beech forest

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In forests, dead wood is a key habitat for biodiversity as more than 25% of forest species depend on it (= saproxylic species). Forest management for timber production drastically alters not only the structure of forests but also the availability of habitats therein, often leading to a reduced quality, quantity and connectivity of dead wood. While dead wood enrichment in managed forests has already become a policy objective, the role of its spatial distribution is often overlooked.

We investigated the impact of dead wood amount and distribution across several spatial scales (20-200m radius) on diversity of saproxylic beetles, wood-inhabiting fungi, and epixylic bryophytes and lichens on 62 plots in a Swiss beech forest. To further study if 'Single Large or Several Small' habitat patches harbor a higher diversity (SLOSS-debate), we exposed freshly cut beech branches in bundles of different sizes (1, 3, 6 and 12 branches) on each plot to be colonized by saproxylic beetles.

While dead wood amount could repeatedly be shown to be the main driver of overall saproxylic species richness, spatial distribution also mattered: (1) a reduced connectivity on larger scales led to a decreased local diversity of fungi, bryophytes and lichens and (2) pooling the initially dispersed small branch bundles from a plot resulted in an equal number of beetle species compared to the large bundle, despite fewer branches (10 vs. 12 branches).

For supporting the conservation of saproxylic species in managed forests, increasing the quantity of dead wood should be prioritized, but it becomes clear that considering its spatial distribution can help reaching this goal in several ways. A spread-out distribution of dead wood not only increases habitat connectivity but also promotes its heterogeneity. Especially in managed forests, where retained dead wood is often quite homogeneous regarding size or tree species, exposing it to different environmental conditions can promote diverse species communities.

Enrichment of beech stands with Douglas fir or silver fir? Insights from a systematic study on their effects on plant diversity.

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Enrichment of temperate beech forests with more drought tolerant tree species is an important strategy in climate change adaption of European forestry. The conifer species Douglas fir (Pseudotsuga menziesii) and Silver fir (Abies alba) are especially interesting in this context, as they both are considered to grow on a large spectrum of lower mountain ranges and collin sites in Central Europe under future climate conditions. Also, they both produce high quality timber and thrive in mixed stands with European beech (Fagus sylvatica). While Douglas fir is controversially debated due to its status as non-native, silver fir has a long tradition in European forestry, which is not well represented by its comparatively small current distribution. In both species, an expanding cultivation in mixed forests with European beech and other broadleaves is planned throughout central Europe.

As there still are knowledge gaps regarding the ecological impacts of such silvicultural interventions, we studied both species effects on forest plant communities when they were admixed to beech stands in different proportions (25%, 50% and 75%). Pure stands of beech and both conifer species (0%, 100%) were studied as references. We analysed the data for (1) changes in diversity patterns, (2) changes in community assemblages and (3) proportion of forest specialists vs. more generalist species.

Both species were found to significantly increase vascular plant diversity along the mixing gradient. Both species also significantly altered the original beech forest community in terms of species inventory and relative abundances. However, Douglas fir admixture was comparatively associated with an increase in the relative abundances of generalists, disturbance-indicators and plant species typical for open habitats.

We therefore suggest to favour silver fir when both species are considered to be equally suited from a silvicultural point of view.

Landscape scale mixtures of intensively and unmanaged forests increase biodiversity - Empirical effects of the Triad zoning.

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For three decades, the concept of Triad zoning has been proposed to balance the social, ecological and economic demands at the landscape scale by providing intensively, extensively and unmanaged forests in equal proportions. However, the assumed effect on biodiversity was rarely tested against empirical data.

We used the Europe-wide multi-taxon database compiled by the Bottoms-Up Platform to quantify, for the first time, the effects of Triad components' forest landscape composition on regional (multi) biodiversity. We defined Triad components according to the silvicultural system applied; INT: clearcutting with and without species change and coppice, EXT: shelterwood and selection cutting, UNM: natural development. To ensure comparable environmental conditions and avoid regional bias, we searched the database, comprising 88 sites across Europe, for sites of the more or less eutrophic, (sub-) montane beech forest natural vegetation type, keeping only sites with at least two Triad components and two taxa represented, arriving at well balanced dataset of 222 plots from 9 sites from Czechia, France, Germany and Italy.

To analyse the effect of Triad components on biodiversity, the composition of forest landscapes was varied in steps of 10% using 1000 resamplings of up to 20 plots per step (66 unique landscape compositions), quantifying regional (gamma) diversity.

Biodiversity of five taxa responded significantly but differently to forest landscape composition (R^2 from 0.243 to 0.748). Regional diversity of bryophytes, lichens and deadwood fungi was highest for pure UNM landscapes, while birds and deadwood beetles profited from adding INT to UNM. Vascular plants regional diversity was promoted by INT with minor contribution of UNM. Multidiversity culminated in landscapes composed of 70% UNM and 30% INT (95.1%), dropping drastically towards pure EXT and INT (73.3 %) landscapes, suggesting complementarity between unmanaged and intensively managed forests, at least for some taxa.

Generation time in trees: a simulation method

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Generation time is a key metric in species vulnerability assessments, but it is rarely used for assessing the conservation status of trees. The rarity of generation time estimates in trees presumably reflects constrains on both data and methods. To obviate this issue, we propose a workflow that combines the perfect plasticity approximation (PPA) model with trait data. First, we use PPA model parameters from Barro Colorado Island (Panama), and we validate them using external tree ring data. Second, we run single-species PPA model simulations to estimate the generation time of 165 BCI species. Third, we test the ability of PPA model parameters, functional data (maximum height, seed mass, leaf mass area, and wood density), and phylogenetic data to predict our simulated generation time estimates. We show that PPA model parameters are consistent with our tree ring data. In our 165 species, generation time varied between 20 and 557 years. We found a significant and strong correlation between maximum tree height and simulated generation time. Generation time also correlated, albeit weakly, with wood density and phylogeny. These results suggest that it might be realistic to produce generation time estimates for a large proportion of extant trees. The PPA model can be run on a personal computer, its parameters already exist for thousands of species, and such parameters are straightforward to estimate using forest inventory data. When species lack forest inventory data, generation times can be estimated using functional trait data, albeit at the cost of increased estimate uncertainty. Thus, these considerations highlight the workflow we present here as a feasible step in the implementation of many tree vulnerability assessments.

Forest disturbance transforms bird communities across Germany

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Forest disturbance, i.e. canopy cover loss through drought, bark beetle outbreaks, windthrow and fire has been increasing rapidly across Central Europe. Half a million hectares (of mostly Spruce) have been affected since 2018 alone. Further increases are predicted due to climate change. The implications of canopy loss, post-disturbance treatment (e.g. salvage logging vs. non-intervention strategies) and variation in reforestation on biodiversity trends, community composition and abundance are poorly understood, mostly because appropriate biodiversity data are lacking.

We analyzed the effect of forest disturbance on population trends of breeding birds, harnessing data from the German Common Breeding Bird Monitoring for the period 2005 to 2019. We identified losers and winners of forest disturbance at the national scale. We supplement this analysis with data from various own field studies, comparing pre- and post-disturbance community composition and abundance of birds, and predicting the effects of post-disturbance management and reforestation on bird communities.

Our results suggest pronounced reorganization of bird communities due to forest disturbance. Changes were modulated by post-disturbance management. Forest disturbance seems now to reverse the fortunes of many species of conservation concern that had been declining over the past 200 years, when light, open, warm coppice forests and wood pastures were abandoned and transformed into dark, tall, biomass-rich and conifer high forests. Contrastingly, populations of conifer-dependent species that colonized large parts of Germany during the 19th century are currently collapsing over large areas.

Elevation gradient in bird nests

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The local assemblage of higher trophic levels strongly depends on the local forest environmental conditions. However, they are often neglected in biodiversity-ecosystem function research. Bird nests are multifunctional structures that can reveal information about the fitness and adaptation of the breeding species. To assess the effects of an enhanced forest structure on insectivorous breeding birds, 360 nest boxes on 180 patches were monitored during three months in two study sites, the Franconian Hassberge and the Bavarian Forest. In a standardized way eggs and fledglings were counted to determine breeding success. At the end of the breeding season, nests were weighed. According to the thermo-regulation hypothesis of bird nests, a significant increase in nest weight was found with increasing altitude as the ambient temperature decreases. Between closely related sympatric species smaller species built bigger nests than larger species most likely due to higher body heat loss. This year's monitoring will include three more study sites depicting a more pronounced elevation gradient from 40 to ›1000 m.a.s.l., which will allow to further analyze the previous findings as well as relate it to birds' breeding success. An equally positive effect of elevation on nest weights is expected as well as higher breeding success in nest boxes where forest structure was enhanced.

Strength, diversity and spatial arrangement of host-parasitoid networks increase with forest structural heterogeneity

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Parasitism is a complex and fascinating life history strategy where organisms exploit the resources of others, which in the case of parasitoids results in host death. Antagonistic host-parasitoid interactions can be quantified using bipartite and metanetworks, which have the potential to reveal how habitat structural elements relate to this important ecosystem function. Here, we analysed the host-parasitoid interactions of cavity-nesting bees and wasps, as well as their abundance, diversity and species richness from 127 forest research plots in southwestern Germany.

We found that parasitoid abundance, diversity and species richness all increase with host abundance, a potential mediator between parasitoids and forest structure. Both parasitoid abundance and diversity increased with stand structural complexity, possibly mediated by the abundance of hosts. Additionally, parasitoid abundance increased with increasing standing deadwood and herb cover.

The bipartite networks of host-parasitoid interactions showed higher connectance with increasing standing deadwood, herb cover and host abundance. Analyses of interactions within the host-parasitoid metanetwork revealed that increasing host abundance and decreasing canopy cover diversify the suites of interactions present at plot-level. These results demonstrate that forest structural elements can improve the stability and resilience of host-parasitoid networks indicated by changes in diversity, strength and spatial arrangement of ecological networks.

Tree species identity and canopy structure drive canopy arthropod diversity and trophic composition

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Forest canopies maintain a high proportion of terrestrial arthropod diversity. The drivers that structure these communities, however, are yet poorly understood. As recent forest diebacks call for new forest management strategies, integrative research connecting tree species identity, stand properties and canopy arthropod composition is required.

We investigated within a temperate forest ecosystem how the taxonomic, functional, and trophic community composition of arboreal arthropods is affected by tree species composition and associated differences in canopy structure. We collected canopy arthropods using insecticidal fogging and flight interception traps in monospecific and mixed stands of European beech, Norway spruce and non-native Douglas fir. We integrated metabarcoding, stable isotope metrics and mobile laser scanning.

Coniferous stands had higher structural complexity and higher canopy arthropod abundances than beech stands. However, taxonomic and functional diversity of arthropods were lower in non-native Douglas fir than in native beech stands, and at the landscape scale, also native Norway spruce reduced arthropod diversity compared to pure and mixed beech stands. Arthropod community composition differed between monospecific stands, with beech-conifer mixtures mitigating these differences. Irrespective of tree species identity, taxonomic, functional and trophic richness of canopy arthropods increased in structurally heterogeneous canopies, but only few traits dominated.

We show that canopy structure and tree species identity are interlinked in shaping canopy arthropod communities. Contrasting to results from the forest floor, non-native Douglas fir had severe negative consequences for canopy arthropods. As broadleaf-conifer mixtures mitigated negative conifer effects, they may serve as a sustainable forest management option. Intermediate rather than high structural heterogeneity might foster more stable ecological communities.

Wildfire and post-fire management modulate arthropod diversity, community dynamics and related ecosystem services in pine forests (*Pinus sylvestris*) in Germany

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In the light of global changes, understanding and identifying the processes driving community assembly is crucial to face and adapt to future environmental change and build resilient conservation strategies. Forests are a substantial carbon sink worldwide and support biodiversity and ecosystem functions and services, which are seriously compromised by climate change and its consequences (e.g. wildfires).

In this study we aimed to understand the effect of wildfires and post-fire strategies on both soil-emerging and surface-active arthropod communities, their dynamics and the related ecosystem services. The study area is located in the state of Brandenburg, Germany with 13 sites with different post-fire management and two unburned control areas which were sampled continuously for a period of 12 months (2021-2022) using paired emergence tents and pitfall traps. Organic matter degradation and predation rates were measured by using bait laminas and dummy caterpillar respectively.

Our results indicate a negative effect of wildfire on both the abundance and taxonomic diversity of arthropods, but wildfire also altered the community composition independently of the post-fire management. Local patterns in emergence of soil-developing arthropods differ significantly from communities of surface-active arthropods. Post-fire management in terms of tree establishment and dead wood removal were the most important factors determining community structure. Organic matter degradation and predation rates were modulated also by the wildfire and Post-fire management.

The high abundance and diversity of arthropods in unburned sites can be explained by the fact that the present litter layer increases soil fertility, the availability of food resources. Not all arthropod taxa were negatively affected by fire and post-fire management as very mobile taxa showed more resistances to fire and even dependent on fire to fulfil their life cycle. In fact, the diversity of habitats created by fire including intact patches and large amounts of dead wood, increase the diversity of arthropod communities. Identifying the current processes driving community assembly is crucial in understanding biodiversity dynamic and its response to future wildfires and post-fire management.

Forest gaps increase true bug diversity by recruiting open land species

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Forests canopy gaps play an important role in forest ecology by driving the forest mosaic cycle and creating conditions for rapid plant reproduction and growth. The availability of young plants, which represent resources for herbivores, and modified environmental conditions with greater availability of light and higher temperatures, promote the colonization of animals. Remarkably, the role of gaps on insect communities has received little attention and the source of insects colonizing gaps has not been studied comprehensively. By using a replicated full-factorial forest experiment (treatments: Gap; Gap + Deadwood; Deadwood; Control) we show that following gap creation there is a rapid change in the true bug (Heteroptera) community structure, with an increase in species that are mainly recruited from open lands. Compared with closed-canopy treatments (Deadwood and Control), open canopy treatments (Gap and Gap + Deadwood) promoted an overall increase in species (+59.4%, estimated as number of species per plot) and individuals (+76.3%) of true bugs, mainly herbivores and species associated to herbaceous vegetation. Community composition also differed among treatments, and all 17 significant indicator species (out of 117 species in total) were associated with the open canopy treatments. Based on insect data collected in grasslands and forests over an 11-year period we found that the species colonizing experimental gaps had greater body size and a greater preference for open vegetation. Our results indicate that animal communities that assemble following gap creation contain a high proportion of habitat generalists that not occurred in closed forests, contributing significantly to overall diversity in forest mosaics.

Temporal dynamics in communities of xylobiont beetles in the Leipzig floodplain forest: seasonal dynamics dominate over inter-annual patterns

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Seasonal and inter-annual dynamics have a high influence on arthropod communities in temperate forests. However, little is known how they interact with spatial structures like vertical stratification in the canopy or how they differ between tree species.

We compared alpha and beta diversity patterns, as well as indicator species composition, functional diversity, and species abundance distributions of xylobiont beetle species in the canopy of the Leipzig floodplain forest among seasons and years over two years.

We found differences in alpha and beta diversity between vertical strata and tree species to be more variable among seasons than among years. Species richness was highest in spring for all strata and tree species. Heterogeneity of communities was highest within in the upper canopy for seasons and years. Species abundance distribution patterns among years and seasons differed stronger between tree species than between strata. A dominance of log-series patterns across all investigated species abundance distributions emphasized the role of stochastic processes in community assemblies. Niche-based processes such as habitat filtering were also detectable, but their influence varied between habitats and seasons. There were more indicator species for the upper canopy than for any other habitat in all years. Differences between seasons in the distribution of feeding guilds were more pronounced than differences between years.

Our results underline the importance of covering the full range of species' phenologies for a thorough understanding of spatial and temporal diversity patterns and their dynamics.

Identity matters – potential habitat trees promote epiphytic lichen and bryophyte diversity dependent on tree species identity

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Lichens and bryophytes respond more sensitive to environmental conditions than vascular plants and are, therefore, threatened by changing conditions. Trees play a major role for epiphytic lichens and bryophytes, as trees are the direct substrate for these organisms. It is known that bigger trees harbour more epiphytes, because of special microhabitat characteristics and of providing habitat continuity. In management, structural elements, like habitat trees and deadwood, were retained to promote biodiversity in total. Our aim was to investigate whether potential habitat trees in continuous- cover forestry are richer in epiphytic bryophyte and lichen species compared to average trees of smaller sizes. The study was conducted in the Southern Black Forest, Germany, on 135 1ha study plots within the framework of the project Conservation of Forest Biodiversity in Multiple-used Landscapes (ConFoBi). On 10 trees (5 habitat trees, 5 average trees) per plot, all epiphyte species were sampled from 0-2 m above the stem base. Habitat trees turned out to have a higher species richness than average trees, and that beech trees have a positive effect on species richness and simpson diversity of bryophytes. Silver fir, as habitat tree, has a positive influence on simpson diversity of lichens but the species richness of lichens is not significantly different on different tree species. Additionally, our models showed that both bryophyte and lichen species richness benefit from large sized habitat trees, but DBH shows no significant effect. However, deciduous trees appeared to be more appropriate for bryophytes, whereas not such pattern was detectable for lichens. Ordination also showed that the tree species harbour unique bryophyte and lichen assemblages. Therefore, we suggest for habitat tree selection in continuous-cover forestry rather focusing on tree species diversity than only on trees with higher DBH, to protect lichen and bryophyte diversity.

Distributional patterns of epiphytic lichens and bryophytes in forest ecosystems – proximity effects between neighbouring host trees

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Epiphytic lichens and bryophytes play a crucial role in forest ecosystem function by influencing water and nutrient flows. Their community compositions are affected by various environmental factors, which are classified into different scale dimensions, such as tree, stand, and landscape scale. Forest ecosystems thereby provide a heterogeneity of "habitat islands" in terms of host trees that differ in traits and epiphyte community compositions. Established old-growth host trees typically exhibit a higher diversity of epiphytes, which enhances the diversity of the forest stand. Apart from observing diversity on individual host trees, it is essential to consider the interaction between trees in a stand and how neighbouring trees affect each other in terms of epiphyte diversity. For instance, old-growth, species-rich host trees may have a positive impact on surrounding trees in a stand.

Our study aims to investigate the impact of old-growth trees on epiphytic lichen and bryophyte diversity in forest stands, as well as their influence on neighbouring trees (proximity effect). We aim to identify the key environmental factors that drive these patterns.

We studied 24 forest plots in the Southern Black Forest, analysing 48 pairs of host trees to compare the relationship between distant and proximate trees. Each pair consisted of an old-growth central tree and a neighbouring tree, differing in diameter, with two pairs per plot. The three most common tree species (*Abies alba*, *Picea abies*, *Fagus sylvatica*) were included.

To tackle the main drivers of the respective patterns, we conduct a comprehensive examination across multiple scales. This includes evaluating factors such as tree species, diameter at breast height (*DBH*), microclimate, bark chemistry, soil-bark relation, bark water holding capacity, wood moisture content, and internal decay at the tree scale, forest type, management type, tree species richness, number of trees, mean DBH/classes at the stand scale, and elevation and aspect at the landscape scale.

Spider assemblages in a restored forest share characteristics of communities in a primary forest in Ghana

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Deforestation causes forest losses of approximately 3.4 million ha per year in West Africa. Ghana has an estimated 9.2 million ha of rainforest and forest resources are lost faster than in other developing countries due to agricultural intensification, logging, infrastructure development and mining. Spiders are valuable indicators for restoration success in forests and contribute to the provision of ecosystem services by regulating insect pests. We evaluated the taxonomic diversity of ground-dwelling spiders across a habitat gradient ranging from a primary forest to an agroforestry plantation and a forest restored after mining in the Ahafo region of Ghana to understand the state of different forest ecosystems in regards to Arachnid diversity. Spiders were most abundant in the primary and restored forests, with lower abundances in the agroforestry plantation. Individuals in Araneomorpha accounted for 16 spider families, while individuals in Mygalomorpha accounted for 5 families, with a total of 15 families present in the primary forest, 14 families in the restored forest, and 12 families in the agroforestry plantation. Of the 21 total families, Lycosidae, Zodariidae, Salticidae, Ctenidae, and Cyrtaucheniidae formed 60% of all spiders. The Lycosidae included the genera *Pardosa* (*Pardosa injucunda* and *Pardosa gefsana*), *Lycosa* and *Geolycosa*. The observed results indicate that agroforestry plantations have lower abundances and family richness compared to restored forests, which resemble spider assemblages in primary forest habitats in family composition and diversity. Active restoration of post-mining sites in the study region can promote spider diversity more than alternative land-use strategies such as agroforestry. As arthropods are severely understudied in the region, but are valuable indicators of ecosystem states in other region, we propose follow-up studies that add vegetation-dwelling spiders to evaluate the benefits of restoration activities on spiders.

Is light availability driving soil seed bank diversity in temperate forests under management?

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Soil seed bank ensures the maintenance of plant and genetic diversity as it contains seeds from current and past understory plant community. Also, this storage of seeds is crucial for forest regeneration, as well as for habitat restoration. In temperate forests, management is of great importance in the determination of conditions to which the vegetation is exposed to, especially via changes in light availability. These variations in light availability can have important impacts on understory plant diversity. However, it remains unclear how these variations in light conditions generate responses in the soil seed bank community. In this research, we aimed at assessing how light availability impacted soil seed bank diversity and how these variations were related to the aboveground understory plant diversity. We hypothesized that higher light heterogeneity would increase diversity in the soil seed bank as germination and replenishment would be promoted for a larger range of species. To test this, we sampled soil on 6 subplots (25 m^2) in 30 locations in the Southern Black Forest and we measured seed bank species composition via a germination experiment. Additionally, we measured light availability, and we assessed the species composition of the understory plant community. In total, we counted and identified 653 seedlings belonging to 30 plant species. Most of these species were identified were characterized as light demanding and long-lived species. Soil seed bank plant community only accounted for 17% of the understory plant community. The light variation among the plots could not explain diversity differences among plots, nor light quantity. It appears that the observed seed bank community could be representative of a previous plant community with higher light requirements and that light conditions at present could only determine future seed bank community composition.

Effects of canopy openness and forest management on decomposition rates and decomposer communities of carrion

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Decomposition of dead organic matter, necromass, is a key ecosystem process in all ecosystems as it affects local soil fertility and global carbon cycling. The quantification of the contribution of decomposer communities to the decomposition rates is largely unknown. Considering ongoing global biodiversity loss and particularly declines in insect populations and diversity, a better understanding of the role of different decomposer taxa is needed.

In forests, canopy cover and other characteristics associated with forest management are affecting decomposer communities and decomposition rates. To improve our understanding of decomposition processes and associated carbon and nutrient cycles, studies are needed which compare the role of different drivers of the decomposition of necromass.

To study how canopy openness and forest management affects decomposition rates and the decomposers communities in carrion, we compare decomposition rates of dead rats between paired sites of closed forest and forest gaps along a gradient of forest management intensity within the framework of the Biodiversity Exploratories. In each plot, one rat is exposed in such a way that invertebrates and microbes are able to access it, while invertebrates are excluded from another rat. This way the contribution of the different taxa to the decomposition process can be quantified. Differences in decomposition rates between treatments and effects of invertebrate decomposer communities are presented. Our results can help to gain a better understanding of the role of drivers of carrion decomposition in forests ecosystems.

Rake in the forest: Tools for the care of plant communities of open forests

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The collection of leaf litter has been a common practice in forests for centuries, contributing significantly to the reduced nutrient levels and high understorey plant diversity of former forest ecosystems. Using an 11-year field manipulation experiment, we investigated whether the reintroduction of this type of traditional management, specifically the regular removal of litter, could mitigate eutrophication and protect the ancient plant diversity of open forests. We examined vascular plant composition in 64, 3 × 3 m plots in 32 randomized blocks, each consisted of one litter-removal and one control plot in a subcontinental thermophilous oak forest dominated by *Quercus petraea* (Czech Republic, Central Europe). We analyzed how regular litter removal influenced the changes in topsoil nutrients and diversity and abundances of perennial, short-lived monocarpic and open oak forest plant species. The regular litter removal significantly mitigated eutrophication by a reducing total nitrogen, and significantly decreased the amounts of base cations Ca^{2+} and Mg^{2+} in the topsoil. The studied plant species groups responded differently. Perennial and open oak forest species significantly increased their richness and abundances in the litter-removal plots and at the same time their diversity did not change significantly depending on inter-annual weather conditions. In contrast, litter removal negatively affected abundances of short-lived monocarpic species, whose richness was also considerably influenced by weather conditions (decreased the most in years with spring droughts). Moreover, we have found a protective effect of regular litter removal on drought-sensitive open oak forest species that survived in the litter-removal plots, whereas some completely disappeared from control sites during the period of repeated drought events. Our study thus demonstrates that litter removal is a tool with high potential in maintaining biodiversity in open forests affected by climate change.

Evaluating the impact of European forest management strategies on key forest taxa using integrated species distribution models

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Forest-based climate change mitigation pathways play a crucial role in reducing net greenhouse gas emissions and achieving the climate neutrality goals of the European Union (EU). However, reaching these goals is complicated due to interactions between socio-economic demands, management strategies, natural disturbances, or climate change that shape forests. Moreover, because the climate and biodiversity crisis are deeply interlinked, there is the need for an integrated modelling approach to assess how European mitigation pathways can effectively meet policy objectives while simultaneously conserving biodiversity. Here, we present an ecological modelling framework based on integrated species distribution models to evaluate the impacts of forest management and environmental change on biodiversity across the EU. Our framework encompasses a diverse range of forest taxa, including plants, insects, reptiles, amphibians, birds, and mammals, with a particular emphasis on species listed by the European Environment Agency (EEA). For this, we integrate species data from publicly available databases as well as data from several national forest inventories. Environmental covariates include forest structure variables, such as tree species composition, basal area, or dead wood biomass, simulated for different management strategies by coupling forestry and land-use models (i.e., GLOBIOM, G4M-X). Additionally, we include current and projected future climate scenarios into the modelling framework. We will present the modeling framework and show present-day and projected species distribution trends for forest taxa under different forest management strategies.

Are colonization patterns of waterfilled tree holes affected by forest management?

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Water-filled tree holes in forests provide habitats for aquatic insect larvae and other aquatic invertebrates. Relative few studies have investigated the temporal dynamics of tree hole food webs and their cross-system interactions with surrounding habitats, especially over more than one season. In this study, artificial tree hole analogues were sampled sequentially over a 15-months period beginning in April 2015 in three regions in Germany, with a particular focus on the effects forest management on the colonization patterns of aquatic insects.

We found that all artificial tree holes were colonized after less than 2 months. Overall, total abundance and species richness of communities followed a third-order polynomial relationship with a maximum in July followed by a decline in the following month. Abundances, but not species richness, were higher in the following year. Although overall abundance was not strongly influenced by forest management intensity, we showed that altered tree composition and dispersal limitation had a negative effect. Abundance was also influenced by water volume and temperature concordant with previous studies, and additionally by the orientation of the container with respect to cardinal direction. Species richness was related to abundance but did not respond strongly to the environmental variables when corrected for abundance. Community composition also showed strong temporal dynamics, differed significantly between the regions studied and was highly significantly related to forest management and the dominant tree species of a forest stand.

The present study contributes to the understanding of community dynamics in forest by demonstrating indirect effects of management via altered environmental properties on these microhabitats. A careful selection of forest management practices to maintain the biodiversity of these microhabitats in temperate forests is advisable.

Impacts of enhanced structural beta diversity in production forests on the taxonomic diversity of understorey plant communities

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Understorey vegetation is a major component of temperate forest diversity hosting the majority of forest plants and regulating many direct (pollination, seed dispersal, decomposition) and indirect (habitat provision) biotic interactions. Understorey vegetation plays an essential role in multiple ecosystem functions such as primary productivity and nutrient cycling and has a strong impact on tree recruitment processes. While natural forests form a mosaic of different successional stages, current production forests are often characterised by high structural homogeneity and low β-diversity (i.e. low structural complexity among forest patches).

Plants are known to strongly respond to changes in habitat conditions across temporal and spatial scales. There is numerous evidence for shifts in species composition in response to changed resource availability, microclimate, and substrate supply at the local (α-) scale. However, little is known about the impact of natural or silvicultural disturbances on β-diversity and β-multifunctionality in production forests.

Within the BETA-FOR project, we conduct a study to address how the Enhancement of Structural Beta Complexity (ESBC) impacts diversity of understorey vegetation in formerly homogeneously structured production forests. ESBC treatments were established in 2016, 2017 and 2018 at 11 sites in Germany with a focus on manipulations of canopy cover and deadwood features.

In this poster, we will use data from understorey vegetation surveys, as well as aboveground productivity measurements, conducted in summer 2023. We will analyse how ESBC treatments affected taxonomic diversity of understorey plants and biodiversity-productivity relationships across scales. Hill-Chao numbers will be used to explore patterns in taxonomic richness at α-, β- and γ-diversity scales comparing structurally enhanced sites with control sites. Aboveground productivity as a measure of ecosystem functioning will be linked to patterns in taxonomic diversity.

Effects of Douglas-fir mixing on bird reproduction in managed forests

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Due to climate change, silviculture in Central Europe faces the challenge of finding new tree species with higher resilience to drought-induced tree mortality. The non-native species Douglas-fir (*Pseudotsuga menziesii*), with its elevated yields and by being drought-resistant, has emerged as an alternative, yet the impacts of introducing Douglas-fir on native forest fauna remain poorly explored. We investigated the effects of admixing beech (*Fagus sylvatica*) with Douglas-fir or with the native Silver fir (*Abies alba*) on birds in temperate forests by comparing the reproductive success of blue tits (*Cyanistes caeruleus*) in 63 plots encompassing three treatments (beech:Douglas-fir, beech:Silver fir, and pure beech) in northern Bavaria (Germany). During the vegetation period of 2023, we chose two trees in each of the plots, in the case of admixtures a beech and the conifer (i.e. Douglas-fir or Silver fir), and we attached a nest on each tree at a height of 2.5 m always facing south. During the 2023 season, we conducted weekly monitoring of the occupancy rate, laying date start, final clutch size, hatching and fledging rate, and chick mortality. We found the number of nesting boxes successfully occupied by blue tits was affected by both treatment and tree species, with pure beech forests having 53% more occupied nests than forests with Douglas-fir or Silver fir. However, the start of laying eggs was not affected by treatment or tree species. The number of eggs laid was affected by the tree species to which the nest is attached, with an average of 9 eggs in pure beech forests, compared to 4.2 and 5.8 eggs in Beech:Douglas-fir and Beech:Silver fir forests, respectively. Understanding the impact of tree species and species combinations on the breeding success of blue tits can provide valuable insights for forest management and conservation efforts, highlighting the importance of maintaining suitable habitats bird species.

Lighter and less structured primary forests host more understory species

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Nature conservation in the Carpathians focuses on primary forest remnants as biodiversity hotspots. They are recognized by complex structural qualities such as tree size heterogeneity, dense canopy, or occurrence of ancient trees. Studies from managed forests suggest that complex structure increases herb layer diversity. However, it is unclear if such a relationship also occurs in primary forests, where the structure is not driven by time since anthropogenic impacts. We have tested the effect of structural complexity, light conditions, and canopy disturbances on the herb vegetation composition and richness on 150 plots in primary beech forests across Slovakia. The overall species richness is declining with the decrease of available light in the understory and this decline is also true for the richness of forest specialists, although their proportion to the other species is growing. Interestingly, we found no effect of canopy continuity or time since the last disturbance on the plot on the forest specialist's proportion. Our results suggest that, in contrast to managed forests, the richest stands of primary forests are characterized by relatively low structural complexity and much available light, and this is true also if only forest specialist species are considered. The positive relationship between structural complexity and herb richness in managed forests may thus reflect development towards more natural states rather than the general ecological rule.

Stress response of forest insects to silvicultural interventions

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Silvicultural interventions can alter forest microclimates. Depending on silvicultural requirements these interventions are performed distributed throughout a forest stand, which maintains the canopy with its climate buffering capacity, or aggregated leading to microclimatic extremes in forest gaps. Insect diversity reacts to these silvicultural interventions but whether temperature stress responses can be detected at the individual level remains unknown. By combining a laboratory experiment and a forest manipulation experiment, we aimed to understand, if silvicultural interventions affect the stress response of beetles at the molecular level to get a more mechanistic understanding of their abundance patterns. We exposed a laboratory beetle species to different temperature treatments and sampled three different forest beetle species on patches with varying microclimate (i.e., aggregated, distributed and no interventions). We determined their stress response by quantifying the body weight as well as the amount of three stress associated biological amines using high-performance liquid chromatography. We found similar patterns in the laboratory and under real-world conditions albeit in different magnitudes. Since forest beetles are mobile and thus able to escape unfavorable microclimatic conditions, our results indicate that intact forests can buffer temperature stress effects at the individual level, which is particularly important with increasing weather extremes and canopy disturbances in the face of climate change.

Exploring the Forest Volatilome: A Vital Yet Little Understood Part of the Forest Ecosystem

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Volatilomes play a vital although little understood role in ecosystem functioning. By applying an untargeted approach to the analysis of volatiles collected at 1 m height on 234 patches in 11 forests throughout Germany, we hope to gain a better understanding of the volatiles present on production forest patches with different management treatments. Additionally, by collecting targeted dead wood and beetle volatiles as well as variables known to influence volatiles—such as temperature, humidity, wind speed and direction, and solar radiation—we aim to identify volatile compounds that may be indicative of the presence or absence of select organisms, are especially abundant, or differ between patches based on management treatments or at the landscape level. As part of the BETA-FOR research unit, we aim to test whether increasing structural complexity at the alpha level (50 x 50 m patches) leads to increased multifunctionality at the beta and gamma levels. Discovering whether the volatilome of a forest patch can potentially serve as an indicator for patch structural- and biodiversity could be of use for future management and monitoring of forests. We will present initial results.

Let's manage forests for habitat heterogeneity, and biodiversity will come along, right?

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Forest management often aims to improve biodiversity by increasing forest structure heterogeneity using indicators such as tree species richness, deadwood diversity, and natural regeneration. However, existing research report contradictory results on how biodiversity responds to these variables, particularly at large spatial and temporal scales. Our study examined the effect of forest management on forest structure heterogeneity and its biodiversity implications in temperate forests. We performed a systematic review of peer-reviewed studies examining the impact of forest structure indicators on the species richness of four taxa (beetles, vegetation, fungi and lichens). We then evaluated the effect of forest management and local environmental conditions on forest structure heterogeneity in Germany's Black Forest using a Structural Equation Model (SEM). We also analyzed the effect of forest structures and heterogeneity on species diversity and community composition of seven taxa using Generalized Additive Models (GAM) in managed stands in Germany's Black Forest. Lastly, using a partition tree algorithm, we assessed the transition point for the biodiversity of three taxa (lichens, mosses and fungi) resulting from forest structure variables in protected Scandinavian areas. We found that management-influenced forest structures had no significant direct effect on species richness. While forest management actively shapes forest structure heterogeneity, the response of local environmental variables is taxa-specific, and we didn't find any clear pattern to suggest using a forest structure variable as a biodiversity indicator. Deadwood diversity significantly affected the biodiversity of lichens, mosses, and fungi in protected areas, but observed values were far from those in managed forests. Our findings challenge the idea of using forest structures as biodiversity indicators and suggest a taxa-specific approach for conservation and management goals.

SESSION 17:

A Future European Conservation Network

A systematic review of the state of European conservation planning

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Global and European policy frameworks call for an expansion and improvement of biodiversity conservation, through measures such as strict protection, restoration, or improved management actions. However, given the shortages of resources and multiple competing objectives there is a need to prioritise when, where and how conservation objectives are to be reached. Particularly in Europe, cultural and historical predetermined landscapes make the implementation of any conservation and restoration plans challenging, requiring a detailed analysis of synergies and tradeoffs between the impacts of such plans. A specific branch of decision theory, systematic conservation planning (SCP), can assist in identifying best possible places and actions, opportunities, and constraints. Here we present the results of a comprehensive review of the scientific literature with regards to evidence of previous European SCP approaches, both in terms of area- and action-based conservation implementations. We find clear evidence of trade-offs between planning complexity and the relevance of individual frameworks with regards to conservation policy across scales. Especially the lack of any engagement of stakeholders in the design of European conservation planning studies is damning, and spatial and conceptual biases are likely to have prevented them to reach their full potential in making better decisions. We furthermore outline pathways towards maximizing the uptake of decision theory and conservation planning across scales to encourage better decision making. Overall, this work provides a benchmark of the state of conservation planning in Europe.

Spatial prioritisation of threat management for biodiversity conservation across the Natura 2000 network

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Effective conservation must rely on careful planning and strategic investment of limited resources. The last report on the State of the Nature in the European Union (EU), a periodic monitoring exercise at continental scale, shows that biodiversity continues to decline, despite the efforts done in the last decades. Urgent action is, therefore, needed to reverse this trend.

We carried out a gap analysis to identify pressures and threats with no reported management action over the period 2013-2018 and identify priorities to close this gap. We finally prioritised the selection of pressures and threats to be addressed for all species and habitats collectively, to identify management priorities.

We found that 2/3 of all combinations of species/ habitat x pressure/ threat did not have management actions reported. Management gaps were especially large for birds, amphibians and reptiles and marine bioregions in northern EU. The spatial prioritisation analyses showed that all species and habitats could benefit collectively from a reduction in 30% of pressures/ threats incidence by targeting a small proportion of pressures/ threats and Natura 2000 sites.

The prioritisation approach that we demonstrate here could be valuable to plan investment to close the current management gap and inform conservation across the EU.

Future scenarios of European soil biodiversity and functions in relation to their conservation and restoration potential

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Soils are essential for supporting a wide range of organisms and vital ecosystem functions. It is therefore crucial to set conservation priorities and restoration strategies that target soil biodiversity and functions in order to maintain healthy soil ecosystems and mitigate the effects of climate change. We aimed to identify target areas for nature conservation and soil restoration across Europe, taking into account the multiple ecological dimensions supported by soils and integrating ecological and socio-economic factors. We built on the LUCAS survey, which includes observations of biodiversity (bacteria, fungi, protists and invertebrates) and functions in 885 composite samples of topsoil across Europe. First, we mapped the current 'ecological status' of soils based on several ecological dimensions, including alpha diversity, community and functional dissimilarity, and ecosystem services. We then identified areas of high conservation value, i.e. high species richness, particularly unique communities and functional groups, and high functional performance, as well as areas where soils have been highly degraded by human activities and need to be restored. Finally, we developed future scenarios of soil biodiversity and functions under different socio-economic and climate change scenarios.

EVALUATION OF PROTECTED AREAS- representativeness and conservation effects on long-term insect species richness

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Protected areas are a key tool in nature conservation to protect habitats, aiming to keep natural areas in pristine conditions, and to safeguard threatened species. Especially in central Europe, an area under high anthropogenic pressure, protected areas may be important refuges for species.However, few studies have assessed whether protected area networks have effectively protected species richness at the regional scale over long time scales, mainly due to the lack of biodiversity data over larger spatial and temporal scales. In this study, we aim to overcome this gap of knowledge by evaluating the effectiveness of protected area coverage on species assemblies for the German federal state of Bavaria, an ideal study region in central Europe containing a mosaic of different land-use types, climatic zones, and a network of protected areas of different protection status. Specifically, we aim to test whether (1) protected area coverage alone or (2) in combination with biotic and abiotic drivers like land cover and temperature affect communities.

We use animal occurrence observations of different insect groups (dragonflies, butterflies, grasshoppers) from the species mapping database (ASK) of the Bavarian State Agency for the Environment. Our results bear the potential to show the strengths and weaknesses of the current protected areas network.

Assessment of level of protection of existing old-growth forests (OGF) in Europe

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Europe's forests have a strong management legacy of providing wood for heating, cooking, and construction materials. Almost all forests are or have been shaped and managed. However, there are still some forests that are considered primary or old-growth forests, especially in inaccessible areas. Most recent estimates state that primary or old-growth forests in Europe cover a maximum of 3% of Europe's current forest area (1.4-3 million ha) and that the area has significantly decreased over the last decades.Old-growth and primary forests are vital for biodiversity conservation and provide many other ecosystem services. The EU Biodiversity Strategy for 2030 aims to strictly protect all remaining EU primary and old-growth forests as part of a wider target to strictly protect 10% of the EU land area. A current assessment under the European Topic Center 2023 assessed the extent and distribution of old-growth forests within and outside protected forest areas, in all Member States of the European Union, under consideration of different biogeographical regions, and the potential of the 30 by 30 target to improve the protection status of currently existing Old Growth Forest in Europe.

Integrated spatial planning for multi-functional landscapes

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The vast majority of extractive and productive activities undergo planning and application processes and are subject to regulation. Despite this, habitat loss and degradation are still the primary causes of global biodiversity decline, accelerating green house gas emissions and other environmental impacts. Part of the reason is that ecological data and biodiversity objectives are insufficiently considered in these planning processes, while at the same time conservation and restoration planning, especially in the scientific domain, seldom account for other objectives, e.g. food production, timber extraction, job creation. It is therefore not a surprise that these conservation plans often remain academic exercises and do not get implemented. The Kunming-Montreal Global Biodiversity Framework target 1 requires country to have integrated, biodiversity-inclusive spatial planning that addresses habitat loss over 100% of marine, freshwater and terrestrial ecosystems. This could be truly transformative, but it requires a paradigm shift in conservation science and practice.

Here I present few approaches and real-world examples of multi-criteria spatial planning that aim at jointly achieving multiple, typically competing, targets such as habitat conservation and restoration, water management, agriculture and forestry and discuss their advantages and disadvantages in terms of driving forward the science and practice of spatial planning for biodiversity conservation. I will also highlight the obstacles to integrated spatial planning on land in Europe and how these could overcome through specific reforms in planning processes in selected case studies and sectors.

Should forest reserves in Central Europe be big or small?

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Whether single large or several small (SLOSS) protected areas contain more species is a controversial debate. Despite many conservation areas being designed to be as large as possible, empirical results indicate that multiple small patches covering the same area frequently contain more species than a single large area. In the case of forest reserves in Central Europe, the available information is limited, resulting in uncertainty regarding the impact of reserve size on species diversity across different forest types and taxa.

In addition to existing “strict forest reserves” where management ceased over 30 years ago, the state of Bavaria (Germany) has set aside 58,000 ha of state-owned forest land in 2020.

Across the two networks of newly established and existing protected forest areas, we investigate the effect of size and age of forest reserves on biodiversity in different forest types and across different taxa. We selected 44 protected forest areas of different size and age in three different forest types covering a wide range of natural dynamics (floodplain, beech and mountain) and assess the biodiversity of insects, spiders, birds, bacteria and fungi. To ensure a proportional sampling design reflecting the size of each reserve, the number of sample plots was chosen proportional to the reserve area.

The results of this study will uncover how reserve size and age affect alpha- (plot-based) and gamma- (reserve-based) diversity. For each forest type and separately for old and new protected areas we aim to create Quinn-Harrison curves, which indicate whether single large or several small reserves contain more species. Our results will contribute to a better understanding of the SLOSS-debate in central European forests, which can support decision- and policy-makers in achieving conservation goals.

SESSION 18:

Conservation and Climate Change Mitigation

Wind turbines in managed forests partially displace common birds

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Wind turbines are increasingly being installed in forests, which can lead to land use disputes between climate mitigation efforts and nature conservation. Environmental impact assessments precede the construction of wind turbines to ensure that wind turbines are installed only in managed or degraded forests that are of potentially low value for conservation. It is unknown, nevertheless, if animals deemed of minor relevance in environmental impact assessments are affected by wind turbines in managed forests. We investigated the impact of wind turbines on common forest birds, by counting birds along an impact-gradient of wind turbines in 24 temperate forests in Hesse, Germany. During 860 point counts, we counted 2,231 birds from 45 species. Bird communities were strongly related to forest structure, season and the rotor diameter of wind turbines, but were not related to wind turbine distance. For instance, bird abundance decreased in structure-poor (-38%) and monocultural (-41%) forests with wind turbines, and in young (-36%) deciduous forests with larger and more wind turbines (-24%). Overall, our findings suggest that wind turbines in managed forests partly displace common forest birds. If these birds are displaced to harsh environments, wind turbines might indirectly contribute to a decline of their populations. Yet, forest bird communities are locally more sensitive to forest quality than to wind turbine presence. To avoid a further displacement of forest animals, the spatial planning of wind turbines in forests should prioritize forests of lowest quality for wildlife, for instance small and structure-poor monocultures along highways.

Wind turbines in forests repel forest specialist bats – an investigation of potential causes

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The current expansion of wind energy is leading to an increasing deployment of wind turbines in forests. This development is constraining the availability of suitable habitat for forest specialist bats that avoid the proximity of wind turbine sites. Understanding the underlying causes for the avoidance is critical for taking appropriate conservation measures. However, the causes are not yet clear, because wind energy in forests may affect the environment in several ways. For example, foraging habitats may be lost for bats when forest areas are cleared during wind turbine deployment and bats may be deterred when operating wind turbines emit cues such as noise. We installed ultrasonic recorders at turbine clearings and adjacent forest edges as well as in the canopy of the surrounding forests at distances from 80 to 450 m from turbines and quantified the acoustic activity of forest specialist bats (Myotis, Plecotus) at each sampling point. Operating protocols provided information on when wind turbines were in operation. Our results did not show that bats were less active at the wind turbine clearing than inside the forest. However, we observed that acoustic bat activity decreased with increasing wind speed when wind turbines were operating, while their activity remained unaffected by wind speed when turbines were not operating. In conclusion, we showed that forest specialist bats are negatively affected around wind turbine sites in forests. The observed avoidance was however not related to the direct habitat loss caused by the creation of clearings, as these open spaces were still used by bats. Rather, forest specialist bats seemed to be displaced by a combination of wind turbine operation and high wind speeds. This indicates that noise emissions from operating wind turbines, which propagate further at high wind speeds, are the most likely cause for the avoidance of wind turbine sites by bats in forests.

Sorghum bicolor has positive effect on colony performance of *Apis mellifera* in open landscape composition

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Biomass crops are an important component of sustainable energy production, with maize being the most common energy crop in Europe. However, large areas covered by maize have negative consequences for both wild biodiversity and for honey bees, partly because maize pollen is only poor food resource for pollinators. Thus, there is a need for alternative energy crops. One of the potential candidates is Sorghum (Sorghum bicolor), which provides nutrient-rich pollen, and also requires fewer fertilization than maize . Experiments in seminatural conditions have shown that honey bees can use Sorghum pollen as protein source, yet it is unknown whether Sorghum improves bee performance on the landscape level. In this study, we investigated the impact of a Sorghum field on the performance of honey bee colonies in open agricultural landscape, and how it changes along a 3 km gradient. We have found that the colony growth decreased with distance from the Sorghum field, which suggest that the Sorghum had indeed a positive effect on honey bee performance. To support honey bees, farmers can incorporate Sorghum into their existing crop rotations. It is possible that Sorghum has also a positive effect on wild generalist pollinators, for example bumble bees, yet this remains to be tested.

Paludiculture in temperate fens to combat eutrophication, biodiversity loss, and climate change

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Draining temperate fen peatlands created multiple problems such as greenhouse gas emissions, eutrophication and subsidence due to peat mineralization, but also loss of highly specialized biodiversity. Based on recent own publications and (not yet published) studies, we here explore the potential of paludiculture, i.e. the wet use of peatlands, in tackling the multiple challenges mentioned above. Rewetting effectively curbs carbon losses[1,2], but rewetted fens are more enriched in nutrients and differ in vegetation composition compared to natural fens[3]. Harvesting aboveground plant biomass can effectively reduce competition between plant species and also nutrient loads[4], while belowground production leading to peat formation and potential carbon storage is even enhanced by high nutrient loads[5]. Paludiculture has the potential to foster conservation targets across multiple taxa such as plants, arthropods, and birds (Martens et al. unpublished). Drought events occur with increasing intensity and frequency due to climate change. High decomposition under these circumstances, however, is balanced by increased root production[6] due to an elongated belowground growing season[7]. We conclude that paludiculture is a viable management option for rewetted fens that can curb multiple environmental challenges such as greenhouse gas emissions, eutrophication and biodiversity loss.

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2 doi: 10.19189/MaP.2020.SNPG.StA.1951

3 doi: 10.1038/s41467-021-25619-y

4 doi: 10.1016/j.scitotenv.2021.147276

5 doi: 10.1111/1365-2435.13803

6 doi: 10.1007/s10021-020-00570-z

7 doi: 10.1111/1365-2664.14222.

Assessment of aboveground and belowground biomass production and decomposition in natural, drained, and rewetted fens in Central Europe

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Peatlands globally suffer extensive degradation, which results in a loss of their valuable ecosystem services. Rewetting drained peatlands has been demonstrated to reverse many of the negative effects of degradation. To better understand peat formation, and how this service can be restored, understanding the relationships between aboveground and belowground biomass production and decomposition is key. This study examines the rate of biomass decomposition and the production trajectories in rewetted, drained, and undrained fens in Central Europe. Data from 111 plots located in 29 fens were analyzed, based on the two EU-funded BiodivERsA projects REPEAT and PRINCESS, being the geographically broadest investigation of production and decomposition processes in Central-European fens to date. Findings suggest that biomass decomposition was higher aboveground than belowground, and that vegetation composition is unlikely to affect decomposition. Aboveground litter decomposition was positively correlated with increasing levels of N and P in the aboveground plant biomass, and with a decreasing C:N ratio, while belowground litter decomposition was only positively correlated with increasing levels of N in the soil. While drained sites starkly contrasted with rewetted and undrained sites in terms of vegetation and degradation, rewetted sites also displayed substantial transformations, including increased bulk density, lower soil C:N ratios, lower porosity, and the prevalence of tall sedges as dominant vegetation. Belowground biomass production was negatively correlated with increasing degradation. Increased nutrient availability was associated with declining ratios between belowground and aboveground biomass production. Further analyses and integration with insights in aboveground and belowground production and decomposition are suggested to close further knowledge gaps on peat formation in rewetted fens.

Long-term biomass dynamics in Swiss forest reserves

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Forests can contribute to climate change mitigation by sequestering carbon when management intensity is reduced. However, there is high uncertainty regarding biomass dynamics in temperate forests after the cessation of management. We used forest inventory data from an extensive network of 224 plots in 37 natural forest reserves (NFR) in Switzerland covering a wide environmental gradient. Inventories had been conducted approximately every 10 years during the last 60 years. We used mixed effect models to (i) analyse biomass development, (ii) assess the role of time since the cessation of management (TSCM) and (iii) disentangle the environmental and forest structural drivers of biomass change. After the cessation of management and in the absence of high-severity natural disturbances, biomass accumulated gradually over time along a saturation curve. There were large differences in biomass among reserves and among the plots within a reserve, with values ranging from 101 Mg ha^{-1} to 851.2 Mg ha^{-1}, with a median of 362.1 Mg ha^{-1} (SD = 122.5 Mg ha^{-1}). A flattening of the curve was not yet apparent, most likely because the majority of the NFRs do not exceed 100 years of TSCM. Compared to higher elevations, forests at lower elevations (i.e., higher temperature) showed larger total biomass and higher rates of biomass accumulation. We found a reduction by 148 Mg ha^{-1} of biomass per 1,000 m of elevation gain. The strongest positive rate of change (>8 Mg ha^{-1} yr^{1}) was found in forests with high basal area (>60 m2 ha^{-1}) and medium to high levels of tree density (1,500 to 2,000 stems ha^{-1}). Overall, most of the reserves have not reached a biomass equilibrium yet and continue to act as carbon sinks in tree biomass. This highlights the carbon sequestration capacity of forest reserves and their role as carbon pools.

Relationships between the functional composition and climate regulation processes across European habitats

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Nature-based solutions that involve the protection, management and restoration of natural ecosystems are urgently needed to mitigate the climate and the biodiversity crisis, two of the biggest threats in the 21st century. Terrestrial ecosystems affect the climate from local to global scales via reflection of solar irradiation, evaporative cooling or carbon sequestration. The functioning of terrestrial ecosystems is largely determined by the traits of the dominant plant species. Yet, although it is known that plant communities differ in their climate regulation processes, only little is known on how plant traits affect these regulation processes, both within and across different habitat types. To bridge this gap, we related the community-weighted mean values of 20 plant traits to the proportion of reflected solar irradiation, evapotranspiration and net primary productivity across 46,463 vegetation plots, classified into ten types of forest, shrubland and grassland habitats. Using linear models, we found that climate explained, on average, 35.7% of the observed variation in the proportion of reflected irradiation, 18.2% of variation in evapotranspiration and 45.9% of variation in net primary productivity. After accounting for these climatic effects, we observed that in the majority of habitat types, the functional composition of plant communities was still significantly related to the climate-adjusted proportion of reflected solar irradiation (with an average of 9% explained variation), evapotranspiration (2.9%) and net primary productivity (6.4%). The strongest relationships were found in forest and temperate shrubland habitats. Yet, the strength and direction of individual relationships were strongly depended on the type of habitat analyzed. We conclude that any management or spatial upscaling of the effects of plant communities on climate regulation processes must consider the relative contribution of different habitat types.

Protected Areas in China Yield Positive Social-Ecological Outcomes Amid Potential Trade-off Challenges

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Global biodiversity and nature's contributions to people are under significant threat, a trend that protected areas (PAs) aim to mitigate as cornerstones of conservation efforts. However, robust evidence on the effectiveness of PAs to deliver multiple interconnected social-ecological outcomes and boost synergistic results remains scant. In response to this knowledge gap, we leveraged remote sensing observations and a rigorous counterfactual analysis to conduct a comprehensive nationwide evaluation of PAs' effectiveness in China. Our study spanned 655 PAs and delved into the heterogeneity across varying management levels, regional contexts, and the possible trade-offs and synergies between different outcomes. Our findings reveal that PAs, on an average basis, have successfully decreased net forest carbon fluxes by 12.91% [95% Confidence Interval (CI) = 10.74% to 14.98%], augmented water yields by 11.49% (95% CI = 9.28% to 13.61%), mitigated human pressure by 8.68% (95% CI = 4.89% to 12.45%), and curtailed cropland production by 15.24% (95% CI = 11.20% to 19.53%). Notably, the effectiveness of these PAs exhibited limitations and discrepancies across different management levels and regions. In the majority of outcome relationships, PAs fostered mutually beneficial results and curbed both lose-lose and tradeoff outcomes. However, the observed potential trade-offs between cropland production and other outcomes highlight potential conflicts between conservation goals and local livelihoods. These findings underscore the critical need for improved PA management strategies to bolster their effectiveness. Further, they demonstrate the urgency of implementing evidence-based, context-specific solutions to delicately balance ecological conservation and human well-being. These strategies should effectively navigate potential conflicts between disparate social-ecological outcomes to maximize the effectiveness of PAs.

How biodiversity-productivity relationships change along elevation gradients of mountain forests in temperate Europe and subtropical Asia

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Enhancing understanding of the relationship between plant biodiversity and productivity along environmental gradients is critical for both carbon sequestration capacity and biodiversity conservation. Theory predicts that the effects of biodiversity on productivity will be stronger in harsh environments than in more favorable conditions. However, little is known about how biodiversity-productivity relationships vary along elevational gradients in natural forests and how patterns differ between climatic regions.

Here, we fill this critical knowledge gap with tree inventory data from over 152 plots spanning approximately 1100 meters of elevation in subtropical forests in Asia and temperate forests in Europe. We estimated aboveground productivity based on species-specific allometric equations to assess how biodiversity-productivity relationships (BPRs) change with elevation while accounting for different facets of biodiversity (i.e. taxonomic, functional, and phylogenetic diversity).

We found no overall significant BPRs in temperate mountain forests and significant negative BPRs for taxonomic and functional diversity in subtropical mountain forests. When the effect of biodiversity on productivity was tested separately in the different elevation zones, significant and marginal BPRs were observed only in the mid-elevation zone of both sites, while other BPRs were mostly neutral (i.e. non-significant). Our findings highlight the need for carbon-focused management programs in mountain forests to focus not only on promoting carbon sequestration, but also on conserving biodiversity to mitigate the adverse effects of climate change.

Large-scale experiment for novel seed-substrate combinations at River Inn

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Grasslands are endangered worldwide, and many secondary ('cultural') grasslands are red-listed in Europe. Successful conservation of grasslands requires large areas and high connectivity among patches. Thus, synergies between green infrastructure and nature conservation are a way forward to avoid conflicts between agriculture and nature conservation. An interesting case are river dikes, which can serve both as grassland habitat and corridor, and which are currently (re)build in adaptation to climate change. Restoration of such grasslands should reconcile dike stability with enhanced biodiversity by modifying seed mixes, substrates, and initial management.

Therefore, we have started a new scientific project to explore dike restoration at River Inn. There we set up a large-scale experiment over several dike kilometers to test different combinations of seed mixes, substrate types and initial management. We investigate effects of substrate depth (5, 15, 30 cm) and soil origin (contrasting P levels) to modify the abiotic filter. The initial management (+/- mowing in late autumn) will change the biotic filter by reducing competition in the following year. The dispersal filter will be addressed by contrasting seed mixes (using species pools of hay meadows or calcareous grassland), with the same community-weighted means of specific leaf area and seed mass.

The aim is to identify the most appropriate seed–substrate combinations for the riparian and the terrestrial slope of the dikes. Restoration success is evaluated based on erosion control, vegetation cover, flower abundance, species richness and characteristic species composition compared to reference sites.

The effect of small stream restoration on terrestrial biota

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The restoration of rivers and streams aims to improve water retention in the landscape and mitigate weather extremes caused by climate change. It also enhances the ecological value of the watercourse. Many renaturation projects target small streams with a maximum width of 1.5 m that have been straightened or canalized, affecting several hundred meters of the stream course. The technical implementation includes the renewal of meanders, the planting of woody vegetation along stream banks, or the simple abandonment of the maintenance measures to allow natural succession near the stream. The ecological value of restoration efforts on short stretches of smaller streams is poorly documented, as most research studies have focused on larger streams and rivers. It is unlikely that their benefits lie in improving aquatic biota, as unrestored sections of small streams are a barrier to colonization of the restored areas. Therefore, the ecological benefits of restoring small streams likely lie in the positive effects on terrestrial biota. In this project, we investigate the effects of small stream restoration on terrestrial biota, particularly plants, insects, and birds. We compare 40-50 restored stream sections each with non-restored sections of the same water bodies. We use conventional methods such as vegetation surveys and observations to record plants and birds. Insects are captured using Malaise traps and identified through DNA metabarcoding. The main objective of the project is to assess the benefits of renaturation and determine which measures are helpful for specific taxa. This information will, in turn, contribute to improving the ecological value of future renaturation projects.

Roadmap for the rewetting of organic soils in Germany - relevance for nature conservation and the mitigation of biodiversity loss

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The reduction of greenhouse gas (GHG) emission by peatland rewetting is one of the most pressing challenges in climate change mitigation in Germany today. The majority of peatlands in Germany have been drained for agriculture and thus contribute strongly to GHG emissions from agricultural land. According to the amendment of the Climate Change Act, the sector Land Use, Land Use Change and Forestry is expected to provide a GHG sink of 40 mio. t CO2-eq. a^{-1} by 2045. This cannot be achieved without considerable efforts in peatland rewetting. Furthermore, the potential of peatland restoration for reducing biodiversity loss is addressed in several strategies such as the German Peatland Strategy or the National Biodiversity Strategy of Germany. At the same time, the recent amendment of the Renewable Energy Sources Act expanded the field for photovoltaic into agriculturally used peatlands in combination with rewetting ("peatland PV"), which evokes questions on the response of taxa to this new land use option. As peatlands are important habitats for endangered and highly specialised species, the future transformation of peatland use will have considerable impacts on for biodiversity conservation, including possible trade-offs.

The overarching aim of the interdisciplinary project "Roadmap for the rewetting of organic soils" is to develop an implementation concept for the rewetting of organic soils in Germany. For this purpose, site-specific land use options including restoration, paludiculture and "peatland PV" will be evaluated with regard to their mitigation potentials and economic efficiency. Also, the relevance for nature conservation and the mitigation of biodiversity loss will be evaluated at different scales. Especially, trade-offs regarding secondary habitats and the so far un-studied impacts of "peatland PV" on endangered species will be analysed and implemented in the development of the roadmap. Here, we present the concept to achieve this implementation as well as first preliminary results of a literature review.

Red kites fly at critical rotor heights of wind turbines across the entire range of occurring wind speeds

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The utilization of renewable energies has progressively increased in recent decades and, with it, the construction of wind turbines (WT), causing exposure especially for highly mobile species such as raptors. Gaining a better understanding of the flight activity and flight altitude of collision-prone species is crucial to develop effective mitigation measures of WT. We analysed the flight activity and altitude of 26 adult Red kites *Milvus milvus* tracked by GPS in Hesse, Germany, over three consecutive years. We related the flight activity and altitude of the birds to the occurring wind speeds recorded 10 m above ground and determined the proportion of activity within the critical rotor-swept area (RSA) of the WT currently operating and planned in the study area.

Flight activity increased with increasing wind speeds, reaching a plateau of maximum flight activity at intermediate wind speeds. Flight altitudes were constant at calm wind speeds and slowly declined at higher wind speeds. Consequently, the proportion of flights within the critical RSA of operating WT hardly changed with wind speeds. At currently planned, taller WT the proportion of flights within the RSA would reduce, but still a non-negligible exposure to collision persists.

Our findings show that significant proportions of Red kite flight activities occur in critical RSA of WT throughout the entire range of occurring wind speeds. However, given that the main flight activity takes place at calm wind regimes, we call for an increase in cut-in wind speeds of the WT operation as an effective mitigation measure for sustainable wind energy utilization. Thus, sustainable wind energy development could be advanced while actively protecting a collision-prone species of international importance.

SESSION 19:

Land Scarcity and its Impacts on Biodiversity

Land use conflicts in urban-rural fringes: Overview and causes

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Nature conservation and restoration measures to combat biodiversity loss often require land, but land is a scarce resource that is in high demand also for other uses, such as housing, agriculture, and energy production. A thorough understanding of the conflicts that characterize our land use systems is therefore necessary to develop successful conservation measures that take diverse land use interests into account. Against this backdrop, the aim of this presentation is to provide an overview of the land use conflicts that occur in urban-rural fringe regions in Germany, and their causes. It reports results from the research project ReGerecht that (among others) conducted a comprehensive analysis of land use conflicts in the urban-rural fringes of Schwerin and Cottbus. We conducted 65 semi-structured interviews with key land use actors through which we obtained information about 232 different land use conflicts. Applying qualitative text analysis, we identified common types of conflicts, as well as common causes. The presentation further points out connections between land use conflicts and biodiversity conservation, highlighting how conservation efforts can both be obstructed by land use conflicts or be the cause of them.

Solar power plants & biodiversity – contrary or compatible?

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Two of the biggest challenges of our time are tackling the climate and biodiversity crises. In addressing the climate crisis, photovoltaics is considered one of the key technologies for reducing greenhouse gas emissions and to achieve climate neutrality for Europe by 2050, which has led to the expansion of solar parks across Europe. Their size is up to several hundred hectares and the influence on biodiversity is discussed controversially. The ecological assessment of existing ground-mounted photovoltaic systems is diverse, ranging from markedly negative impacts on the landscape and biodiversity to potentially positive effects on ecosystem services and on several animal species groups. In this context, the BIODIV-SOLAR project focuses on developing measures for increasing biodiversity in ground-mounted solar systems to reconcile solar power energy generation and nature conservation demands. First, a concept for designing native seed mixtures was developed that can be flexibly applied to a wide variety of system designs and site characteristics and that specifically promotes pollinators. In a second step, different mixtures containing 17 to 39 species were tested in eight demonstrators in Eastern Germany, including solar parks and agrivoltaic systems. We present our initial successes in establishing species-rich grasslands, but also highlight the challenges and constraints that exist in establishing multifunctional ground-mounted photovoltaic systems and the solutions we have found to address them. In principle, the generation of added value for biodiversity seems possible, but is highly dependent on the location and previous use.

The opportunity costs of environmental exclusion zones for renewable energy deployment

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Exclusion zones, like protected areas or setback distances, are the most common policy instrument to mitigate environmental impacts of human land-use, including the deployment of renewable energy sources. While exclusion zones may provide environmental benefits, they may also bring about opportunity costs. This paper aims to understand and quantify the drivers determining the opportunity costs related to environmental exclusion zones. Using a simple analytical model, we propose that opportunity costs of exclusion zones can be decomposed into a substitution effect (because production is shifted to sites with higher or lower marginal production costs) and an output effect (because more sites may be needed to satisfy demand for produced goods). We provide a numerical illustration for the opportunity costs for two examples of environmental exclusion zones – setback distances to settlements and forest bans – which are implemented for wind power deployment in Germany. The numerical illustration builds on a spatially explicit optimization model using GIS data for more than 100,000 potential wind turbine sites in Germany. Our analysis reveals that opportunity costs may primarily arise in terms of higher local environmental impacts of wind power generation. Opportunity costs are mainly due to the output effect for setback distances, and the substitution effect for forest bans. We also show that the actual sign and size of opportunity costs depends a lot on the cost criteria under consideration as well as the type and stringency of the environmental exclusion zone. Our analysis emphasizes the importance to properly understand possible opportunity costs, and compare them carefully with possible benefits when implementing exclusion zones.

Abandoned pastures for energy biomass - trade-offs or synergies with biodiversity conservation?

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Agricultural and forest biomass are cornerstones in European strategies to mitigate climate change. However, despite the mitigation potential of energy biomass, its cultivation is associated with indirect land-use changes and negative environmental impacts. Hence, utilization of marginal land or non-managed land have been suggested as alternative sites for biomass cultivation and tree plantation. Based on a spatial analysis of Swedish marginal and non-managed land, we conclude that a large share of land being abandoned in Sweden are pastures. To get a better understanding of the ecological value of marginal land, we have used a space for time substitution approach in a mixed farm-forest landscape in South Sweden to analyze two likely bioenergy scenarios for marginal land. We sampled plant diversity in abandoned pastures, pastures converted to spruce plantations or ley fields, and active pastures. When comparing the two bioenergy scenarios, spruce plantations maintain most of the plant species richness for the early stage of the forest, but as the canopy closed, the alpha diversity is significantly decreased, which is also the case for sown ley fields. Pasture abandonment without any land conversion did however not significantly decrease alpha diversity, indicating that abandoned land may play an important role in preserving farmland biodiversity.

Compensation areas in transport infrastructure projects in the context of climate and landscape change: Legal framework in Germany, Austria and Switzerland

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Road infrastructure projects regularly lead to interventions in nature and the landscape. In order to compensate for these interventions, compensatory measures must be implemented. The aim of these measures is to compensate for the significant impairment of the performance and functionality of the natural balance and the landscape caused by the projects. In this context, it is also important to meet the challenges of climate and landscape change. This problem is addressed by the project “Compensation areas in transport infrastructure projects in the light of climate and landscape change”, which is funded by the Austrian Research Funding Agency. In none of the three countries involved in the project (Germany, Austria, Switzerland) is there a uniform procedure for the planning, securing, maintenance and control of compensation areas, which means that the long-term security of the measures is often not given. Controls and success evaluations are not carried out uniformly. These circumstances make the implementation of compensation schemes and measures very complex in practice. The lack of generally applicable standards and guidelines for compensation measures also leads to a lack of consistency in implementation in order to guarantee long-term compensation. The central aim of the project is therefore to develop proposals on how the planning, securing, maintenance and control of compensation areas in transport infrastructure projects can be improved in the future. The conference contribution gives an overview on the German legal basis for compensation, i.e. the impact mitigation regulation (cf. Sect. 13 ff. Federal Nature Conservation Act), and presents the methodological approach for the comparative analysis of the legal framework for compensation in Germany, Austria and Switzerland. From the results of the comparative analysis, suggestions for the further development of the legal basis for compensation and its enforcement are to be gained.

No net land take until 2050? The EU's ambition to curb the artificialization of land and its implications for biodiversity

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In the European Union, the areas used for settlements and infrastructure increase year by year at the expense of agricultural, forest and other semi-natural land. This artificialization of land ("land take") contributes to the erosion of biodiversity, impairs ecosystem services and reduces the land area available for other purposes. The EU Soil Strategy for 2030 sets the target of reducing the "net land take" within the EU to zero until 2050.

Next to illustrating the detrimental ecological effects of "land take" in the EU, this presentation asks whether and how progress is made toward the "No net land take" goal: Have all EU Member States adopted strategies for reducing their demand for new building land? How do they implement such strategies and does this effectively slowdown their "land take" rates? What are major obstacles for reaching "No net land take" and is the upcoming EU Soil Health Law expected to be a game changer?

Based on a questionnaire and a literature review, we present the approaches of selected EU countries to combat and compensate "land take" on their territories. Given the ongoing degradation of natural habitats in Europe, it is of particular importance whether these approaches pay off for biodiversity.

Current EU legislation and its potential to protect biodiversity in the context of transboundary farmland investments

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Large-scale transboundary investments in agricultural land are globally on the rise. This development increasingly encroaches on human rights and the environment, especially in low-income countries. Investors gain control over large areas of farmland through purchase or long-term lease. This ensures a.e. the production of food and access to resources while the land serves as object for investment and speculation. Local land users often face displacement or lose access to land as a consequence. Moreover, the investment processes frequently result in environmental destruction as small-scale agriculture is replaced by large agri-businesses. They are a central driver of land use change and often affect biodiversity-rich ecosystems such as forests, wetlands and savannas. The agricultural cultivation in monocultures, intensive pesticide-use and overfertilization inflict further severe damage on the biodiversity in these areas and in their respective soils.

Currently, transboundary investments in agricultural land are not sufficiently regulated. National law in the host countries is not effectively implemented, transnational regulatory approaches are only just emerging and comprehensive regulations on the part of the home states of investors are missing. As a result, the people and the environment in investment areas are left mostly without legal protection.

This regulatory gap could be closed by EU legislation, at least in regard to investments by European actors. This presentation examines the proposals for an EU Corporate Sustainability Due Diligence Directive and an EU Deforestation Regulation as two current pieces of legislation that are of particular interest in terms of their potential impact on transnational large-scale farmland investments. The focus is on how the two instruments are supposed to protect biodiversity. Furthermore, it will be compared which economic actors are bound by the two laws and how this group overlaps with investors in agricultural land.

Land Expansion, Scarcity, and Ethical Reconciliation: Exploring the Relevance of Aldo Leopold's Land Ethic in the European Modern Context

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This paper explores the evolving dynamics surrounding land in the European modern context, characterized by a dual movement of land expansion and the idealization of space. It begins by examining the processes of territorial expansion, exemplified by colonial projects and the notion of "terra nullius," as well as John Locke's belief in the unlimited availability of land through human labor.

However, the contemporary reality presents a contrasting narrative: the scarcity of land. This study elucidates various dimensions in which land becomes scarce, such as urbanization, deforestation, and the privatization of natural resources. It investigates the socio-political, economic, and ecological implications of land scarcity, acknowledging the challenges it poses to sustainable development and resource allocation.

Finally, this research examines the potential of Aldo Leopold's land ethic to respond to the predicament of land scarcity and foster ethical harmony. By analyzing Leopold's ethical framework, grounded in the intrinsic value of land and the interconnectedness of ecosystems, it assesses its applicability and effectiveness in addressing the challenges posed by the scarcity of land.

This study seeks to critically engage with the complex interplay between land expansion, land scarcity, and the potential ethical solutions offered by Leopold's land ethic. By considering the historical, philosophical, and ecological dimensions of the topic, it contributes to a comprehensive understanding of the contemporary challenges surrounding land use and resource allocation. Furthermore, it encourages further reflection and discussion on the role of ethics in promoting sustainable land practices in the face of scarcity.

In conclusion, this research investigates the dual movement of land expansion and the scarcity of land in the European modern context. It explores the dimensions in which land becomes scarce and the implications thereof. By assessing the relevance of Aldo Leopold's land ethic in addressing the challenges posed by land scarcity, this study aims to foster ethical reconciliation and guide sustainable land management practices in the present-day context.

Strong decrease of ruderal plant species through urbanization in only one decade

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The current decline of ruderal plant species in the villages, with the related impact for ecosystem functions, is often associated with the urbanization of their historically anthropogenic disturbed habitats. However, regarding the extent and speed of the processes, this is a poorly studied field, and urbanization as a complex of factors is hard to assess. Here, we took the age of village parts in three rough categories (‹1945, 1945-1990 and ›1990) as a simple proxy for urbanization and studied its impact on the population numbers of 13 selected ruderal plant species. We investigated seven villages in the eastern part of Germany in 2011 and again in 2022. Age of village part had a positive impact on population numbers, with the oldest parts harboring the most populations. The number of species as well as the number of their populations decreased from 2011 to 2022. But in these eleven years, the population numbers in the older village parts decreased, during they increased in the newest parts. Likely not only the presence of traditional village structures positively influenced the population numbers of the ruderal plant species, but also the duration of time after construction of the village parts. Newer village parts become more divers in their habitats with time, while older village parts lose their traditional structures, leading to a habitat homogenization in the villages. We could show, that age of village parts is a useful proxy for urbanization, and that the strong negative impact of urbanization for the diversity and abundance of typical ruderal plant species of villages can be clearly determined in only one decade.

Cross-scale drivers of agro-forest frontier dynamics in Latin America

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The agro-forest frontier is the dynamic border between agricultural and forested lands.

We studied three agro-forest frontiers in Mexico (Marques de Comillas and La Sepultura) and in Brazil (Zona da Mata) where smallholder rain-fed farming systems are characterized by extensive livestock grazing and a mix of subsistence and commercial crops. Each site is in a biodiversity hotspot and adjacent to or partially overlapping with state-protected areas. We quantified forest dynamics over 35 years and combined it with insights on socio-environmental dynamics to deduct the main cross-scale drivers of forest dynamics.

We found that each site showed temporal changes in higher-level (national, regional and global) drivers which initially focussed on establishing and stimulating agricultural production, and shifted more towards conservation in the last two to three decades. During this period, forest cover in ZdM forest cover showed a slight increase, MDC forest cover continued to decrease, while in La Sepultura forest cover was stable. The Mexican sites we see contrasting strategies for land sparing and land sharing. The land sparing approach in MDC allows for agricultural development, is characterized by the existence of conflicting policy instruments, and has not resulted in halted deforestation. The land sharing approach in La Sepultura is characterized by strict enforcement of conservation policies with agricultural marginalisation and halted deforestation as a result. In Zona da Mata, local stakeholders were effectively mobilised by church groups, NGOs and farmers cooperatives to align with the conservation-discourse, which contributed to agricultural development combined with a slight increase in forest cover.

Synthesis. Governance instruments for conservation and restoration may fail to reach intended effects, or have adverse social side-effects, when local actors are not involved. Unequal power balances are a barrier for this involvement. Collective action through social movements can empower farmers to exert influence on higher-level governance, resulting in locally adapted measures that have the potential to create synergies between conservation and production in agro-forest frontiers.

Golf courses as elements of multi-use strategies for biodiversity conservation

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As land is scarce, multi-use strategies are needed to reach nature conservation goals. Despite an often negative attitude of conservationists towards intensively managed golf courses, these may represent suitable elements in such strategy due to them holding either a suit of ecologically valuable habitats and/or a potential for an ecological upgrading. Yet, whether or not a golf course hold this suit of ecologically valuable habitats may depend on their size or age. Here, we analysed the habitat structure of twelve golf courses of different ages and landscape context in Schleswig-Holstein. We used PlanetScope imagery with a pixel resolution of 3 x 3 m and EnMap Box 3, an open-source GIS plug-in, for the classification of land-cover classes and different metrics from the *landscapemetrics* package in R to quantify the course and landscapes composition and configuration. The selected golf courses were built or refurbished between 1952 and 2014 and ranged from 55 to 113 ha in size. On average, the courses contained 60% of ecologically valuable habitat elements but differed systematically with age in this coverage. Golf courses from the late 1980s and 1990s had the lowest coverage, aligning with a fast growing number of golf courses and golf club members during this time. In relation to their landscape contexts in a 1500 m buffer around their centre, golf courses held up to two thirds of the amount of semi-natural elements. Moreover, due to the oftentimes linear configuration of hedgerows or extensive grasslands between the fairways, these elements of golf courses can function as corridors and increase the patch size if located adjacent to areas of high ecological value. For the development of successful multi-use strategies in our human-dominated landscapes, the ecological value of golf course habitats for nature conservation and the success of ecological upgrading will be assessed by recording components of their biodiversity across a set of golf courses across Germany.

SESSION 20:

Drivers of Biodiversity Change

Plant diversity dynamics over four decades of Arctic warming

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The Arctic is warming four times faster than the global average, and plant communities are responding through shifts in species abundance, composition and distribution. However, the direction and magnitude of pan-Arctic local plant diversity changes remain uncertain. Using a compilation of 42,234 records of 490 vascular plant species from 2,174 plots at 45 study areas across the Arctic, we quantified how species richness and composition have changed over time during up to four decades (1981 - 2022), and identified the key drivers behind these changes. Despite plant species richness being greater at lower latitudes and warmer plots, pan-Arctic species richness did not change directionally over time. However, 99% of the plots experienced changes in species abundance, with 66% of plots either gaining or losing species. Species richness increased where it had warmed most over time, and shrub expansion led to greater species losses and decreasing richness. Finally, Arctic plant communities did not become more similar to each other over time. Overall, Arctic plots changed in richness and composition in all possible directions, but climate and biotic interactions emerged as the main drivers of directional change. Our results show a variety of diversity trends, which could be precursors of future changes for Arctic plant biodiversity, altered ecosystem function, habitat for wildlife and livelihoods for Arctic peoples.

The relationship between environmental change and biotic homogenization of US bird

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Since the past century, the environment has experienced dramatic changes due to human activities. In the United States crops such as corn and wheat, and urban infrastructure have become dominant everywhere. This should cause a homogenisation of the environment as agricultural and urban intensification increases over time. Yet, the current environmental state can show a differentiation trend, e.g., crop patches introduced into natural forest areas. It is well known that environmental changes are tightly linked to biodiversity change. Human activities have led to widespread declines in biodiversity and biotic homogenisation, where assemblages of species across regions become similar. However, it is unknown how the current trend of environmental change affects biodiversity. Here, we investigate if changes in forest and agricultural coverage over time (1992-2018) cause the environmental heterogeneity to increase or decrease, and how the environmental trend relates to the biotic homogenisation of bird species across the United States. We expect that the environment is undergoing a differentiation phase, i.e., a larger number of land uses and coverage increases over time in a unit area and that the changes in the environment affect biotic diversity, where potentially specialised species are disappearing and generalist species are dominating, leading to more homogeneous bird assemblages in the US.

Biodiversity change, causal attribution, and time series length

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Detecting change in ecological systems is critical for our understanding of biodiversity and its responses to anthropogenic pressures. However, whether the detected signals of change are transient or characteristic of the system state depends on the time scale at which we measure. When shorter time intervals do not capture the long-term dynamics of a system, conclusions about the nature of the detected change and the drivers of it can be erroneous. This problem is especially relevant in ecology since most ecological datasets represent relatively short time series. Using simulations and data from the North American Breeding Bird Survey, we explore how time series length affects our ability to describe the long-term dynamics of both ecological communities and the exogenous pressures (e.g., climate change) on those communities. We then investigate how time series length impacts our perception of what drives biodiversity change. We found that the mean level of change was dependent on sample size, with larger samples exhibiting constant levels of change regardless of the time series length. Variance, however, declined with increasing time series length regardless of sample size. These results highlight the caution required when inferences about long-term change are based on short-duration time series.

Small and bright for the win: Rapidly increasing temperatures favor small and light-colored species in alpine butterfly communities

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Climate warming forces many species to shift their distributional ranges poleward or uphill in order to track their climatic niches, potentially favoring species with certain life history traits. However, few studies have addressed community-level responses of insects to climate change across elevational gradients. Here, in 2019, we repeated a butterfly monitoring from 2009 on 33 grassland sites along five transects in the National Park Berchtesgaden (Germany). We sampled adult butterflies from May until September and recorded the diversity and abundance of potential host plants. Further, we collected several life history traits of each observed butterfly species from literature. We quantified changes in the elevational distributions of butterflies over time, both at the species and community level and could link those rather to regional global warming than shifts in host plant communities, although we did not find consistent patterns for all species. Further, community changes over time seemed to go hand in hand with changes of certain life history traits, as body size, color lightness and dispersal ability showed clear trends over time. Those were especially pronounced in Nymphalidae, while other families responded less distinctly.

The vegetation of coastal ecosystems and its relation to coastal urbanization

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Coastal ecosystems are influenced by both anthropogenic and natural forces. They are strongly shaped by human settlements and, furthermore, natural forces such as hurricanes, despite being phenomena that are part of the dynamics of coastal zones, can have negative effects on coastal ecosystems when they have low or no integrity. A combination of these factors can alter the functioning of coastal ecosystems and, in the long run, their integrity can be diminished and compromised. We used the concept of integrity to refer to the conservation status of coastal ecosystems. We explored the link between urbanization and the integrity of beaches, dunes, and mangroves in the Gulf of Mexico. First, we explored the impact of human activities on beaches and coastal dunes by analyzing species spatio-temporal changes. Second, we analyzed the positive effects of ecosystem integrity on human settlements in terms of storm protection using Bayesian networks. Our results show that increasing urbanization along the coast is higher in localities closer to the tourist areas. Plant species richness decreased with urban expansion, whereas the proportion of functional plant types was altered. Species that were not tolerant to the beach-dune environment became more abundant in the more urbanized localities, while the abundance of psammophilous plants decreased. On the other hand, the constructed Bayesian networks indicated that the greatest risk was associated with (i) reduced (or absent) coverage of mangroves and coastal dunes, (ii) conservation status of coastal dunes, (iii) occurrence of shoreline erosion, and (iv) higher population density. These results demonstrate that anthropogenic disturbances, such as land use change and a growing population, lead to important changes in the coastal configuration. The use of Bayesian networks could be an effective tool for identifying the drivers of change and highlighting the importance of maintaining ecosystem integrity.

Vegetation community composition and strategies along environmental gradients in an anthropized estuary

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The tidal marshes in the nature reserve of the Seine Estuary in northern France have been shaped by long-lasting and extensive human activities. In this anthropized setting, we have studied the vegetation communities along gradients of disturbance (inundation and salinity), under different land use types (grazing and mowing) and tidal regimes (tidal restriction and tidal influence) in the – often overlooked – oligohaline marshes of the estuary. Our aim was to identify and hierarchise the instrumental factors behind the characteristic patch dynamics of the vegetation communities along these gradients, and to foresee possible trajectories of the communities in a context of climate change and rising seawater levels.

Canonical Correspondence Analysis between vegetation and soil surveys revealed that topography, soil pH, conductivity and organic carbon explained most of the differences between vegetation communities, followed by exchangeable cation availability. Community-weighted means applied to functional trait data from the TRY-database and our vegetation surveys have provided evidence for acquisition- and conservation-based strategies at the community level. This method also revealed the stress- and perturbation gradients of our study sites, through Grime's CSR strategies. The stress gradient was negatively correlated to topography and acquisition strategy, while disturbance and conservation gradients could mostly be explained by land use. We also found that the local hydrodynamic conditions of each site were responsible for significant shifts in community assemblages.

Finally, we measured significantly longer disturbance gradients on the tidally restricted sites, implying larger ecotones. Tidal restriction may therefore be an appealing decision-making tool for ecological conservation and agricultural practices.

Urbanization in rural areas – village edges are more biodiverse and often support more species, if situated far from cities in forested landscapes

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Both agricultural intensification and urbanization threaten biodiversity, while the first focuses on different agricultural land uses away from settlements, and the second one typically on cities with rural areas as reference. However, villages, often at the interface of these threatening processes, are understudied with largely unknown outcomes, whether they can act as a rural island or also impoverish biodiversity. Therefore, here we studied biodiversity of Hungarian and Romanian villages (N=72) in semi-natural forested vs. agricultural landscapes and with contrasting distances to mid-sized cities, thus in villages in the agglomeration often characterized by houses with ornamental gardens (city near) vs. villages characterized by houses with rather typical traditional rural gardening (city far). Additionally, we sampled village centres vs. village edges by surveying plants (1296 1×1m quadrates), arthropods with pitfall traps (1440 traps), D-vac (864 samples) and trap nests (224 traps), and birds (144 count points). We registered 496 plant species, 90 carabid and 221 spider species from pitfall traps and 83 bird species. D-vac samples and trap nests are under evaluation, with very high amount of arthropods. In the case of plants, we found an elevated species richness in forested vs. agricultural villages, especially at village edges. Both spiders and carabids were more species-rich and abundant in village edges compared to centres with strongly elevated carabid abundances in agricultural villages far away from cities. Finally, bird species richness was higher in forested villages and also in village edges, except for villages further from cities. However, bird abundance was higher in village centres than in edges with high abundances of synanthropic species, but it was also lower close to cities and in forested landscapes. In summary, we showed that villages are also affected by urbanization (edge and agglomeration effects) and agricultural intensification.

How do local floral resources and landscape heterogeneity affect flying insect communities in cities?

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Cities are expanding worldwide, and urbanisation is considered a global threat to biodiversity. Urban development results in an increase of impervious surfaces, habitat loss and fragmentation, introduction of non-native species, heat-island effects, and environmental contaminants with largely negative effects on wildlife. Insects are the most diverse group of animals and a vital component of terrestrial biodiversity, and of great conservation concern due to reports of drastic declines in their abundance and biomass. One of the main hypothesised drivers underlying insect declines is landscape alteration and degradation as a result of urbanisation. Here, we investigate how local floral resources and landscape heterogeneity within the urban ecosystem can affect flying insect species richness, abundance, and community composition. We have sampled over 300 locations using standardised yellow pan traps across the cities of Halle (Saale), Leipzig and Hamburg during the summer of 2022 and assessed flowering plant richness and abundance, by performing standardised vegetation surveys. Our data will allow us to explore how local environmental and landscape-scale factors play a role in shaping flying insect diversity across the cityscape. This information will help conservation management actions by providing insights on mitigating the adverse effects of urbanisation on flying insect communities.

Climate change-related winners and losers in biodiversity time series

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Human activities are known to cause rapid turnover in species composition over time, where some species increase abundance or occupancy over time, while others decrease. However, it is still unclear how human-driven threats contribute to variations in temporal trends across species. Climate warming is a major threat to biodiversity, and the response of a species in a given assemblage is expected to be influenced by its position within the species' thermal tolerance limit, which ranges from the cold to warm range margins, but this relationship has yet to be investigated. Here, we compiled 200 metacommunity time series of multiple taxa from terrestrial, freshwater and marine realms worldwide to examine how species in sites where temperature was closer to their cold versus warm range margins differed in how they changed their abundance and site occupancy over a decade or more years the metacommunities were monitored. We found that, on average, species closer to their cold range margins tended to increase occupancy, while species closer to their warm range margins tended to decrease in terrestrial and marine realms. In marine and freshwater realms, the relationship between changes in occupancy and abundance and thermal position depended on regional temperature changes. In regions experiencing stronger warming, increases in abundance and occupancy for species closer to their cold range margins and decreases for species closer to their warm range margins were more severe. Our findings provide strong evidence for climate warming-driven compositional reorganization, indicating a challenge to maintaining species composition as the world continues to warm in the future.

Climate rather than forest change drives 21st-century declines in forest understory diversity in a protected mountain landscape

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Protected areas are central to global biodiversity conservation, but changing climate and increasing disturbances threaten their future conservation potential. Mountains such as the European Alps, a plant diversity hotspot, are already warming rapidly. Projecting change is challenging for forest understory plants, which respond to forest microclimate conditions that may be decoupled from macroclimate change. Here, we used the process-based, forest landscape and disturbance model iLand in an 8,645 ha Northern Limestone Alps landscape (Berchtesgaden National Park, Germany) to ask: (1) How do understory plant communities respond to 21st-century changes in climate and forests? (2) How important is macroclimate versus forest change in driving understory responses? Stacked individual species distribution models fit with climate, forest, and site predictors (248 species, 150 widely distributed field plots, overall AUC = 0.86) were used with projected climate and modeled forest drivers to predict plant community change. Nearly all species persisted in the landscape in 2050, but on average 15% of the species pool was lost by the end of the century. By 2100, landscape mean species richness and understory cover declined (-14% and -8%, respectively), warm-adapted species increasingly dominated plant communities (i.e., thermophilization, +15%), and plot-level turnover was high (0.66). Higher elevations experienced the greatest richness declines, most thermophilization, and highest turnover, resulting in plant community homogenization across elevation zones. Both climate and forest drivers were important for projecting forest floor communities, with implications for ecosystem functioning and services. However, climate rather than forest change was the dominant driver of understory change. Even in protected areas, the magnitude of 21st-century change is likely to erode the ability of mountain forests to conserve biodiversity.

Pioneer plant communities on the forefront of receding Pichillancahue glacier, Araucanía Region, Chile.

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Climate change is affecting wide areas of the planet, with local and regional variation in warming and high temperature events. In Chile, climate change has so far generated an increase in temperatures of 1.1 ºC, along with a decrease in precipitation throughout the country, most markedly between the arid and Mediterranean climate zone (about 3000 km from north to south). Severe impacts are generated by heat waves, which have increased considerably in recent years. High mountain ecosystems, especially those associated with glaciers, are particularly vulnerable to such events and glacier retreat is now commonly observed along the Andean Mountain range. In order to fill gaps in the knowledge of the impact of glacier recession on vegetational communities, we are currently studying the advance of vegetation at the forefront of Pichillancahue glacier on the slopes of the Villarrica Volcano, Araucanía Region, Southern Chile. Using remote sensing we found that during the last 20 years, the glacier has lost an average of 150 ha in area, also, in the last periods some groups of vegetated patches were detected in the retreat glacier zone. Furthermore, with ground data was possible to find that the vegetational communities are increasing in size being mainly dominated by vascular plants. We found that grasses are pioneers in the deglaciated volcanic areas, with almost no presence of mosses or lichens. The results show that climate warming accelerates plant colonization of areas without permanent ice, with vascular plants being the most efficient colonizers.
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Understanding species loss impacts on ecosystem functioning: a synthesis on removal experiments

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Species loss effects on ecosystem functioning are studied with biodiversity experiments, which either create synthetic communities de novo or manipulate existing communities by removal. Here we leverage 38 plant removal experiments from 12 countries to ask whether species removals negatively affect productivity. So far, the results are contrasting and depend on the species removed and whether additional disturbances, such as drought and warming, are imposed on the communities. By analyzing the amount of species excluded from the experimental communities, i.e., using the proportion of species removed, our results unveil a consistently negative effect on productivity. On average, removing 50 % of the species means the productivity will decrease by half. Furthermore, other than species loss, additional anthropogenic drivers may change ecosystem functioning. Then, it is plausible to expect these disturbances to alter the magnitude or the direction of species loss effects on productivity. We found no direct effect between species removal and additional disturbances, but in particular, disturbances increase the variation in productivity. Our study demonstrates the power of removal experiments to improve our understanding of the impacts of species loss on ecosystem functioning. Nevertheless, we emphasize the need for more studies accounting for the direct removal effect and other disturbances.

Plant Functional Traits as Predictors of Species Vulnerability to Multiple Drivers of Environmental Change in the South African Cape Floristic Region

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A generalized understanding of species' vulnerabilities to environmental change is fundamental for successful conservation management that mitigates future biodiversity losses. Differentiated species-specific responses to multiple aspects of environmental change poses a challenge for such integrated risk assessments. In the field of plant ecology, functional traits are an established approach to generalize findings across species, which is of particular importance for highly species-rich ecosystems.

We investigate how plant functional traits determine species' vulnerabilities to multiple drivers of environmental change over the entire distribution ranges of 26 Proteaceae species in the South African Cape Floristic Region. The study builds on demographic analyses for the species-specific parameterization of population models that enable range-wide population viability analyses under different scenarios of multiple and interacting environmental changes (climate change scenarios, changing fire regimes, land transformation and wildflower harvesting). Variation in species' vulnerabilities to environmental change is then related to a set of plant functional traits (e.g. leave traits, seed traits and plant architecture) that determine demographic responses for example to fire regime, wildflower harvesting and extreme drought events.

The combined analysis of functional trait data and simulated population viability identifies sub-regions where Proteaceae are particularly threatened, both within and outside of present reserve networks, and provides a trait-based understanding of species' vulnerability to multiple drivers of environmental change. These results contribute to ongoing broader stakeholder initiatives on biodiversity risk assessments and conservation prioritization and can be integrated across the study species to assess general threats to functional and phylogenetic biodiversity in this plant biodiversity hotspot.

Climate, soil properties and grazing govern grassland plant diversity across spatial scales

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Temperate grasslands, renowned for their richness in plant species at small grain sizes, face substantial degradation due to land use. However, our understanding of the factors governing grassland plant diversity remains limited to studies focused on a single grain size. However, biodiversity changes and their drivers may strongly depend on the scale of the study plots, impeding the translation of local-scale experiment results to broader policy and management contexts.

We conducted a comprehensive analysis of vascular and non-vascular (bryophytes and lichens) plant communities using standardized sampling methods (https://edgg.org) across diverse grassland habitats in Ukraine at 382 subplots (grain size 10 m²) nested within 191 plots (100 m²). We assessed species richness and evenness at both the 10 m² (alpha diversity) and 100 m² (gamma diversity) scales. We also examined the relationship between these scales, referred to as beta proportional diversity (gamma/alpha). Climate, soil properties, and land use (grazing, mowing, and abandonment) were evaluated as potential drivers of plant diversity.

Our analysis revealed that climate variables exerted the strongest influence on plant diversity across spatial scales. Specifically, intermediate levels of mean annual precipitation and temperature associated with the highest levels of alpha and gamma diversity. Beta proportional diversity exhibited a weak positive response to climate, suggesting consistent climate impacts across the 10 m² and 100 m² grain sizes. Similarly, intermediate levels of soil properties (soil sand, silt, and organic carbon contents) were associated with the highest biodiversity and evenness, with consistent effects observed at both scales. Increasing grazing intensity negatively impacted species richness of non-vascular plants, while vascular plant diversity remained unaffected. These grazing effects persisted across the grain sizes. Prioritizing climate drivers in grassland policy and management across soil and land-use gradients is crucial, especially in the context of global change.

Testing the effects of grassland mowing regimes and landscape configuration on butterflies at large spatial scales

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Extensively managed grasslands are amongst the most biodiversity-rich ecosystems in Europe. While grassland management is essential to prevent afforestation, frequent and early mowing can have highly detrimental effects on farmland biodiversity. Especially insects like butterflies are affected due to increased mortality and a decrease in habitat quality. However, it remains largely unclear how different mowing regimes affect butterfly diversity and if the configuration of the landscape and species traits (i.e., habitat specialisation, mobility, and voltinism) modulate potential effects. Here, we tested the effects of grassland mowing regimes and landscape configuration on butterflies by linking high-resolution satellite data on mowing regimes to transect-level butterfly data from a national-scale monitoring scheme. Specifically, we analysed the relationship between the annual number and timing of mowing events on species richness, abundance and trait composition of butterfly communities between 2017 and 2021, while considering effects of edge density as a measure for landscape configuration. Our analysis showed that higher edge density had a positive effect on species richness and abundance, particularly for grassland specialists. Although the overall effects of mowing regimes were weak, inter-annual analyses revealed stronger effects, with grassland specialists showing a more positive response to delayed mowing events and fewer cuts. Preserving and fostering a higher density of field margins and hedgerows, thus, seems critical to preserve butterflies in intensively managed grasslands. Further, less intensive mowing regimes are important to increase habitat quality of grasslands and safeguard biodiversity, especially for grassland specialists. In conclusion, our research shows the potentials and limitations of remote sensing data in combination with a large-scale monitoring scheme for revealing the drivers of butterfly richness and abundance at large spatial scales.

Same driver different routes? Assessing the biodiversity footprint of agriculture under different metrics

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Agriculture is one of the biggest drivers of biodiversity loss, with almost half of all land surface already converted to agricultural land uses (LUs). Better understanding its impacts on biodiversity is thus essential to develop, implement and monitor more sustainable practices along the food supply chain. However, the multidimensionality of the biodiversity concept challenges the metrics to capture its complexity. The Brazilian Cerrado biome is simultaneously a biodiversity hotspot and the biggest agricultural producing region in Brazil, with almost half of it already converted to agriculture. We used three biodiversity indicators (Species Threat Abatement and Restoration - STAR metric, Species Habitat Index - SHI, and countryside Species Area Relationship - cSAR) to estimate the biodiversity footprint of agriculture in Cerrado and assess their comparability and complementarities. The STAR metric is based on scope and severity of threats to species and quantifies the potential contributions that the abatement of these threats and restoration activities could make to reduce species' extinction risks. The SHI is based on changes on area size and connectivity of species' area of habitat and quantifies the integrity of an ecosystem, or trends in populations. The cSAR metric is based on species numbers and affinities to LUs and quantifies the disappearing species in a landscape due to LU transformation. All indicators capture biodiversity loss associated with agriculture, and pasture has consistently the biggest share. In cSAR, geographical patterns of species loss are analogous across taxonomic groups, but differ across agricultural LUs. In SHI, geographical patterns of habitat integrity loss differ across taxonomic groups and agricultural LUs. In STAR metric, geographical patterns for species threat abatement differ slightly across taxonomic groups and LUs, and also from those patterns in SHI and cSAR. These preliminary results reinforce that different biodiversity footprint metrics can lead to different interpretations of how agriculture affects species

Fire disturbance drives Eurasian steppe bird abundance and richness following post-Soviet changes in fire and grazing regimes

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Grassland ecosystems have evolved with the interactions between fire disturbance and grazing land-use. Avian biodiversity in grasslands is shaped by these regimes. The Eurasian steppe biome contains 10% of the remaining global grasslands, especially in Kazakhstan. The collapse of the Soviet Union in 1991 brought a massive land-use land cover change in Kazakhstan, namely land abandonment, declines in livestock grazing and an increase in steppe biomass. Consequently, a higher fuel availability prompted an unprecedented increase in fire disturbance, making the Kazakh steppe a global fire hotspot. Responses of avian biodiversity to these land-use changes are poorly understood. We harnessed a unique bird abundance dataset covering the entire Kazakh steppe and semi-desert and modelled the response of bird species richness and abundance as a function of fire legacy effects – fire extent, cumulative fire area and fire frequency over eight years, and variation in grazing intensity. Our results reveal significant negative associations between all fire legacy variables and bird richness and overall abundance, but their impact varies with land-cover and grazing intensity. A further species-specific analysis on 22 species reveal more loser species than winners from increased fire disturbance. We conclude that the increase in fire disturbance across the entire Eurasian steppe biome has led to strong bird declines, and changes in abundance patterns and community assembly. Climate change is likely to further increase fire activity. Therefore, to gain back control over wildfires and prevent biodiversity loss, a restoration of the traditional free-ranging grazing systems that evolved long ago on the steppes and were maintained until the collapse of the Soviet Union, seems much needed.

Disturbance as a driver of multi-scale biodiversity change: a metacommunity approach

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Understanding the dynamics of biodiversity change requires a multi-scale approach to both quantify patterns and elucidate potential mechanisms driving change. Various global analyses suggest context dependence in the magnitude and direction of biodiversity change at local scales, sometimes with conflicting patterns observed at different scales. It has been proposed that explicit consideration of multiple scales can help shed light on the drivers of change and make sense of conflicting observations. Pulse disturbances in ecosystems such as fires, droughts, and hurricanes are known to alter the composition of ecological communities and are often suggested to be a potential driver of biodiversity change. Understanding how these types of disturbances reshape communities is an important component of our understanding of biodiversity change globally, especially since they have the potential to be anthropogenically forced. Here we take a metacommunity approach to understand the interaction between community and disturbance dynamics in shaping biodiversity patterns at multiple spatial scales.

Using a discrete time spatially explicit metacommunity model we explore how the size of disturbance interacts with the internal parameters of the metacommunity to structure patterns in biodiversity change. We find that the size of disturbance can have non-linear effects on biodiversity at local and regional scales, leading to both homogenization and differentiation depending on the scale of the disturbance in the landscape. We also find that dispersal and niche breadth of the metacommunity interact to influence changes in local and regional occupancy patterns, shaping the metacommunities sensitivity to disturbance in predictable ways. Our results suggest that particular archetypes of disturbance and metacommunity structure leave behind distinct signatures of biodiversity change across scale that can be used to better parse observations in empirical systems.

Artificial light at night (ALAN) causes shifts in soil communities and functions

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Artificial light at night (ALAN) is increasing worldwide. To date, most ALAN studies focus on the responses of organisms and functions that are directly exposed to artificial light sources. Accordingly, responses of soil organisms have been excluded, despite their high biodiversity and importance for ecosystem functions such as nutrient cycling, carbon sequestration, and decomposition. We tested the influence of experimental manipulation of ALAN on two taxa of soil communities (microorganisms and soil nematodes) and three aspects of soil functioning (soil basal respiration, soil microbial biomass, and carbon use efficiency) over three months in a highly-controlled Ecotron facility. We show that during peak plant biomass, increasing ALAN reduced plant biomass and was also associated with decreased soil water content. Despite reduced soil respiration under high ALAN at peak plant biomass, microbial communities maintained stable biomass across different levels of ALAN and times, demonstrating higher microbial carbon use efficiency under high ALAN. While ALAN did not affect microbial community structure, the abundance of plant-feeding nematodes increased, and there was homogenization of nematode communities under higher levels of ALAN, indicating that soil communities may be more vulnerable to additional disturbances at high ALAN. In summary, the effects of ALAN reach into the soil system by altering soil communities and ecosystem functions, and these effects are mediated by changes in plant productivity and soil water content at peak plant biomass.

The impact of dams on the global distributions of riverine fish species

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Although dams provide multiple societal benefits, such as renewable energy, water security and flood protection, they also fragment the habitat of freshwater species. This may result in local extinction if a remaining fragment is too small to support a viable population. Here, we assessed for the first time how the isolation effects of fragmentation by dams may affect the distributions of riverine freshwater fish species globally. We developed a novel macro-ecological relationship between geographic range size and body size for riverine freshwater fish, to estimate species-specific minimum area requirements. Using this, we assessed whether isolated range fragments are too small to support a species, considering the effect of ~32,000 existing dams obtained from global dam databases. Furthermore, we used complementary datasets to study the additional impact of small dams in specific regions. We found that on average across species, dams affect only a small part of the range (0.1%). However, for some fish species in Brazil or Southern Asia, the impact of isolation by dams is substantial (range loss up to 100%). In Brazil, the greater Mekong region and the United States, the inclusion of small dams in addition to large dams showed a considerable additional potentially lost range (impacts increased by a factor of 3 to 6). Our approach can be used to assess species and regions at risk, which can aid strategic planning of new dams or restoration efforts such as dam removal.

Development of a spatially explicit global Human Pressure Index to map anthropogenic pressure on biodiversity from 1990-2020

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The loss of biodiversity due to human activities that cause habitat change and fragmentation is a widely-recognized, worldwide problem. Since the advent of the industrial revolution the loss of plant and animal species has increased dramatically, with 25% of species now at risk of extinction. Conventions and targets to protect biodiversity have been implemented, but with limited success. The Aichi targets for 2020, for example, were almost all missed, with worsening trends for 12 out of the 20 targets. One reason for this failure is the ineffective application of broad-scale measures that are not tailored to the underlying causes of biodiversity loss. Knowledge on the spatial and temporal distribution of anthropogenic drivers of biodiversity loss would therefore enable targeted interventions that address location-specific stressors and thus would be better-adapted measures to protect biodiversity.

The IPBES has identified five major human-induced drivers of biodiversity change: land use change, resource extraction, environmental pollution, alien invasive species and climate change. However, data on these drivers are still usually treated separately. We develop a Human Pressure Index (HPI) by quantifying and mapping eight sub-pressures (of the five measures mentioned above) into a single annual index with a spatial resolution of 10 km at global scale covering the period 1990-2020. This allows us to track changes, hot spots and clusters of drivers of biodiversity loss. I will present the first results from this index, focusing on spatial and temporal trends in anthropogenic pressures on biodiversity worldwide.

Biodiversity change under adaptive community dynamics

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There have been few topics more controversial in ecology over the past decade than the nature of recent biodiversity change. While there is some disagreement regarding precisely how biodiversity is changing, few would debate that contemporary communities are undergoing rapid rates of change in species composition. Ecologists' attitudes towards compositional change, however, are quite variable. Some appear to see human-induced species turnover as a universally negative phenomenon, and explicitly advocate for the preservation of historical baseline states. Others often view compositional change more favourably, as a necessary ecological response to environmental change. In this talk, I will introduce adaptive community dynamics as an emerging framework with which to study and understand community compositional change. The adaptive dynamics framework posits that adaptive change in the composition of ecological communities is closely analogous to adaptive evolutionary change in biological populations – i.e., selection-induced compositional change that improves the 'fit' between organisms' traits and the environment, thus increasing or maintaining average fitness. I will argue that mechanisms of 'adaptive change', in this narrow sense, likely underlie much of the compositional turnover induced by contemporary anthropogenic drivers. I will also explore potential implications for ecosystem function and management in dynamic Anthropocene environments. Adaptive community dynamics may lead to desirable or undesirable outcomes for particular stakeholders, or with respect to specific human goals. However, viewing biodiversity change through the lens of adaptive dynamics can help inform efforts to facilitate, accept or resist biodiversity change given pre-specified goals, by drawing a clear delineation between drivers of environmental change (e.g., human-induced land-use change) and adaptive ecological responses (i.e., biodiversity change under resulting selection).

The impact of land use on non-native species incidence and number in local assemblages worldwide

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While the regional distribution of non-native species is increasingly well documented for some taxa, global analyses of non-native species in local assemblages are still missing. Here, we use a worldwide collection of assemblages from five taxa - ants, birds, mammals, spiders and vascular plants - to assess whether the incidence, frequency and proportions of naturalized non-native species depend on type and intensity of land use. In plants, assemblages of primary vegetation are least invaded. In the other taxa, primary vegetation is among the least invaded land-use types, but one or several other types have equally low levels of occurrence, frequency and proportions of non-native species. High land use intensity is associated with higher non-native incidence and frequency in primary vegetation, while intensity effects are inconsistent for other land-use types. These findings highlight the potential dual role of unused primary vegetation in preserving native biodiversity and in conferring resistance against biological invasions.

Invasive earthworms change understory plant community traits and reduce plant functional diversity

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The mechanisms behind the loss of species diversity in response to biological invasions into native ecosystems and the consequences associated for ecosystem processes can be diverse. When establishing in native ecosystems, invasive species can take over the role of a new abiotic and/or biotic filter acting on native communities. They directly affect native species via competitive or feeding interactions, but their effects can also be indirect, i.e. mediated by their effects on other organisms or the environmental conditions.

Here, we investigated understory plant community changes in forests as affected by invasive earthworms, by studying the α-diversity and functional diversity responses of the plant community.

Our results showed that although the α-diversity of the plant community did not change due to the presence of invasive earthworms, it modified the dominance structure of different plant functional groups. Invasive earthworms act as an environmental filter on the plant community by promoting fast-growing plants at the expense of slow-growing ones: the cover of fast-growing grasses increased, while the cover and species richness of slow-growing woody plants decreased in the presence of invasive earthworms. Moreover, earthworms altered the plant community-weighted mean traits and decreased the plant functional diversity. Our study showed a decrease in trait diversity and a plant community trait convergence with plant species being more functionally similar after the invasion. These changes coincided with alterations of abiotic and biotic soil conditions. Our study provides insights into the mechanisms behind the loss of plant functional diversity in response to earthworm invasion.

Bug-Net: A global research collaboration testing the direct and indirect effects of climate on plant-consumer interactions

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A lot of theory predicts that plant-pathogen and plant-herbivore consumer impact varies across environmental gradients such as climatic gradients (latitude, altitude) and plant productivity gradients. Plant-consumer relationships also vary with abiotic and biotic drivers operating at smaller spatial scales, such as plant biodiversity and soil fertility (bottom-up) and predator abundance (top-down). Our understanding of how consumer communities and their impact varies across environmental gradients is surprisingly limited. Existing studies differ substantially in methodology, making generalities across large scales difficult. Through a new global collaborative research network, we aim to bridge this gap in the ecological, global change literature. Our team of >100 scientists collected plant-consumer data, and other ecosystem metrics (such as functional traits, productivity, and soil nutrient levels) from 25 countries across Europe, North America, Latin America, Oceania and Asia. This data has allowed us to determine whether the direct effects of climate are driving patterns in plant-consumer impact or whether the indirect effects of climate on plant communities and plant functioning that then impact plant-consumer impact have a stronger effect on these relationships. We are then aiming to use these global-scale patterns to make predictive forecasts about how plant-consumer relationships will be altered under future climate change scenarios and how these will affect biodiversity in the future.

Changes in moth communities along land-use intensity gradients in forests and grasslands

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The abundance and diversity of natural populations are under threat primarily driven by land-use change and intensification. While forest management in Central Europe is transitioning towards more sustainable practices, the legacy of past intensive management still impacts forest communities. Additionally, the abandonment of seminatural grasslands in marginal areas, coupled with intensified land use in high-production grasslands, poses an increasing threat to biodiversity and ecosystem functions. Land-use intensification has been shown to have substantial effects on plant and insect communities, especially herbivores, which play a vital role in energy and nutrient cycling within ecosystems, yet the comprehensive understanding of herbivore-plant responses in the context of changing land-use intensity remains limited. We investigated the influence of forest and grassland management on the abundance and diversity of nocturnal butterflies by surveying a total of 150 forest and 150 grassland sites with different management in three regions of Germany. In total we captured 456 moth species (forest = 394 spp, grassland = 344), and forest sites harbored on average more individuals (+79%), more species (+ 58%) and had higher diversity (+16%) than the grassland sites. Regarding management intensity in forest, a higher level of management, specifically a higher level of timber harvested, was found to positively influence the number of moth species but not their abundance. In contrast, in grasslands, an increased frequency of mowing led to a reduction in both the number of moth individuals and species, while fertilization and grazing did not show significant effects. Our results indicate that human management can induce shifts in species richness and their abundance differentially in various ecosystem, with targeted management necessary to mitigate potential negative effects.

How does warming alter the effect of a vertebrate top predator on above- and belowground communities in a long term experiment ?

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Climate change causes context-dependent responses in terrestrial ecosystems that may be prominently driven by biotic interactions. For instance, warming can alter the strength and direction of trophic cascades in simplified food webs, but only a few studies have investigated climate-induced trophic cascades on above- and below-ground communities. Here, we explore how warming alters the effect of a vertebrate top predator, the common lizard, on above-below-ground linkages.

Using a seven-year-long warming experiment in outdoor, semi-natural, mesocosms, we investigate the response of multi-trophic communities encompassing plants, aboveground arthropods, soil invertebrates and microbes (metabarcoding), over time. Our design enables to test the separate and interactive effects of lizards' presence/absence and of +2/3°C warming compared to present temperatures (IPCC projections for 21st-century).

We found that top predators had large effects on multi-trophic diversity, reaching up to soil microbial communities. The effect of lizards could even override those of long-term warming. Our results further revealed interactions between warming and lizards. Lizards tended to buffer or even revert warming effects for particular taxonomic and functional groups. Those effects corresponded to shifts in community composition of aboveground arthropods and subsequent trophic levels, suggesting cascading effects resulting from changes in top predators' diet in response to warming.

Our findings demonstrate how trophic cascades can unravel the context-dependent responses of above and below-ground communities to warming. A more holistic view of terrestrial communities will thus be crucial to improve future forecasts of the ecological consequences of climate change.

Insect distance-decay relationships behave differently depending on land use type

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Distance-decay relationships are widely studied in ecology and now there is a growing interest in understanding the drivers of biological heterogeneity via distance-decay curves. Land use is a strong driving force of insect assemblages, which shapes communities in various ways, depending on land use types and intensities. We used an empirical dataset including insect taxa from the LandKlif project, which compares forest, urban, agricultural and meadow land use types in order to test if the distance-decay patterns vary within these, using geographical distance (km) and community similarity.

Urban and agricultural land use types are expected to homogenise insect assemblages, producing similar communities over spatial distances, given the relatively uniform resources and vegetation structure produced by these intensely modified land use types. Forests and meadows however offer more diverse habitats and resources, therefore we predicted a steep distance-decay curve within these land use types, meaning that community differences increase rapidly with increasing distance within forests and meadows. We modelled the distance-decay curves according to species body size and mobility, and calculated different community metrics taking species rarity into consideration. We predicted rare species' communities to change the most over spatial distance, but dominant species' communities responded more strongly to spatial distance, becoming more different over distance; especially in urban, and agricultural land use types. On the other hand, communities on meadows seem to be quite stable, independent of spatial distance.

Covering the most common land use types with an empirical dataset from Germany, we provided some insight on how different land uses shape insect assemblages. Interestingly, one type of human modified landscape (meadow) made insect communities more homogenous, but another one (urban) created more distinct communities on a spatial scale. However, the drivers of this pattern need further attention, it is exciting to show, that human activities can achieve very different insect responses on a community-scale.

The effects of urban landscape heterogeneity on cavity-nesting Hymenoptera

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Cities have expanded rapidly in the last century, and it is also forecast that they will continue their rapid global expansion. Urban development is associated with adverse effects on ecosystems, such as increased pollution, impervious surfaces, habitat fragmentation, degradation, and loss. Ultimately, urbanisation leads to the creation of novel ecosystems that exhibit novel abiotic and biotic characteristics and pose a challenge to many organisms, including insects. Hymenoptera is a large order of insects comprising the wasps, ants, sawflies, and bees and provide key ecosystem services, such as pollination and pest control. While there are many ecological studies working with social bees, well-replicated studies on cavity-nesting Hymenoptera are lacking. Here, we have investigated how urbanisation affects fitness, mortality, sex ratio, parasitism, and biodiversity of cavity-nesting Hymenoptera. To do so, in spring 2022, we have launched a citizen science project, in which participants from Hamburg and Leipzig were given an insect hotel. Insect hotels (aka traps nests) were placed in gardens and balconies from March to December of 2022. In total we have collected over 250 bee hotels and assessed landscape composition and configuration using land cover maps. Our data will enable us to determine what are the main urban landscape factors that influence cavity-nesting Hymenoptera and can help guide conservation management to reduce the adverse consequences of urbanisation on cavity nesting bees and wasps.

Competition between a northern and a southern species varies with climate

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As the climate is changing, species respond by changing distributions and abundances. The effects of climate are not only direct, but also occur via changes in the outcome of competitive interactions among species. Yet, the relative importance of competition in mediating the effects of climate is still largely unknown, and often overlooked in studies examining species responses to climate. To examine how competition varied with climate, we transplanted two moss species differing in their climate niches, alone and together at 59 sites along a climate gradient in Sweden. Population samples were taken from southern and northern parts of each species Swedish range. Growth was monitored over three growing seasons from 2019-2021. When growing alone, both species performed better under warm conditions. When transplanted together, the northern species instead performed better under cold conditions, whereas the southern species performed worse. Over three growing seasons, the southern species almost outcompeted the northern in warm climates. Effects of climate on performance and competition also differed between populations of the two species. Our results illustrate how competitive interactions can modify the direct effects of a changing climate on organism performance. Findings such as these, suggest that species interactions can have important effects on how environmental and climate change influence performance and abundance across species ranges.

Fitness and niche differences are both important in explaining responses of plant diversity to nutrient addition

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Plant species loss due to eutrophication is a common phenomenon in temperate perennial grasslands. It occurs in a non-random fashion and is usually explained by increased competitive size asymmetry between co-occurring winner (tall species with optima in productive habitats) and loser species (small plants from typical for unproductive habitats). It remains unclear why nutrient addition decreases diversity in communities consisting of losers only, whereas it has little effect on winner-only communities. Here, I used the framework of modern coexistence theory to explore fertilization-driven changes in fitness and niche differences between different combinations of field-identified winner (W) and loser (L) species. For this, I experimentally estimated competition parameters for plant species pairs constructed from a pool of eight species, including pairs of species from the same (WW, LL) and different species categories (LW) grown in control and fertilized conditions. I found that nutrient addition can reduce but also promote species coexistence depending on the type of species pairs. Whereas nutrient addition made coexistence of losers with winners, but also with other losers less likely, treatment had the opposite effect on the persistence of winner species. It was because fertilization induced large fitness differences between species in loser-winner and loser-loser combinations, but it changed little the fitness differences of species within the winner-winner combination. In addition, the persistence of winner pairs was promoted by larger niche differences compared to loser species, irrespective of soil nutrients. These results suggest that the effect of eutrophication on plant richness cannot simply be explained by an increased competitive asymmetry. To fully understand the effect of fertilization on the diversity of temperate grasslands, interspecific and intraspecific interactions should be explored while considering differences in species' ecological optima.

Tracking climate in mountain forests: disentangling effects of macro- versus microclimatic range shifts

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Mountain species can track 21st century warming with upslope range shifts; however, observed shifts often lag behind expectations under current warming trends. One explanation may be microclimatic heterogeneity within elevational belts: Migration to cooler microclimatic conditions under closed forest canopies may be an alternative climate tracking mechanism related with short dispersal distances, modulating elevation range shifts.

We here studied species distributions (13 functional-taxonomic groups including fungi, plants, and animals) along an elevation gradient (650-1150 m a.s.l.) in a temperate low mountain range in 2006-08 and 2016. We analysed changes in elevation and canopy cover niche optima and widths, asking whether canopy cover shifts and initial niche preferences explain variation in elevation shifts.

Only a small portion of species shifted their niche significantly, suggesting most species were either robust to climatic changes within the scope of the study or limited in their dispersal. In total, we found more downslope (5.4%) than upslope shifts (4.0%) and more shifts to higher (8.4%) than to lower canopy cover (2.2%). Baseline elevation niche optimum was the strongest predictor of elevation shifts with a negative effect across all taxa – i.e., low-elevation species shifted upslope more strongly than those preferring higher elevations. Canopy cover shifts correlated negatively with elevation shifts in vascular plants, moths, Hemiptera, and pollinators, supporting our hypothesis that shifts to cooler microclimates can somewhat compensate for elevation shifts.

Our study highlights the conservation value of heterogeneous landscapes featuring microclimatic refugia. Understanding alternative climate tracking mechanisms and accounting for each species' starting point can improve predictions about future species ranges. We suggest incorporating multiple niche dimensions in species distribution studies drawing on long-term time series to rule out year effects.

How do insect communities and ecosystem processes respond to habitat loss and fragmentation in Chaco forests? Summarizing 20 years of studies in Central Argentina

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Habitat loss and fragmentation are landscape transformations with profound impacts on biodiversity. Insects are particularly affected by these processes, with consequences for ecosystem services. In the Neotropics, the Chaco forest is one of the largest phytogeographic regions and has suffered critical deforestation rates in recent decades. For 20 years, we have studied the impact of these modifications on insect communities in Córdoba, Argentina, and the interaction between forests and adjacent crops. Here, we review 25 empirical studies of the influence of fragment area, forest cover, and edge habitats on different insect functional groups, ecological processes, and ecological networks in fragmented Chaco forests in central Argentina. Small fragments and landscapes with low proportions of forest cover were generally linked to impoverished insect communities across most functional groups. Fragment area reductions negatively affected above-ground processes such as herbivory and parasitoidism, whereas leaf litter decomposition and most network parameters were not affected. Edge effects were variable, favoring some insect groups (i.e., ground-dwelling arthropods and parasitoids) and parasitoidism rates. Moreover, intense insect movement between forests and crops increased ecosystem service provision near the forest. Our results indicate that fragmentation of Chaco forests has clear implications for insect communities and ecosystem services. Maintaining forest remnants and promoting native forest plantations should be prioritized to guarantee insect biodiversity conservation.

Differential effect of grassland mowing on arthropods abundance

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Arthropod decline, particularly insects, is an issue of global importance linked to several factors, including habitat loss and fragmentation, climate change, pesticide use, and intensification of land use practices, such as mowing. Although mowing is known to have a significant impact on arthropod diversity, studies have produced conflicting results due to various factors, including study design, landscape structure, taxonomic level, and landscape management. A comprehensive evaluation of the impact of mowing on arthropod diversity, trying to tease apart the influence of these factors, is required to gain a better understanding of its effects. We conducted a study in three distinct grassland habitats: intensively and extensively used agricultural meadows and urban lawns to test three hypotheses: H1) Mowing reduces the abundance of insects across taxa, but the strength of the effect differs among taxa; H2) The differential effects of mowing on insects become more visible at higher taxonomic resolution; and H3) Taxa living in higher vegetation layers are more negatively affected by mowing than taxa living near ground. Our results revealed that mowing has a significant negative impact on arthropod abundance, reducing on average 69% the total number of individuals. Regarding our hypotheses, for some taxa, mowing had no effect at lower resolutions (e.g. Hymenoptera) but had a significant impact at higher resolutions (e.g. reduced abundance in Heteroptera by 98%). Some differences in the impact of mowing could be attributed to taxa-specific behavior, such as their position in vegetation, response to soil temperature changes, reactions to disturbances, and larval habitats. These results suggest that future studies investigating the effect of mowing on certain arthropod groups should consider using a group-specific design, and that measures to reduce the negative effects of mowing should be adjusted to the specific target group.

Long-term nitrogen deposition alters deadwood decomposition, but not community composition

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Atmospheric nitrogen (N) deposition due to anthropogenic activities is a global phenomenon and driver of ecosystem change. Especially systems that are naturally sparse in N, such as boreal and temperate forests, are likely to be impacted by long-term elevated N deposition. Deadwood is a central component of forest carbon (C) cycling and intensely N limited as a substrate for wood-decaying fungi and bacteria. We hypothesized that changes in nutrient availability would be likely to alter fungal and bacterial decomposition activity and/or community composition.
In a field experiment, we exposed deadwood of thirteen temperate tree species to 40 kg N ha^{-1} $year^{-1}$ simulated N deposition over a period of nine years and measured physiological responses (e.g. mass loss, respiration rates, enzymatic activities) accompanied by 16S and ITS metabarcoding to characterize fungal and bacterial communities.
Our findings indicate a (marginally) significant increase in mass loss ($p = 0.04$) and respiration rates ($p = 0.08$) in coniferous deadwood, accompanied by higher laccase activities ($p = 0.02$).
We did not observe significant changes in fungal community composition in either coniferous or broadleaved deadwood, but recorded a marginally significant shift in bacterial community composition ($p = 0.08$) in coniferous deadwood.
We conclude that fungal and bacterial responses to long-term high atmospheric N deposition are rather physiological than driven by community changes, as implied by increases in respiration rate and laccase activity and resulting higher mass loss.

Land use effects on freshwater biodiversity

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Freshwater ecosystems have been heavily impacted by land-use changes, but syntheses on land-use impacts on freshwater ecosystems are still limited. The effects of land-use change on freshwater biodiversity, including multiple biodiversity metrics and assemblages, change across multiple scales, is not well understood. Therefore, it is timely to carry out a synthesis to figure out the effects of land-use on freshwater biodiversity. To accomplish this, we constructed a comprehensive database (all freshwater ecosystems and taxa) by meticulously searching open access literature and contacting authors. The database includes 250 datasets and 5000 sites, incorporating abundance data in land use intensity. This study aims to conduct a synthesized analysis of biodiversity and assemblage composition by comparing less impacted sites with more impacted sites, utilizing multiple metrics.

Effects of fragmentation on plant dispersal and persistence traits in Pannonian forest steppe fragments

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Land use change is one of the primary drivers of biodiversity loss worldwide, causing extensive habitat loss, fragmentation, and degradation. In our study, we dealt with the effects of two important fragmentation factors (landscape-scale habitat connectivity and local-scale grassland fragment size), and their joint impacts on the vegetation composition of two fragmented grassland types, i.e. loess steppes on kurgans (ancient burial mounds) and open sand steppes in the Pannonian forest steppe zone. We assessed three plant species groups (specialists, generalists, and exotics) and their trait composition related to local persistence (life span, clonal propagation and soil seed bank type) and propagule dispersal potential (dispersal strategy and seed mass). Based on our results, both fragment size and landscape-scale connectivity were important in shaping the trait composition of the vegetation. We observed more fragmentation effects in generalist than in specialist species. We found that isolation resulted in fewer specialist species with autochorous dispersal strategy in loess steppe fragments, but, at the same time, also fewer exotics. Isolated loess steppe fragments harboured fewer generalist species with persistent seed bank. Large loess steppe fragments supported more wind-dispersed species than smaller ones. In isolated sand steppe fragments, generalists were more frequent with endozoochorous dispersal strategy and without clonal propagation. Life span, clonal propagation and seed mass did not depend on the level of fragmentation in the two grassland types. Our results imply that both sand and loess steppe fragments can rely to some extent on the persistence of clonal perennial specialist and generalist species in small and isolated patches to mitigate fragmentation effects. In conclusion, these processes should be supported by the preservation of large fragments, increase of habitat connectivity combined with targeted management of exotic species.

Urbanization impacts top predators in multi-trophic interactions involving pollinators and weakens the direction of regulation

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Urbanization as a major driver of global change modifies biodiversity patterns and the abundance and interactions among species or functional species groups. Within urban food webs urbanization might negatively affect predators, which can have cascading effects on other species and trophic levels within the ecosystem. However, empirical studies on how urbanization modifies multi-species and multi-trophic interactions are limited in number. Here, we used a predator-prey-mutualistic relationship involving insect-pollinated vascular plants, pollinators (bees, hoverflies), predatory spiders and sand lizards as top predators and tested i) the effect of urbanization on abundance and species richness at different trophic levels and ii) the effect of urbanization on the regulation of biotic interactions. We found that sand lizards, predatory spiders and pollinators were less abundant in high compared to low urbanized areas while plant cover was not significantly impacted by urbanization. In contrast, species richness of predatory spiders was negatively impacted by urbanization but not so species richness of pollinators and plants. Mutualistic interactions between plants and pollinators remained relatively stable regardless of the level of urbanization. Further, we found that the regulation of biotic interactions was bottom-up controlled in both high and low urbanized areas; however, stronger in low compared to high urbanized areas. These insights contribute to our understanding of multi-trophic interactions in urban areas and associated ecosystem services such as pollination and can support urban biodiversity conservation.

SESSION 21:

Pollinator Responses to Global Change

Effect of conservation measures on wild bee populations - 5 years of monitoring in the BienABest project

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Wild bees are declining due to the loss of habitats, floral resources and other anthropogenic influences. Wide ecological and economical interest evolved to preserve wild bees and their pollination service. To promote wild bees, floral strips and artificial nesting hills were established within the BienABest project (www.bienabest.de) at 20 locations across Germany. The development of the wild bee populations in the study plots and nesting hills was examined by a systematic monitoring for five years. We recorded approximately 25,000 bee-flower interactions per year involving 60 % of the bee species of Germany. Our results show that the established procedures attracted ca. 75 % of the bee species of semi-natural habitats in the close surrounding. The diversity and abundance of well-selected plant species and management strategies for floral strips lead to an increase of visiting bee species, particularly rare and threatened ones. Concerning the nesting hills established we found that their conditions are also critical to promote diverse bee species, for example the sun exposure highly influenced the number of nesting bee species and individuals. These results show that high quality conservation measures can promote wild bee populations. We also found that intensively managed grasslands in the surrounding of the study plots had an overall negative effect on the wild bee occurrence. Other landscape variables produced diverging response patterns that were particularly pronounced during early and late season. Beside local and landscape parameters, the bee populations were also influenced by extreme weather events within the 5-year project duration, such as heavy rainfalls that negatively influenced the number of occurring bees. Further population dynamics of the bee community and of distinct groups such as oligolectic and cuckoo bees and their responses to climatic conditions, plant availability and land use factors are currently analysed.

Driven by pollinators? Semi-natural grassland plant reproduction varies along land-use mediated and experimental gradients of pollinator availability

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Reports of pollinator declines are fueling concerns about negative consequences for plant reproduction, not only in agricultural crops but also in semi-natural plant communities. The extent to which variation in pollinator availability matters for wild plant reproduction is poorly understood. Here, we use a combination of observational and experimental gradients in pollinator availability at the plant community level to assess flower visitation and seed production. We set up research plots in 18 semi-natural grasslands in Sweden, situated along a gradient of proportion of arable crops in the landscape (1km radius), with a systematically varying composition in share of forest, permanent (semi-natural) grasslands and leys. In each site we compared two subplots, an open subplot and a subplot where pollinator access is experimentally manipulated with a semi-open tent covered with a fishnet. Results show significant variability in flower-visitation across the landscape gradient, and effect sizes in the experimental manipulation (~40% decrease in bumblebee visitation and a slight increase in solitary bee visitation) that are useful to obtain realistic experimental contrasts within the grassland. Responses in seed production among wild leguminous plants (visited by bumblebees, amongst others) and Asteraceae matched the plant-level availability of the pollinators. Our results show that the effects of landscape context on plant reproduction, as mediated by pollinator availability, will differ based on the identity of the pollinators. They also suggest that spill-over from surrounding land-use, and concentration/dilution effects, may lead to counter-intuitive effects not only on pollinator communities, but also on reproduction of plant communities in semi-natural grassland fragments.

Effect of surrounding land-use on seed set moderated by pollinator dependence in three grassland plant species

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Reproductive output is a key factor determining the survival of wild plant species, and is affected by pollinator visitation frequency occurring in the respective habitat. These frequencies can be influenced by surrounding land-use types, leading to potential cascading effects of land-use on plant reproductive success. However, while these relationships have been explored for single species in specific contexts, we have limited understanding of the more general mechanisms underpinning the pollinator-plant-landscape relationship. We expect that these relationships can be modulated by factors such as pollinator dependence of the respective plant or preference of pollinator groups for certain land-use types. Here, we show that for three sample grassland plant species of varying pollinator dependence, composition of the surrounding land-use is indeed affecting seed set in the species that are dependent on insect pollinators to some degree. In one case, we found a consistent effect of the land-use type on the dominant pollinator of the plant, while in other cases, the relationship was less straightforward. Our results show that surrounding land-use can affect seed set in grassland plants by cascade effects via modulating pollinator abundance, and reinforce the notion that those mechanisms are species-dependent. Our modelling approach can be applied to a wider range of species to contribute to a more universal understanding of environmental factors contributing to plant reproductive success. In a world where insect pollinator declines are a reality, an understanding of their effects on the persistence of wild plant species, especially in grasslands which host a high species diversity, can contribute to deciding on appropriate conservation strategies.

Context dependent response of plant-pollintor networks to intensive grazing: why functional traits matter.

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Land use change towards intensive grazing has been shown to alter plant and pollinator communities and their interactions in different ways. In Eastern Europe, management of highly-diverse semi-natural grasslands is shifting towards more intensive grazing, but few studies have examined how this influences plant-pollinator networks. We hypothesized that the effects of grazing on networks will depend on how plant communities and their floral traits change. We assessed plant and pollinator diversity and composition and the structure of plant-pollinator interactions in traditionally managed hay meadows and intensive pastures in Transylvania, Romania. We quantified the abundance of flowering plants, and used transect walks to observe pollinators interacting with flowering plants. We evaluated the effects of management on diversity, composition and network structure. Plant and pollinator diversity mostly declined with intensive pasture management and their taxonomic composition shifted. Plant functional traits in turn changed less predictably. Interestingly we found that visitation frequency by pollinators was not always correlated to flower abundance. This seemed mostly to be because Apis mellifera, a pollinator dominating both land use types, preferred less abundant plant species with flowers closely matching its traits. A. mellifera was also found to strongly drive network structure, leading to similar Shannon diversity and interaction evenness. Network generalization and niche overlap tended to be higher in pastures than in hay meadows. Intense grazing at our sites strongly changed the diversity and composition of plants and pollinators, reduced the abundance of pollinators and altered the structure of plant-pollinator interaction networks. However, in contrast to our original hypothesis, we found that importance of floral trait dominance in shaping the response of plant-pollinator interactions to land use change may also depend on pollinator preference patterns.

Experimental evidence that tropical agroforestry farming system increases pollinator abundance, richness and visits to crops

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Pollination services contribute to crop productivity worldwide, but insect pollinators are declining in most agricultural landscapes, mainly due to land use changes and agricultural intensification. To reduce the negative effect of land use changes and agricultural intensification, ecological interventions, such as diversifying agricultural systems have been widely adopted by farmers. However, the impacts of diverse farming systems, particularly agroforestry on pollination services, have typically been approached theoretically rather than experimentally.

Using common beans (Phaseolus vulgaris L.) as the focal crop, we experimentally tested whether the agroforestry farming system would support pollinator communities and improve pollination and yield. To test this, we examined agroforestry plots paired with non-agroforestry (monoculture) plots to document abundance, species richness, and the visitation rate of pollinating insects visiting crop flowers and how they contributed to the bean yield.

We found that agroforestry had almost twice as many insect pollinators, three times higher species richness, and almost twice as high visitation rates than non-agroforestry plots. We also found a significant positive interaction effect of the farming system and landscape tree cover on insect pollinator abundance and visitation rate but not on species richness. Crop yield parameters such as the number of pods per plant, seed per pod, yield quantity and yield quality were significantly higher in unbagged beans in which insect pollinators were allowed to access bean flowers than in bagged beans. The yield gap between unbagged and bagged beans was greater in agroforestry plots than in non-agroforestry.

Our results lend experimental support that, compared to monoculture, agroforestry generally promotes and maintains pollination service, and hence supports the perspective that a diverse farming system can help conserve insect pollinators and support higher crop yields. Through agroforestry, farmers have the potential to increase and sustain the pollinator population over time.

Flower visitor networks in urban dry grasslands

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Insect-provided pollination services are increasingly threatened due to alarming declines in insect pollinator populations. One of the main threats to insect pollinators and consequently pollination is urbanisation. Here, we investigate the effects of local habitat quality (patch size, flowering plant richness, bare soil cover, vegetation structure), degree of urbanisation (impervious surfaces) and 3D connectivity on bee, hoverfly and butterfly flower visitors and plant-flower visitor networks in flower-rich urban dry grasslands. Overall, the degree of urbanisation and the quality of the local habitat influenced the flowering plant and pollinator communities. Although flowering plant abundance increased with urbanisation, bee species richness and butterfly species richness decreased with increasing impervious surfaces. Flowering plant richness and ground nesting resource availability were positively related to bee richness and local vegetation structure boosted hoverfly and butterfly visitation rates. In terms of plant–pollinator interactions, insect pollinators visited a lower proportion of the available flowering plants in more urbanised areas and network modularity and specialisation increased with patch size. Our findings show that urban dry grasslands are valuable habitats for species-rich pollinator communities and further highlight the importance of minimizing the intensity of urbanisation and the potential of local management practices to support insect biodiversity in cities.

Energetic trait matching improves the prediction of plant-pollinator interaction networks

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Functional traits shape mutualistic interactions between plants and animals and may have profound effects on predicting interaction networks. Morphological traits related to size have been recognized as main drivers and can be used to identify species linkages. However, in addition to morphological trait matching, it has been rarely explored whether energetic trait matching improves the predictability of plant-pollinator networks.

In order to understand the underlying mechanisms of plant-pollinator interaction networks, we monitored 5469 interactions between 271 plant species and 211 pollinator species across 16 study sites and four time periods. As a baseline, we measured classic morphological traits for plants (shape, size and corolla tube length) and for wild bees (intertegular distance, head width and tongue length). In addition, we quantified plant energetic traits (nectar amount, nectar sugar concentration/ composition, pollen amount, pollen protein:lipid ratio and pollen morphology) in combination with the energetic demands of wild bees (wing loading and foraging distance).

Based on trait-matching approaches to analyze interaction probabilities, we will quantify the added value of considering energetic, and phylogeny-based latent traits in addition to classical morphological traits. We expect that combining analyses of morphological and energetic traits improves the predictability of plant-pollinator networks and that energetic trait matching can be crucial to predict resource-consumer associations in diverse ecological communities.

The resurrection of collapsed ecological networks: importance of trait variation and historical network architecture

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Ecological networks such as mutualistic networks often exhibit alternative stable states. Such networks can suddenly transition to undesirable states, such as collapse, due to small changes in environmental conditions. Recovering from such a collapse can be difficult as reversing the original environmental conditions that led to the collapse may be infeasible. Additionally, such networks can exhibit hysteresis, implying that even if the environmental conditions return to the previous state, ecological networks may not recover. Here, using dynamical eco-evolutionary framework, we try to resurrect mutualistic networks from an undesirable alternative stable state to a high-functioning stable state by focusing on a single species. We found that restoring the original parameter space or environmental conditions rarely aided in recovering the original network due to the presence of hysteresis. By combining frameworks from signal propagation theory and eco-evolutionary dynamical modelling, we show that network resurrection could be readily achieved by perturbing a single species that control the response of the dynamical networks. We show that during the resurrection of collapsed networks, the historical network architecture, levels of trait variation, and eco-evolutionary dynamics could aid in the revival of the network even at undesirable parameter spaces. Our study points to the fact that restoring original environmental conditions could rarely lead to the recovery of large communities, but focus should be instead applied to a few species whose dynamics one could steer to resurrect the entire network from a collapsed state.

Providing flowering resources to mitigate pesticide effects on plant-pollinator interactions

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Bees are exposed to various stressors, including pesticides and lack of flowering resources, but the role of co-flowering plants to mitigate pesticides effects are not understood.

In my talk, I will first present full-factorial semi-field experiments with flight cages to assess the single and combined impacts of the globally used azoxystrobin-based fungicide and three types of flowering resources (phacelia, buckwheat, and a floral mix) on Bombus terrestris colonies followed by a field experiment on the effect of glyphosate-based herbicide on Bombus terrestris. I will show that flower mixtures can mitigate negative impacts on several endpoints of bumblebee colonies. I will then discuss what this means for agricultural landscapes. To do so, I will present community changes in pollinator networks of farms managing different flowering resources and habitats in their orchards across an intensive apple-growing region in Germany. Although long-term perennial habitats providing flowering and nesting materials are needed across ecosystems, short-term provisioning of flowering resources is a realistic and to certain extend valuable conservation strategy for farmers. I conclude that (1) co-flowering crop plants should be integrated in pesticide risk assessments and (2) providing flowering habitats or at least flowering resources in agricultural landscapes need to become a best-practice management.

Pesticide risk and habitat loss additively drive loss of wild bee pollinators from crops – a quantitative synthesis

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Abstract not authorized to be published

Bombus terrestris under double stress: Combined effects of pesticides and heatwaves on colony growth and reproduction

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Two factors are typically discussed as major drivers of the ongoing pollinator decline: increased pesticide use due to more intense agriculture, and climate change. However, lab experiments investigating their effects have typically been conducted separately for each factor. In our study we aimed to analyze the interaction between those two factors. Therefore, we studied the combined effect of heatwaves and three different pesticides (azoxystrobin (Amistar®, fungicide), flupyradifurone (Sivanto Prime®, insecticide) and sulfoxaflor (Closer®, insecticide) on the food consumption, survival, and reproductive fitness of Bombus terrestris micro colonies. We simulated two distinct heatwave scenarios in climate chambers: a present-day scenario and a future scenario expected in approx. 50 years from now. Bumblebee micro colonies were kept in two chambers for 21 days and fed with pollen and nectar either treated with field-realistic concentrations of pesticides or untreated (control).

We revealed interactive effects of heatwave scenarios and pesticides on the bees' brood development and survival, while pollen and nectar consumption were mostly affected by pesticides and not by heatwaves. Contrary to our expectations colonies performed slightly better under the future than under the current heatwave scenario. The strongest negative effect on the colonies was found for sulfoxaflor, which led to low survival rates, slow (if any) brood development, as well as a decreased pollen and nectar intake.

Organic agriculture and annual flower strips reduce parasite prevalence in honey bees and boost colony growth in agricultural landscapes

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Despite the major role that wild and managed insect pollinators play in crop production, agricultural intensification drives them into decline. Agri-environment schemes (AES) have been developed to mitigate the negative effects of agriculture on insect pollinators, including honey bees (Apis mellifera). In a novel, simultaneous comparison of the efficacy of different AES (including conservation of semi-natural habitat) on honey bee colony health, we monitored experimental honey bee colonies in each of 16 landscapes that comprised orthogonal gradients of three commonly used conservation measures (organic agriculture, annual flower strips/fields, perennial semi-natural habitats). Using structural equation modelling, we then assessed the direct and indirect effects of these measures on the prevalence of 11 parasites (viruses, Protozoa, Microsporidia), Varroa destructor parasitic mites loads and colony growth. Increasing area coverage of perennial semi-natural habitat around focal colonies increased V. destructor load and indirectly limited colony growth. Increasing area of annual flower strips/fields limited V. destructor load and indirectly benefited colony growth. Increasing area of organic farming lowered parasite prevalence and improved colony growth, highlighting direct and indirect benefits of organic agriculture for honey bee colony health. Landscape features can affect insect pollinator health directly through the provision of food resources and indirectly, for example through modulation of parasite transmission. To promote honey bee colony health in agro-ecosystems, our results suggest that organic agriculture and annual flower strips/fields should be prioritized AES.

Flower visitation patterns and landscape features shape virus transmission in plant-pollinator networks

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Anthropogenic land-use change along with high numbers of managed pollinators such as honeybees may impact wild pollinators not only through lower floral resource availability, increased resource competition and altered plant-pollinator interactions, but could also facilitate pathogen transmission among pollinators. Pathogen transmission likely occurs via shared use of flowers. Therefore, factors such as overlap in flowering plant visitation among pollinators, their role in the flower visitation networks or flower traits could influence this transmission. To investigate drivers of pathogen transmission of three viruses commonly found in managed honeybees (Black Queen Cell Virus BQCV, Deformed Wing Virus DWV A and B), we assessed loads of these viruses in 19 pollinator species from 12 plant-pollinator networks along a gradient in pollinator-friendly habitat. We found that increased floral resource overlap between managed honeybees and wild pollinators was related to high viral loads in wild pollinators. At the same time, pollinators in landscapes with high amounts of pollinator-friendly habitat exhibited lower viral loads, likely via a decreased resource overlap between honeybees and wild pollinators in these landscapes. Further, wild pollinators which were well connected in the network and visiting a high proportion of open (dish-type) flowers had lower BQCV loads. Our results highlight that virus transmission among pollinators is driven by species' individual foraging preferences including the degree of niche overlap with manged honeybees as well as the landscape features. Moreover, our study indicates that promoting floral-rich pollinator-friendly habitat, beyond the direct benefits of enhanced floral resource and nesting opportunities, can reduce pathogen transmission and counteract potential negative consequences on pollinator health. This provides a further argument for the maintenance and restoration of such high quality habitat for pollinators.

Wildflower strips for pollinators: Conservation measure or hotspots of disease transmission?

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Agricultural intensification over recent decades has put considerable pressure on insect pollinators. To restore pollinator populations and the ecosystem service of pollination, targeted conservation measures have been established in agroecosystems, including agri-environment schemes promoting sown wildflower strips (WFS) along field margins. Although successful in establishing a high density of insects, the impacts of concentrating pollinators in dense patches of flowers on disease transmission remain unclear. To test the role of WFS in disease ecology, we recorded high-resolution plant-insect visitor networks over a year from ten farms in Southern England applying different levels of agri-environment schemes, and measured infections of three common viruses across pollinator communities: acute bee paralysis virus (ABPV) and deformed wing virus types A and B (DWV-A, DWV-B). In early summer, when WFS provide significantly more flower resources than control farms, agri-environment schemes reduced the prevalence and load of DWV-B in honeybees Apis mellifera, suggesting a dilution effect. For DWV-A, we found that, in addition to the effect of scheme, increasing niche overlap (a plant-insect network index measuring shared resources between pollinators) also reduced prevalence, consistent with this dilution effect. In contrast, the transmission of ABPV, a virus which shows a narrow host range of common and generalist social bees, seems not to be influenced by scheme and network structure, but rather by the proportion of bumblebees in the pollinator community. With this work, we show that actions to support wild pollinator nutrition can mitigate the transmission of economically important bee diseases, and enhance the potential of securing pollination as an ecosystem service.

Local and landscape effects shape pollinator health and pollination services differently in bumblebees and syrphid flies

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In recent years, pollinators have rapidly declined, with various anthropogenic stressors such as the conversion of habitats and intensive land-use accompanied by emerging diseases and climate change playing key roles. Land-use intensity, one of the most important and widely discussed stressors, reduces the abundance and diversity of flowering plants and thus pollinator food source, and is accompanied by an increased use of harmful pesticides.

We conducted a field study in grasslands of the Biodiversity Exploratories, where we aimed to understand how local, plot-based parameters and the surrounding landscape around each plot affect different health traits of the bumblebee Bombus lapidarius and the syrphid fly Episyrphus balteatus as representatives for bees and flies. We also wanted to answer, whether pollination services are affected by changing health status, plot-level parameters and/or the surrounding landscape. As proxies for health, we measured body size and viral prevalence in both species. Additionally, we analysed the cuticular chemical profile, which plays an important role in communication and colony maintenance, as a further health trait for bumblebees. To assess pollination services, we recorded the number of pollen and its diversity on the surface of each individual.

Our results show that both species react differently to local and landscape factors. Bumblebee health traits were affected indirectly by local land-use via floral resources and directly by land-use in the surrounding landscape, whereas pollination services were affected by body size (i.e. a health trait) and indirectly by local land-use. In syrphid flies we could not find such a clear picture. Health traits were affected by landscape-level land-use, but not local land-use, possibly explained by higher flight ranges and the migration of syrphids. Pollination services in syrphids were affected directly by body size and indirectly by local land-use intensity. Additionally, climatic factors affected health traits in both species.

Overall, local land-use intensity, landscape parameters and climatic factors affect pollinator health and pollination services. However, the social bumblebees and migratory syrphid flies respond differently.

Global interactive impacts of climate change and land use on pollinator biodiversity

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Pollinator biodiversity is facing multiple interacting pressures that are accelerating with environmental change. Among pressures, land-use change and climate change are particularly important. I will present a study investigating how interactive effects of climate change and land use are impacting pollinator biodiversity in natural habitats and agricultural areas globally. We highlight regions of the world where we expect the strongest pollinator biodiversity changes from interacting effects of climate change and land use. We further show how these pollinator biodiversity changes may impact agriculture through their overlap with the production of crops that depend on animal pollination.

Bee communities in lime-stone quarries are influenced by local site characteristics, but also benefit from high connectivity to other quarry sites and close-by dry grasslands

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Habitat loss leads to a severe decline in wild bees, threatening vital ecosystem functions such as pollination. Bees prefer inclined habitats with a warm micro climate and a high proportion of open soil which are usually found in dry grasslands, but are often lost due to intensification or abandonment. Due to similar site characteristics, quarries might be substitutes for dry grasslands.

We hypothesize (I) that bee abundance, species richness and richness of threatened bees increase with quarry size, age and floral resources, but decrease with high woody vegetation, (II) that bees are positively affected by high levels of landscape diversity and habitat connectivity between quarries and nearby dry grasslands and (III) that local and landscape variables interact, resulting in synergies or trade-offs.

Bees were surveyed during transect walks in 19 quarries in southern Lower Saxony, Germany. We recorded overall 114 bee species, including 34 red-listed species. Flowering plant species richness positively affected bee abundance and species richness. Quarry size had a positive effect on species richness. Abundance and species richness increased with quarry age, but only at sites with low cover of woody vegetation. Bee species richness increased with connectivity. For threatened bee species, this positive effect of connectivity was greater in larger quarries.

We conclude that extensive, flower-rich quarries with high ages and low cover of woody vegetation can sustain large, species-rich bee communities. Species richness can be enhanced through improved habitat connectivity. Especially large, well-connected quarries had a high richness of threatened bee species. Thus, conservation should consider anthropogenic habitats of high conservation value, such as quarries, to restore and sustain diverse bee communities with many threatened species. Long term stability of these habitats should be achieved through measures that reduce shrub cover and enhance habitat connectivity.

Smaller, more diverse and on the way to the top: Rapid community shifts of montane wild bees within an extraordinary hot decade

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Global warming is assumed to restructure mountain insect communities in space and time. Theory and observations along climate gradients predict that insect abundance and richness, especially of small-bodied species, will increase with increasing temperature. However, the specific responses of single species to rising temperatures, such as spatial range shifts, also alter communities, calling for intensive monitoring of real-world communities over time. We empirically examined the temporal and spatial change in wild bee communities and its drivers along two largely well-protected elevational gradients (alpine grassland vs. pre-alpine forest), each sampled twice within the last decade. We detected clear abundance-based upward shifts in bee communities, particularly in cold-adapted bumble bee species, demonstrating the speed with which mobile organisms can respond to climatic changes. Mean annual temperature was identified as the main driver of species richness in both regions. Accordingly, and in large overlap with expectations under climate warming, we detected an increase in bee richness and abundance, and an increase in small-bodied species in low- and mid-elevations along the grassland gradient. Community responses in the pre-alpine forest gradient were only partly consistent with community responses in alpine grasslands. In well-protected temperate mountain regions, small-bodied bees may initially profit from warming temperatures, by getting more abundant and diverse. Less severe warming, and differences in habitat openness along the forested gradient, however, might moderate species responses. Our study further highlights the utility of standardized abundance data for revealing rapid changes in bee communities over only one decade.

Long-term study on climate effects on bumble bee fitness: Temperature and precipitation affect health, survival and colony formation in wild-caught spring queens

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Many bee species are experiencing widespread declines and climate change is an important factor implicated in these losses. A changing climate can potentially impact bee fitness directly, e.g. affecting development or hibernation, or indirectly through food resources or interactions with pathogens or symbionts. To better understand how climate affects bee health, we use long-term demographic data (2000–2014) from 4640 Bombus terrestris spring queens caught from two sites in Switzerland and reared under standard lab conditions. We test how temperature and precipitation in the year before queens emerge from hibernation affected their subsequent body mass and likelihood of hosting a gut parasite (Crithidia) and phoretic mites. We test how climatic and non-climatic factors interact to shape spring queen survival and reproduction assayed in the lab. We find effects of climate on fitness and health traits at various levels. At an annual level, warm temperatures in the year preceding queen collection reduced body mass but elevated Crithidia prevalence, while wet years were associated with an increased presence of phoretic mites. Both climatic variables affected demographic traits but in inconsistent directions: warm, wet years reduced queen survival, wet years reduced the probability of colony establishment but warm years increased it. Fitness and health traits were affected by climatic variation at different times of the year: For example, a sliding windows analysis showed that spring queen body mass depended on temperatures in the preceding spring (indicating the importance of early-life effects and natal colony conditions), while effects on Crithidia were largely due to temperatures queens experienced during hibernation (suggesting interactions between temperature and Crithidia on overwinter survival). This long-term study shows that climatic variation can affect bumble bee health and fitness, with the potential of further deterioration with increasing climate change.

Influence of local and landscape parameters on wild pollinators in fragmented calcareous grasslands in northern Bavaria, Germany

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Wild pollinator diversity has been declining rapidly over the last decades due to habitat loss and agricultural intensification. Calcareous grasslands represent one of the most species rich pollinator habitats in Europe and are crucial for the survival of wild pollinators. Due to the progressive intensification of agriculture, calcareous grasslands are becoming more isolated and are nowadays highly endangered and so are wild pollinators. However, pressures and drivers of these wild pollinators remain unclear. We expect a positive influence of increasing habitat area and flower cover on wild pollinators. In addition, landscape parameters such as increasing habitat amount are expected to positively influence species richness.

Here, we focus on the effects of local (habitat area, flower cover, area of nesting sites) and landscape parameters (habitat amount, habitat connectivity, edge density, amount of semi-natural habitats within a 2 km buffer around study sites) on wild pollinators on 40 calcareous grasslands in two regions (Lower and Upper Franconia) in northern Bavaria, Germany. Study sites were selected to maximize the gradient between local habitat area, habitat amount, and edge density within a 2 km buffer around the study sites. Wild bees, syrphid flies and butterflies were sampled in variable transect walks five times in 2022. The study is part of the overarching EU-Horizon 2020 project Safeguard.

In total, 225 wild bee (10874 individuals), 90 butterfly (19741 individuals) and 49 syrphid fly species (1523 individuals) were recorded. Wild bee species cover 42 % of the total wild bee occurrence in Bavaria, butterfly species cover 48 % and syrphid flies 13 %.

Knowledge about threats to wild pollinators in valuable habitats embedded in an agricultural landscape helps to make management decisions in agricultural policy and nature conservation. Identifying important factors influencing wild pollinators at local and landscape scale can be used to derive management schemes, that will ensure the survival of wild pollinators.

Bumble bee intraspecific body size as a response trait to anthropogenic disturbance in agriculturally dominated landscapes

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Phenotypic variation within a species is both the foundation and the result of evolutionary and ecological processes. It is critical for the maintenance of populations in that it buffers them from decline in response to environmental stochasticity and enables them to successfully contend with novel environments. In the context of increasing anthropogenic pressures, understanding how phenotypic variation responds to environmental stressors is more pressing than ever. Body size is one of the most fundamental life-history traits, with pervasive effects on individual fitness, population dynamics, and the structure of ecological networks. Importantly, it is also a trait which, in bumble bees, shows considerable intraspecific variability. In this study, we assessed the impact of local environmental factors (temperature, local floral food resources) and habitat heterogeneity in agriculturally dominated landscapes on bumble bee body size and its variation. We placed commercially reared Bombus terrestris colonies (n=72) at 6 sites that vary in their intensity of agricultural land use and landscape heterogeneity across Saxony-Anhalt (Germany) and measured the body size of 20 workers of each colony (n=1440) that developed in these sites. Our data allow assessment of the importance of local environmental and landscape factors on bumble bee body size and to identify potential environmental stressors that relate to the maintenance and variability in body size.

Abundance and phenophase, but not intraspecific variation in body size, influence bumble bee diet breadth

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Patterns of abundance across space and time, and intraspecific variation in body size, are two attributes of bee species potentially related to diet breadth. Despite their known importance, the relative influence of these attributes on diet breadth are often assumed to be equal across groups of species, and intraspecific variation in body size is frequently neglected, leading to an incomplete understanding of how attributes of bee species are associated with diet breadth. To understand how attributes of bee species differ and which are more strongly related to diet breadth for groups of bees, we observed bee-flower interactions in multiple locations across southwest Montana, USA, for two growing seasons and measured spatial and temporal patterns of abundance, along with interspecific and intraspecific variation in body size for prevalent species throughout this region. Bumble bee species had higher local abundance, occurred in many local communities, and had more intraspecific variation in body size compared to non-bumble bee species. In turn, communities with a higher proportion of bumble bees also had higher intraspecific variation in body size at the network level. Local abundance and phenophase duration had a stronger positive effect on diet breadth of bumble bee species compared to non-bumble bee species, indicating that attributes of species leading to chance interactions between bees and flowers more strongly influence bumble bees. While intraspecific variation in body size did not influence bumble bee diet breadth at the species-level, body size may have a stronger effect on bee diet breadth when co-occurring species are similarly sized. Further, network-level intraspecific variation in body size was weakly positively correlated with diet generalization. While intraspecific variation in body size did not influence diet breadth at the species level, it may be required to confer foraging flexibility and reduce the strength of competition for floral resources.

How do changes in plant diversity affect floral and nutritional niches of bee pollinators?

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Wild bees are an important pollinator group in European landscapes. They largely depend on flower resources, in particular pollen, to raise their offspring and hence maintain their populations. Bees are thus strongly affected by changes in the diversity and composition of plant communities often seen as a consequence of global change.

In this study, we investigated how changes in the composition and diversity of plant communities as seen along a gradient of increasing land-use intensity influenced the floral taxonomic composition as well as the nutritional composition of pollen collected by different wild bee species. We integrated information from field observations, pollen DNA metabarcoding, analytical chemistry, and network analyses to infer floral and nutritional niches of different wild bee species in relation to variable floral resource landscapes. Our findings indicate species-specific changes in floral and nutritional niches with changing plant communities. They also provide first hints on intriguing correlations between pollen chemistry, bee pollen choices and bee "health".

The wild bee community composition of Braunschweig: A homogeneous pattern of heterogeneity

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Land-use change is a major driver of biodiversity loss, whereby urbanisation represents one of the most profound types of land-use change. Therefore, environmental conditions characteristic for urban areas may act as strong environmental filters for wild bee communities. Whether dominant filters lead to a systematic loss of species and consequently to biotic homogenisation, remains unknown. Alternatively, different environmental conditions could lead to different biological communities within urban areas. Here, wild bee community composition across 49 study sites in the city of Braunschweig, Lower Saxony, Germany was examined. The study sites covered a gradient from the city centre to the rural surrounding. The sampled wild bee species represented 30% of the species known for Lower Saxony and included red listed species. The sampled communities differed markedly. Thereby, dissimilarity of the community of flowering plants had a significant positive effect on these differences in wild bee community composition, as well as dissimilarity of soil characteristics. In contrast, geographic distance between study sites, the distance to the city centre, or dissimilarity of land use had no effect. Exponential Shannon diversity of the sampled bee community of most study sites was low compared to the citywide wild bee community. This, in combination with the differences in community composition, shows that cities provide suitable habitats for various wild bee communities. The composition of these communities are driven by the composition of flowering plants and soil characteristics rather than by dominant urban-specific environmental filters. Consequently, a heterogenic set of species is resulting. This shows the importance of preserving and creating heterogeneous plant structures in cities to conserve or even improve the urban wild bee community.

Simulating the effect of landscape structure and land use change on honey bee vitality for Germany

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Honey bees (*Apis mellifera*) are exposed to multiple stressors such as pesticides, forage gaps, diseases, land use change and management failures. It is therefore a long-standing aim to develop a robust understanding how stressors impact honey bee vitality. Especially the role of landscape structure and amount of mass flowering crop in the landscape on bee vitality is discussed in the literature. However, experimental and monitoring studies are limited in their ability to assess these relationships between stressors and honey bee vitality systematically. Therefore, we use the established honey bee simulation model BEEHAVE in combination with land use classification maps to contribute to the assessment of honey bee vitality in Germany. This work is one use case of the BioDT project to develop digital Twins for biodiversity. In this presentation we will focus on the effect of landscape structure on relevant end points such as winter mortality and honey production. Our results are in line with previous findings that temporal foraging gaps are severe threads to honey bees and that landscape elements (e.g. semi natural grasslands) that provide resources in absence of mass flowering crops (e.g. oilseed rape) are essential for honey bee population performance. This study is an important step towards a model-based, automatic, easy and free to apply Germany-wide assessment of honey bee vitality for agricultural landscapes.

Same or different? Unveiling the hidden travelers in plant pollination through DNA metabarcoding

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Animal pollination represents one of the most important ecosystem functions. Different tools, e.g., palynology or DNA metabarcoding, have been used to investigate interactions between plants and pollinators, frequently insects, underlying the pollination service. However, current methods have primarily focused on the pollinators' side of the interaction through e.g., analysing mixed pollen samples. While such analyses provide detailed information on e.g., pollinator visitation patterns or preferences, they hardly allow any inferences on the plant's perspective, e.g., the type or amount of viable pollen received.

Our study investigated whether DNA metabarcoding of plant stigmas can be used to analyse homo- and heterospecific pollen transfer. Plant stigmas of three *Ranunculus* species (*R. acris*, *R. bulbosus*, and *R. repens*) were collected on 20 plots of differing land-use intensities within the Biodiversity Exploratories. Stigma pools were then analysed by sequencing the internal transcribed spacer 2 (ITS2) gene region using DNA metabarcoding. As the presence of diverse wild pollinator communities is known to have a positive effect on plant pollination, we expected to find a higher diversity of heterospecific pollen on *Ranunculus* stigmas at plots with low land-use intensity and thus more diverse pollinator communities.

Effects of wildflower patches on wild bee species and functional diversity at urban roadsides

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Ever growing cities are one of the high impact drivers of anthropogenic change and its negative impact on diversity of wild bee and other pollinator populations. Urbanization is accompanied by high densities of roads, which contribute to fragmentation, degradation or even destruction of habitats. Nevertheless, recent studies report overall positive effects of diverse roadside vegetation on wild bees and other pollinators, highlighting an untapped potential for conservation of urban biodiversity, while research on roadsides in cities is still rare. To study local and landscape factors that drive wild bee species composition as well as species and functional diversity, we successively established 75 flowering patches with a customized wildflower mixture along five major roads in Munich. Sampling took place three times a year from 2019–2021. We analyzed wild bee community composition and interactions of species and functional diversity with local plant diversity as well as the surrounding urban landscape. We found overall positive effects of enriched floral availability at roadsides on wild bee diversity, with landscape factors (green space, landscape diversity) shaping species and functional community composition. We conclude that improved urban roadsides support wild bees in cities and therewith can be used as green space element that complements higher quality urban habitats.

Effects of surrounding land-use on pollinator availability and flower visitation in semi-natural grasslands

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Many semi-natural grasslands are remnants of larger grazed areas, and are now surrounded by intensive agriculture and forests. Since pollinators have been negatively impacted by intensification of agricultural management, loss of natural habitats and habitat fragmentation, this raises concerns about the persistence of plant species dependent on insect pollination for their reproduction. We survey pollinators and flower-visitation in 18 semi-natural grasslands in Sweden, situated along a gradient of proportion of arable crops in the landscape (1km radius), with a systematically varying composition in share of forest, permanent (semi-natural) grasslands and leys. Preliminary results from 2 years of plant-insect observations show that response to landscape composition differed among insect groups. Flower visits from bumblebees and butterflies were positively related to the proportion arable crops as well as to mass flowering crops, and negatively related to the proportion leys. Visits from hoverflies and other flies were negatively related to the proportion permanent grasslands, and butterflies negatively whereas other flies positively related to increasing proportion forest in the surrounding 1 km. The effects of landscape context on plant reproduction will thus likely differ based on the identity of a plant's pollinators. We are currently analyzing species richness patterns based on flower visitation and pan traps to contrast how landscape composition affects grassland plant pollination and pollinator diversity. Furthermore, we are analyzing seed-set, biomass and plant community survey data to understand how land-use driven pollinator-assembly-change impacts plant reproduction, community composition and ecosystem functioning.

Changes in wild bee community composition and pollination provision along biodiversity and temperature gradients.

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Pollination is essential to most crops and wild plants, yielding fruits and allowing for genetic diversity. Still, the decline in pollinator species richness reduces ecological redundancy, making agricultural and natural systems less resilient. Indirect measures of pollinator diversity and habitat quality derived from landscape indices are widely used since there is evidence that landscape heterogeneity benefits insect biodiversity. However, the presence of wild pollinators is complex to model as they are influenced by numerous (a)biotic factors and interactions, such as the spatial and temporal fluctuation of floral resources and the scale at which the landscape affects distinct species.

We designed a study in South Tyrol, Italy, to investigate pollinator communities' composition along a temperature gradient and one of local biodiversity. For the temperature gradient, we selected 12 sites along an elevational gradient (elevation difference of 793 m and a range of 4.85 K of mean annual temperature (MAT), while keeping the multidiversity index (based on species richness of vascular plants, grasshoppers, butterflies, birds and bats) almost constant. We chose 12 other sites with increasing multidiversity index (the biodiversity gradient) while limiting the temperature range. To collect data, we employed coloured pan-traps, observations on visitation rate on target plants of strawberry and radish, and an exclusion experiment measuring yield between bagged and non-bagged plants.

Focusing on wild bees, preliminary results show that abundance weakly correlates with MAT and the multidiversity index. Species richness strongly correlates with the multidiversity index, but it does not with MAT, and this could be explained by the influence of land use intensity, which only partially coincides with the temperature (and elevation) gradient While the visitation rate of wild bees depended on the date rather than on MAT or multidiversity index, the fruit set and yield of the studied plants were highly correlated with the multidiversity index and pollinator abundance.

Interactive effects of drought, insect pollination and intercropping on faba bean flower traits and yield

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Climate change induced extreme events, such as droughts threaten provisioning and regulating ecosystems services, such as food provision and pollination by reducing crop yields and disrupting plant-pollinator interactions. A diversification measure that enhances the resistance of crops against environmental stress is intercropping. It is, however, unknown whether enhanced stress resistance in intercrops can prevent adverse drought-stress related effects on flower traits of crops and how drought and intercropping interactively affect floral traits, associated with pollinator attraction, pollination success and crop yields.

We installed 56 pollinator exclusion cages and rainout shelters over winter faba bean (*Vicia faba* L.) sole stands and winter faba bean – winter wheat intercrops (28 in each cropping system). A two-level drought treatment (well-watered/drought stressed) was crossed with a two-level pollination treatment (insect pollination/pollinator exclusion). Based on the data, we evaluate the potential of intercropping in mitigating negative drought impacts on plant traits with cascading effects on insect pollinators and pollination services. Furthermore, we investigate the interaction between drought stress and insect pollination on yields of the faba bean. We expect insect pollination to compensate for negative effects of drought on bean yields via yield recovery by outcrossing. The results of the experiment will help to better understand the direct and indirect effects of climate change and biotic interactions in different cropping systems and will contribute to the development of novel cropping practices that strengthen resilience to climate change.

Landscape scale assessment of the effect of agri-environment schemes on pathogen prevalence among bee communities

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Anthropogenic changes such as agricultural intensification lead to habitat conversion, monotonous food resources and increased exposure to harmful pesticides, all of which can jeopardize bee health and increase their vulnerability to pathogen infection. Agri-environment schemes have been implemented to combat these negative effects. Important measures include the re-establishment of semi-natural habitats, the sowing of flower strips and the shift to organic farming. To examine the impact of these agri-environment schemes and their interactions on parasite prevalence and transmission in managed and wild pollinators, we collected honey bees (*A. mellifera*), and wild bees (*Bombus spp.*, *Colletes* spp., *Andrena* spp., *Lasioglossum* spp.) at flowers from 16 study sites located along independent gradients of landscape composition that varied in the % area of organic farming, % area of semi-natural habitats, and the % area of annual flower strips. We screened individual honey bees, bumble bees and other wild bees for common bee viruses by qPCR: DWV-A, DWV-B, BQCV, SBV, ABPV, and intestinal parasites by PCR: Trypanosomes (*Crithidia* spp., *Lotmaria passim*), Neogregarines (*Apicystis* spp.) and Microsporidia (*Nosema bombi, N. ceranae*). The prevalence of DWV-B and BQCV was highest in *A. mellifera* while the prevalence of ABPV was highest in *Bombus* spp. Wild bees harbored generally less viral pathogens but more eukaryotic parasites than honey bees. The association of agri-environment scheme and pathogen prevalence varied across the habitat type and bee taxa. Our study will provide insight into the combined efficiency of agri-environment measures in mitigating pathogen transmission among bee communities.

Effects of pesticide exposure in agricultural landscapes on the gut microbiome of *Bombus terrestris*

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The gut microbiome of pollinators plays an essential role on the hosts' health and fitness by regulating their development, nutrition and immunity, and may serve as a proxy for the evaluation of pollinator health. In controlled laboratory experiments, previous studies have shown the adverse effects of pesticide exposure on the gut microbial composition of *Bombus spp.*. In real agricultural settings, quantitative data of pesticide exposure are difficult to obtain and often excluded. Therefore, only few studies have yet evaluated the effects of pesticide exposure on the gut microbiome under complex field conditions. In this study, we tested the associations of pesticide exposure, pathogen prevalence, and the composition of the gut microbial community of *B. terrestris* workers before and during the blooming of a mass flowering crop (oil seed rape). We placed 30 colonies at ten study sites selected along a gradient of arable land, conducted a farmer survey to obtain quantitative data on pesticide applications, and analyzed the gut microbial composition of *B. terrestris* workers using 16S rRNA amplicon sequencing. We evaluated whether pesticide exposure is influencing the composition of the gut microbiome and pathogen loads in agricultural landscapes and if the diversity of local nutritional resources can buffer the negative effects of pesticide exposure.

Plant-bee pollinator networks in savannas of Burkina Faso, West Africa

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West African savanna ecosystems are severely threatened by intensified land use and increasing degradation of natural habitats. Bees are crucial for pollinating crops and native plant species. However, little information is available regarding their mutualistic interactions with woody plant species. As first network study from Sub-Saharan West Africa we investigated the plant-bee community- and network structure considering three land-use intensities (LUI) plus dry and rainy season. In total, 5686 flowers of 53 woody plant species and 100 bee species were observed. Flower visitor richness and number of interactions was higher in the low LUI site compared to those with medium and high LUI. Bee and plant species richness and number of interactions was higher in the dry compared to the rainy season. Regarding the network architecture we only found connectance and modularity to be higher in the dry compared to the rainy season. Overall, it seems that the seasonal effects are more pronounced compared to land-use intensity influences. The lower connectance and higher modularity in the rainy season suggests the existence of isolated groups of interacting bee and flower plant species in that season. A very high modularity actually prevents the access to alternative resources and can be linked to decreased community stability and functioning.

Temporal and spatial variation of host – cuckoo bee populations in the BienABest project

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Global change is leading to a sharp decline in wild pollinators. In this context, cuckoo bees are studied much less frequently than pollen-collecting bee species, although they make up one third of the bee community. However, parasites, such as cuckoo bees, are probably much more sensitive to environmental changes because they obligatorily dependent on the ecology and physiology of their hosts.

In the BienABest project, we are investigating the diversity and composition of pollen-collecting wild bees and cuckoo bees, comparing different regions across Germany in a period of five years. Our aims are to examine the wild-bee community structure in terms of land use and to shed more light on population dynamics of host-cuckoo bee interactions.

We performed an intensive bee survey with 50 sampling events on 180 study sites. We were able to collect 290 host and 97 cuckoo bee species, thereby capturing a large proportion of the wild-bee fauna, especially of the cuckoo bees of Germany. Furthermore, the composition of the bee community varied greatly between the different regions of Germany, while the population sizes varied between years.

Studies like ours make an important contribution to understanding wild bee decline, as cuckoo bees represent high species numbers in the wild bee community.

Particulate matter in bees and flowers: how to measure it and why it matters

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Anthropogenic particles, e.g. micro plastic, soot or heavy metals, are daily released into the environment. This ubiquitous pollution has a massive impact on organisms. Not only airborne particles are harmful, but also when deposited on various surfaces and in different substrates. It has been shown that these anthropogenic particles can deposit on insects in flight and insects take them up e.g. when eating polluted leaves, resulting in reduced life spans, altered foraging behavior and inhibited growth. Pollutants may even alter their gut system. However, the possible routes for these particles into insect bodies as well as their effect on their well-being and performance are still poorly understood, particularly for pollinators, such as bees, foraging e.g. on flowers close to roads.

We set out to explore if anthropogenic particles (i) are deposited inside flowers growing close to roads, and (ii) are taken up by bees via e.g. contaminated nectar. We also want to understand (iii) how this contamination ultimately affects bees.

We present our methodological approach for assessing variation in particle contamination in the environment and show some first results. Revealing the level of contamination in both flowers and flower visitors as well as effects on pollinators, such as bees, will be important not only for conservation efforts but also to foster the discussion about the ongoing daily release and accumulation of substances that can be detrimental to both environmental and human health.

How diverse are pollen of insect-pollinated plants in space and time?

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Pollen and their analysis are becoming more and more important due to their biological and ecological importance. Microscopic pollen analysis has been established as the gold standard. But, the trend is towards automated, database-driven pollen analyses that are cheaper, less time-consuming and allow better reproducibility than the traditional microscope-based methods. Such an automated method is imaging flow cytometry linked with machine learning. It enables microscopic brightfield and fluorescence images and traits (e.g. diameter) of pollen to be recorded quickly. Based on this data, a neural network classifier can be trained, which then allows pollen identification. The accuracy of all methods is based on the reference database and its quality. Most databases of automated methods are based on only a small number of reference samples per species (e.g., two to ten samples per species from different plant individuals). Although some studies have shown that pollen traits can vary greatly within a species, most reference databases report only mean trait values. Lack of variation in reference databases can be a reason why a classifier can only be applied to diverse samples in a limited way. Our aim was to quantify spatial and temporal patterns of intraspecific pollen trait variability based on traditional traits (e.g. pollen size and shape) and additionally, new pollen traits (e.g. fluorescence, texture), taking advantage of a novel high-throughput analytic method. Specifically, we measured pollen samples from six representative European insect-pollinated herbaceous plant species using imaging flow cytometry, analysing six pollen traits. We found that most species showed significant spatial as well as temporal variability for at least one pollen trait. Our results provide evidence for the importance of considering variability in pollen traits for future pollen databases and analyses.

Pan trapping for bees: the impact of bowl diameter on sampling results

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Although pan traps are used as an established method for sampling bees across a wide range of habitats and geographical regions, uncertainty persists as to how pan-trap characteristics influence sampling results. We investigated the effect of pan-trap diameter on sampled bee communities at agricultural sites around Braunschweig, Lower Saxony, Germany. We installed 108 pan traps at six sites, with equal proportions of color-diameter combinations per site (yellow, blue and white; 22 cm versus 12 cm in diameter). We sampled bee individuals over a period of 24 hours in March/April, June and August/September 2021, respectively. In total, we collected and identified 1154 bee individuals. We observed interacting effects of pan trap color and size on the number of sampled bee individuals and species. Larger pan traps collected significantly more bee individuals and species than smaller pan traps independent of trap color. The estimated number of sampled species based on the same number of sampled individuals (individual-based rarefaction) was higher for larger pan traps than for smaller pan traps at all sampling sites. Based on our findings, we advocate for the use of larger pan traps for sampling bees in order to increase trap efficacy and efficiency.

Effects of combined agri-environmental measures and honeybee densities on the colony development of bumblebees and honeybees

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Agri-environmental measures were introduced in Europe to protect biodiversity and their services in modern agricultural landscapes. Flower strips and organic agriculture are promising measures to benefit bumblebees (*Bombus* spp.) and honeybees (*Apis mellifera*). The latter are increasingly used to counteract failing pollination services, which can lead to competition for resources between wild and managed bees. However, effects of combined agri-environmental measures and honeybee densities at the landscape-level on their colony development remain unclear. To fill this knowledge gap, a novel combined analysis of the impact of organic agriculture and annual flower fields along a landscape gradient of perennial semi-natural habitats on colony development was conducted in 32 landscapes in the vicinity of Göttingen, Germany. Two *Bombus terrestris* colonies and four honeybee hives were installed to monitor their colony development. In half of the landscapes, an additional 80 hives were installed to induce greater honeybee densities. Honeybee colony development was positively affected by annual flower fields, suggesting a preference towards densely flower-rich habitats. Bumblebee colony development was enhanced by a higher proportion of organic agriculture in June and by more semi-natural habitat in July but negatively affected by annual flower fields in July, explicitly in landscapes with enhanced honeybee densities. This suggests resource competition between bumblebees and honeybees in flower fields, which can be lessened by the availability of organic fields and semi-natural habitats, in which bumblebees acquire resources for colony development. These findings underline the importance of heterogeneous agricultural landscapes with combined agri-environmental measures as well as preservation of semi-natural habitats to promote colony growth and avoid competition between wild and managed bees.

Flower functional traits mediate the transfer of con- and hetero-specific pollen in hummingbird-pollinated plants

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Co-flowering plant species interact with each other through their shared pollinators, giving rise to diverse indirect effects that can be advantageous for certain species while detrimental for others. Functional traits of flowers and flower abundance influence these indirect effects, which are modulated by the extent of shared pollen. We explored the assembly of interaction networks among co-flowering plant species that share pollen distributed by hummingbirds, and assessed how functional traits and floral abundance influenced the structure of plant-plant networks in the tropical Andes. We sampled three sites in the southern Ecuadorian Andes, over three periods from August 2022 to January 2023. We conducted flower abundance censuses and performed a stratified sampling of stigmas based on abundance. A total of 1388 flower stigmas were collected, comprising 26 plant species from 8 different families. We found that 96.8% of the pollen grains found on stigmas belonged to con-specific pollen, while 3.12% were heterospecific pollen. *Chuquiragua jusseii* (Asteraceae) and *Giadendrum punctatum* (Loranthaceae), characterized by generalist flower traits, displayed a high abundance and acquired the highest loads of hetero-specific pollen, conversely, species with specialized flower traits such as *Gaultheria glomerata* (Ericaceae) and *Salvia corrugata* (Lamiaceae) had lower abundances but obtained substantial loads of con-specific pollen. These results indicate that the interplay between floral abundance and functional traits might play a crucial role in regulating indirect interactions among co-flowering plants. For some plant species, a high abundance of flowers could create a trade-off between the positive effects of an increased chance of receiving con-specific pollen and the negative effects of increasing the presence of heterospecific pollen; conversely, rare plant species, with specialized phenotypes, could benefit from the presence of abundant and generalist species that might attract hummingbird pollinators.

Plants partition the pollinator niche by depositing pollen on different parts of the pollinator body

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Co-flowering plant species can partition their pollination niche (i.e. the pollinators that visit a given plant species) to reduce interspecific competition and promote species coexistence. Using plant-pollinator interaction networks it is possible to identify the breadth and position of a plant species pollination niche. Network analyzes, however, are usually based on information about pollinator visits to plants, without considering information on pollen deposition on a pollinator´s body, which actually determines the direct interaction between a plant and its pollinators. In this study, we evaluated niche partitioning of flowers in the location of pollen in different body parts of hummingbird species. We worked in three locations of the tropical Andes of southern Ecuador, in ecosystems dominated by scrubs. At each location, we captured hummingbirds using 10 mist-nets for three consecutive days in three different sampling periods from August 2022 to January 2023. Pollen samples were collected from five regions of each captured hummingbird: bill, bill-base, front, throat and chest-belly. We captured 145 individuals of 9 hummingbird species during 951.25 hours/net and counted 165,000 pollen grains that belonged to 49 botanical taxa. We built interaction networks between the five pollinator body regions and the plant species, using pollen loads as connections among these levels. The interaction networks showed that the throat and the bill-base are the regions that transported the highest loads and species of pollen. Furthermore, we found niche partitioning by certain plant species in the location of pollen in certain regions of pollinators. Our study shows that in plant communities that share pollinators, flowers can divide their pollination niche into finer scales, allocating pollen to pollinator-specific body regions. This strategy is likely a mechanism to avoid the mixture of pollen across species, thereby increasing the movement of conspecific pollen. Our findings on the partitioning of the body niche of pollinators by flowers suggest that it is potentially an important mechanism of plant coexistence , since they can reduce interspecific competition by sharing pollinators.

Interacting effects of agri-environmental measures and landscape structure on plant-pollinator networks in agricultural landscapes

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The decline of wild bees has emerged as a critical environmental issue, with potentially far-reaching consequences for biodiversity, ecosystem stability, and food production. Numerous studies have highlighted the detrimental effects of intensive agriculture, which leads to a reduction in floral resources and a loss of semi-natural habitats, and therefore a loss of pollen and nectar resources as well as habitat for bees. Organic farming and flower fields are two popular agri-environment schemes (AES) which have been shown to enhance bee diversity and abundance in farmland by providing floral resources. However, it remains unknown how these two AES interact at the landscape scale and how their effectiveness changes with the availability of semi-natural habitats (SNH), which might provide important nesting and foraging sites for bees.

To examine these potentially interactive effects on the abundance and species richness of wild bees as well as on their plant-pollinator networks, we selected 32 landscapes with three orthogonal landscape gradients (percentage area of organic crops, annual flower fields and SNH) and conducted three transect walks across the year to record flower visiting bees. We expected to find the highest wild bee abundance and diversity in landscapes with high amounts of all three habitat types, both forms of AES and SNH. Furthermore, we hypothesized that plant-pollinator interaction networks have higher connectance and interaction diversity in landscapes with larger amounts of organic crop, semi-natural habitats, and annual flower fields in comparison to landscapes with less organic agriculture and low amounts of semi-natural habitat and flower availability. Additionally, we expect that higher floral richness in landscapes with several AES results in a higher level of specialization of interacting plants and pollinators in the networks. We interpret our results in the light of those on honeybees, which reveal the benefits of organic agriculture and flower fields, but not SNH, for colony growth and survival.

SESSION 22:

Biodiversity Change Across Ecosystems

Linking human impacts to community processes in terrestrial and freshwater ecosystems

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Human impacts such as habitat loss, climate change and biological invasions are radically altering biodiversity, with greater effects projected into the future. Evidence suggests human impacts may differ substantially between terrestrial and freshwater ecosystems, but the reasons for these differences are poorly understood. We propose an integrative approach to explain these differences by linking impacts to four fundamental processes that structure communities (sensu Vellend 2010, 2016): dispersal, speciation, species-level selection and ecological drift. Our goal is to provide process-based insights into why human impacts, and responses to impacts, may differ across ecosystem types using a mechanistic, eco-evolutionary comparative framework. To enable these insights, we review and synthesize (i) how the four processes influence diversity and dynamics in terrestrial versus freshwater communities, specifically whether the relative importance of each process differs among ecosystems, and (ii) the pathways by which human impacts can produce divergent responses across ecosystems, due to differences in the strength of processes among ecosystems we identify. Finally we highlight research gaps and next steps- including building dynamic and mechanistic models incorporating impacts, processes and responses- and discuss how this approach can provide new insights for conservation. By focusing on the processes that shape diversity in communities, we aim to mechanistically link human impacts to ongoing and future changes in ecosystems.

Climate change reshuffles northern species within their niches

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Climate change is a pervasive threat to biodiversity. While range shifts are a known consequence of climate warming contributing to regional community change, less is known about how species' positions shift within their climatic niches. Furthermore, whether the relative importance of different climatic variables prompting such shifts varies with changing climate remains unclear. Here we analysed four decades of data for 1,478 species of birds, mammals, butterflies, moths, plants and phytoplankton along a 1,200 km high latitudinal gradient. The relative importance of climatic drivers varied non-uniformly with progressing climate change. While species turnover among decades was limited, the relative position of species within their climatic niche shifted substantially. A greater proportion of species responded to climatic change at higher latitudes, where changes were stronger. These diverging climate imprints restructure a full biome, making it difficult to generalize biodiversity responses and raising concerns about ecosystem integrity in the face of accelerating climate change.

Marine biodiversity change - from global patterns to national assessment and conservation

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Driven by climate change, marine biodiversity is undergoing a phase of rapid change that has proven to be even faster than changes observed in terrestrial ecosystems. Understanding how these changes in species composition will affect future marine life in the global oceans is crucial, especially due to increasing demands for marine natural resources. At the same time, the majority of conservation measures are usually coordinated at national or regional levels and implemented at even smaller spatial scales. This calls for a more detailed knowledge of the locally acting processes and dynamics as well as an understanding of the administrative and legislative framework and stakeholders, since these highly influence the development and implementation of conservation measures.

This talk combines model projections from a global habitat suitability model for marine species with insights gained from an ongoing national marine (and coastal) biodiversity assessment. While globally climate change and its entailed changes in environmental conditions is already leading to distinct shifts in species distribution patterns, locally multiple forms of anthropogenic use are still the main drivers of changes in biodiversity. Both aspects need to be taken into account in order to achieve internationally agreed on biodiversity targets, such as the recently adopted Kunming-Montreal Global Biodiversity Framework.

Aquatic and terrestrial habitat factors influence the population ecology of newts

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Amphibian populations are declining worldwide. In addition to many other factors, habitat changes are a major driver. In order to protect local amphibian populations, it is therefore necessary to know their preferred habitat characteristics. Although amphibians are native to both aquatic and terrestrial habitats, most investigations in Europe focus on the spawning waters, while the terrestrial habitat requirements remain understudied. Using the example of smooth (*Lissotriton vulgaris*) and crested newts (*Triturus cristatus*), we investigate the influence of aquatic and terrestrial habitat conditions on the body condition of the individual animals, the activity density and the reproductive success in and around ten individual water bodies in the Leipzig floodplain system. Aquatic investigations took place from April to July using minnow traps and landing nets, and terrestrial investigations from June to September using transect searches with a newt detection dog. Both aquatic and terrestrial conditions affected newts on individual and population level, but the relative importance of both differed among them. On individual level, the relative importance of aquatic and terrestrial conditions were almost equal. Contrarily, on population level of the breeding population, the relative importance of aquatic conditions was slightly higher (60-70%) than that of terrestrial conditions (30-40%), depending on the parameter investigated. Differences of the relative importance were stronger between individual and population level than between species, suggesting a more general pattern for amphibians, which need more investigations in the future. Interactions between aquatic and terrestrial habitats happen on various ecological levels and are particularly visible in floodplain forests. Thus, permanent conservation of species needs a profound understanding of dynamic ecological processes across realms.

Trends of aquatic food webs in the Anthropocene

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Human activities are reshaping biodiversity in unprecedented ways. This reorganization has profound consequences on species interaction networks, like food webs that support ecological and evolutionary processes essential for life on Earth, prompting calls for including food webs in conservation planning. Yet, we still know little about the direction and magnitude of food web changes, especially at large spatial scales. Early work predicted that global environmental change would cause systematic loss of species and an overall homogenization of biological communities, leading to simplified food webs dominated by generalist species and their interactions. However, recent studies have shown that biodiversity responses in the Anthropocene are complex and suggested that different regions of the globe will experience greater or lower rates of change depending on the biogeographical context and the strength of human pressures. Combining extensive datasets of assemblage time-series, trophic interactions, and species traits, we reconstructed a global database of food web time-series in aquatic ecosystems to identify temporal and spatial patterns of changes in the structure and functioning of food webs. We inferred more than 16,000 food web time-series distributed in both freshwater and marine environments. The analysis of these time series showed that Global Environmental Change also affects other facets of biodiversity beyond population and community diversity changes. Despite the high variability we observed in the global trends, the response of food webs is spatially structured, with different rates of changes according to the biogeographic regions and environmental realms. Our results highlight that exploring other facets of biodiversity, like species interaction networks, is crucial to better understanding the current reshaping of biodiversity.

The significance of partial migration for food-web and ecosystem dynamics

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Migration – salmon swimming up streams, birds flying between continents, ungulates marching across vast plains – connects ecosystems around the world and can strongly shape food web and ecosystem dynamics. Less familiar, however, is that the majority of migrations in nature are partial migrations: only a fraction of the population migrates while the other individuals remain in their resident ecosystem. Although the past decade has seen burgeoning empirical and theoretical interest in understanding the significance of migration for community and ecosystem dynamics, the partial nature of migration has been largely overlooked. We demonstrate different impacts of the partial nature of migration rendering it fundamental to understanding the dynamics of food webs and ecosystems connected across space via migration. First, partial migration affects the spatiotemporal distribution of individuals and the food web and ecosystem-level processes they drive differently than expected under full migration. Second, whether an individual migrates or not is regularly correlated with morphological, physiological, and/or behavioural traits that shape its food-web and ecosystem-level impacts. Third, food web and ecosystem dynamics can drive the fraction of the population migrating, enabling the potential for feedbacks between the causes and consequences of migration within and across ecosystems. These impacts, individually and in combination, can yield unintuitive effects of migration and drive the dynamics, diversity and functions of ecosystems connected across space via migration. By integrating partial migration and trophic (meta-)community and (meta-)ecosystem ecology, we provide a roadmap for studying how migration affects and is affected by ecosystem dynamics in a changing world.

Tropical and temperate differences in aquatic prey use, trophic structure and diversity patterns of riparian communities

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The impact of aquatic resource-inputs on terrestrial communities is poorly understood, particularly in the tropics. We used stable isotopes to track aquatic prey use and quantify impact on trophic structure in 240 riparian arthropod communities in tropical and temperate forests. We then linked these data to changes in riparian community composition and biodiversity patterns. Riparian predators consumed more aquatic prey and were more trophically diverse in the tropics than temperate regions, indicating tropical riparian communities are both more reliant on, and impacted by, aquatic resources than temperate communities. Although aquatic resource use declined strongly with distance from water, we observed no correlated change in trophic structure, suggesting trophic flexibility to changing resource availability within riparian predator communities in both tropical and temperate regions. We did observe distinct, systematic shifts in riparian community composition with distance from water. This was driven by predators (specifically spiders) in the tropics, reflecting their greater reliance on aquatic prey, but non-predatory taxa in temperate sites, reflecting an aquatic influence other than resource-inputs. Our findings suggest aquatic resource-inputs are more important for riparian communities in the tropics, making them more vulnerable from disruptions to aquatic-terrestrial linkages caused by future environmental change.

Insights into taxonomic and functional effects of floodplain decoupling on terrestrial plant and animal communities

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The decoupling of floodplains from their river as a result of river degradation is a big issue in all of Europe. Decoupling alters the hydrological regime and damages the small-scale heterogeneous mosaic of habitats that is typical of intact floodplains. (Geo-)morphological alterations are clearly observable, but what happens to the floodplain's biotic communities when the floodplain is decoupled and river-floodplain fluxes are drastically reduced? The project ElBiota examined four floodplain sections along the Elbe River, two of which are well-coupled to the river while the other two have become decoupled. We compared the taxonomic as well as functional diversity of plant, mollusc and carabid communities in those sections and looked for the environmental factors driving the observed patterns. While plant and mollusc communities showed decreased species richness with many floodplain specific species missing in the decoupled sections, carabid beetles had higher species numbers in those sections. Functional richness was lower in the decoupled sections for all three organism groups, but only molluscs and carabid communities showed a clear shift in their functional identity from more disturbance-adapted in the coupled sections to less disturbance-adapted in the decoupled ones. The results suggest that all three organism groups are affected by floodplain decoupling, though the drivers behind these patterns differ. While plant community composition is more directly associated with river-floodplain connectivity, animal communities depend more on the occurrence of suitable local habitat patches.

Mapping spatial patterns of carabid beetle community assembly processes across Switzerland.

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The processes that rule community assembly from the available species pool are increasingly understood. However, the spatial patterns of these processes remain poorly known. With this study we aim to identify, quantify and predict the spatial variations in carabid beetle community assembly processes across Switzerland. We defined the species pool of each local community using a species co-occurrence-based approach. We considered different community-level metrics including taxonomic diversity, community weighted means of traits and functional diversity. Community assembly processes were assessed by quantifying the shifts in these metrics between a random assembly of species from the pool and the observed local communities. Lastly, we constructed a predictive model using climate, vegetation structure, and land use as predictors and the aforementioned shifts as response. Here, we present countrywide maps of projected shifts in community-level metrics representative of community assembly processes. Climate, vegetation structure, and land use were identified as promising predictors of the spatial patterns of assembly processes. Our results also revealed a spatial mismatch among functional and taxonomic diversity components. This study provides a first step to document and understand spatial patterns of community assembly processes at country scale.

Distribution of breeding birds, taxonomic and functional diversity along the Vjosa river in Albania

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Vjosa River is one of the last free-flowing, large rivers in Europe. The riverine landscape hosts a variety of dynamic, semi-natural habitats for fauna and flora, making the Vjosa a hotspot of European biodiversity and an important reference system for dynamic floodplains throughout Central Europe. However, little is known about the distribution and drivers of biodiversity of important taxonomic groups such as birds along the river course. The aim of this study is to assess the distribution and drivers of taxonomic and functional diversity of breeding birds along the entire course of the river Vjosa in Albania.

We surveyed bird diversity along 2 km transects in 10 river stretches representative of the main functional process zones of the river (meandering, braided, canyon). We calculated community attributes, including taxonomic diversity metrics, community mean trait values, and functional diversity metrics. We modeled their distribution using predictors describing gradients of climate, riverine habitat types and dynamics, and landscape structure in the neighborhood of the transects.

We observed a total of more than 70 species along the Vjosa River, including species whose populations are declining (*Actitis hypoleucos*) or threatened (*Falco vespertinus*, *Streptopelia turtur*). The functional process zones showed clear differences in bird community taxonomic and functional composition. Climate, riverine habitat types and dynamics, and landscape structure were all critical features determining the spatial patterns of bird taxonomic and functional diversity along the Vjosa River.

This study provides important insights into bird ecology in dynamic, semi-natural large rivers in Europe and could pave the way for more integrated conservation measures for the Vjosa River.

Using common responses across bird communities in Africa as a tool for monitoring biodiversity change.

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Making synthesis of community ecology at continental scales might provide useful insights of how ecological communities are responding to different types of human influence an uses this knowledge for monitoring change in communities at continental scales. I revised peer review literature in community ecology of African birds from 1960 to 2023 to detect common responses of bird communities to different types of human influence. I identified in my synthesis fourteen patterns that summarize the complex but common responses of bird communities to different anthropic drivers including land use, habitat fragmentation and loss, logging, exotic species among others drivers. Both forest and savanna bird communities have similar responses to the drivers, but there are also important differences among biomes. Overall, my synthesis shows that synthetizing knowledge about regular responses of bird communities to human influence in Africa can help 1) to define conservation targets for conserving bird diversity in different landscape contexts and across African regions, 2) establish benchmarks for comparing trajectories of communities under different scenarios, 3) explore uncertainties in community change and 4) track the status of ecological communities under different human drivers at continental scales.

SESSION 23:

Regional Biodiversity Change

Long-term occupancy trends across three insect taxa and their potential drivers in Central Europe

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Recent changes in climate and land-use are having substantial impacts on biological organization including population declines, range shifts, and changes in community composition. In contrast, conservation policy like the European Habitats Directive aims to protect biodiversity from negative impacts. However, few studies have managed to compare these influencing factors among multiple taxa in insects especially, particularly because of a lack of standardized time series data over long periods. To make matters worse, existing datasets are typically of low resolution or poor coverage, thereby limiting what inferences can be made from their use. Here, we analyse occupancy changes in butterflies, grasshoppers, and dragonflies using an extensive dataset of highly heterogeneous observation data collected in the central European region of Bavaria over a 40-year period. Using occupancy models, we show that the occupancies (the proportion of sites occupied by a species in each year) of cold-adapted species across taxa have already declined in past decades, while those of warm-adapted species have increased. In butterflies, habitat specialists also decrease, while in the other taxa there was no difference between habitat generalists and specialists. Ant-dependence may have had a stabilizing effect on Lycaenid butterflies. We show that although the Habitats Directive increased monitoring efforts towards species protected in its annexes, occupancy trends both improved and deteriorated after its implementation. Therefore, contrary to its main goal, the European Habitats Directive did not prevent a worsening of species status. Our findings illustrate not only why butterflies, grasshoppers, and dragonflies showed differing trends in the past as well as the effectiveness of Europe's most important nature protection instrument, but also how we might mitigate the detrimental effects of human development on the species' diversity in the future.

Vegetation dynamics in forest and grassland habitats across a century of accelerating global change

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Accelerating global change affects ecosystems, their composition and functioning at an unprecedented rate. While multiple drivers have a strong impact on ecosystems in Europe, our understanding of long-term ecosystem dynamics as a response to global change is limited, hampering an effective adaptation of conservation and management efforts. The Habitat concept is an important measure of biodiversity linking landscape, vegetation and species scales, making it a crucial target of European conservation efforts. Grassland and forest habitats are of key importance for European biodiversity, collectively comprising more than half of the European surface area. However, knowledge on trends in vegetation dynamics within and across habitat classes is scarce. We quantify vegetation dynamics within and across different forest and grassland habitats throughout Germany using combined long-term time series data sets collectively covering the time period from 1927 to 2022. We analyse species cover and weighted Ellenberg indicator dynamics to explore trends in forest and grassland herbaceous vegetation, relationships between the velocity of change and within habitat class dispersion as well as between class distances over time. Our results will help to assess long-term dynamics in changing ecosystem vegetation, aiding a better understanding of trends and directions of change in European grassland and forest habitats informing efforts to adopt conservation and management to global change.

Changes in Czech flora and vegetation over the last six decades

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In the last decades, natural habitats have been affected by climate changes, cessation of traditional management, atmospheric deposition, drainage and other anthropogenic pressures. The aim of our study is to assess how these factors have impacted the Czech flora and vegetation over the last 60 years. We used data from the PLADIAS Database of the Czech Flora and Vegetation to assess the extent of temporal changes in the occurrence of species of the Czech flora. We selected over 4 million species records of 1891 species from 4787 authors collected during the last six decades and analysed changes in species occurrence over time using Bayesian occupancy modelling. Temporal trends of individual species were linked to their characteristics (occurrence in natural habitats, indicator values, functional traits, Red List status, native vs alien). We tested for significant differences in environmental preferences and functional traits among increasing and decreasing species. We identified a decrease in species of nutrient-poor sites and an increase in species with preferences for nutrient-rich sites, which suggests a shift towards a more eutrophic landscape. We also detected a significant decline in specialist species.

Ready to answer questions about regional biodiversity change? Metrics of two large heterogeneous datasets of plant occurrences for visualization and analysis in GBIF and NFDI

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The initiative "Flora of Bavaria" contains accounts of Bavaria's more than 4.000 vascular plants, including naturally occurring, newly naturalized, invasive, and also extinct species. It documents the change of the Bavarian flora since the late 18th century. Two datasets, each with more than 7 million grid-based occurrence data, are available through national and international online platforms. One contains floristic data created, mobilized and curated by hundreds of expert volunteers in regional long-term mapping projects. The other includes occurrence data from monitoring campaigns done under nature conservation perspective designed and led by the Bavarian Environment Agency. Both datasets are managed in installations of the Diversity Workbench, transformed and provided as digital entities via data pipelines compliant with GBIF (https://www.gbif.org/) and NFDI4Biodiversity (https://www.nfdi4biodiversity.org). They are in the process of being included in the NFDI Research Data Commons framework with storage layer, semantic layer and cloud services for data retrieval, visualization and analysis. The two digital entities are clearly identifiable by their two persistent identifiers (PIDs) and regarded as FAIR digital objects with altogether 15 million subunits representing single occurrence records, each with its own persistent identifier.

In this study, we compare the metrics of the two resources with regard to the provenance, grid-based mapping design, time span, regional geographic scope, coordinate transformation, taxonomic distribution pattern, species concepts, data quality concerning floristic and nature conservation categories, community standards for interoperability, as well as aspects of the management of persons and organizations involved as part of a linked open data network. As a result the two digital entities with their millions of single subunits are profiled and ready to be evaluated for their suitability for projects on regional biodiversity change.

The potential of ecoregional range maps for boosting taxonomic coverage in ecology and conservation

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Expert range maps (ExpRMs) are frequently used to inform species distributions, but often incomplete or missing for many species, particularly among plants and invertebrates. Many species without ExpRMs also have too few occurrence records for reliable application of species distribution models (SDMs). Here we evaluate the performance of commonly used range surrogates and recommend tools that can help fill this significant knowledge gap across a wide range of understudied taxa. Specifically, we present an alternative range surrogate (ecoregional range maps; EcoRMs), assess its performance versus traditional approaches for 624 North American butterfly species, and outline its use alone and as part of SDMs. As an alternative range estimate, we propose using terrestrial ecoregions that represent a regionalization of biogeographical zones and we suggest geographical filters and simplifications that improve their performance. We show that consistently across different spatial scales and both in comparison with ExpRMs and SDMs, EcoRMs have an exceptionally high sensitivity and generally a high mean performance. Particularly for species with fewer than 100 occurrence records, EcoRMs outperform other range surrogates. The congruence of species richness patterns was also similar for all approaches.
We suggest a broad spectrum of applications of EcoRMs for conservation and biodiversity research, including their use as domains/masks/offsets in SDMs and as substitute for data-poor species without ExpRMs. We discuss additional advantages of EcoRMs that help overcome issues of the availability, actuality, updateability, and reproducibility of ExpRMs. We suggest further performance assessments of freshwater and marine ecoregions for other taxa. In summary, our results highlight that EcoRMs will significantly boost the availability and accuracy of range surrogates. For example, the adoption of EcoRMs would uniquely provide range information for 17% and improve basic range information for 43% of all butterfly species.

Social media records hold valuable information for conservation planning

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Citizen science plays a crucial role in helping monitor biodiversity and inform conservation. With the widespread use of smartphones, many people share biodiversity information on social media, but this information is still not widely used in conservation. Here, focussing on Bangladesh - a tropical mega-diverse and mega-populated country, we examine the potential importance of social media records in conservation decision-making. We show that adding Facebook data to the Global Biodiversity Information Facility (GBIF) data improved conservation planning assessments by identifying additional important conservation areas in the northwest, southeast and centre parts of Bangladesh, extending priority conservation areas by 2000-5000 km2. Community efforts are needed to drive the implementation of the ambitious Post-2020 protected area targets, especially in mega-diverse tropical countries with a lack of reliable and up-to-date species distribution data. We highlight that conservation planning can be enhanced by including available data gathered from social media platforms.

Long-term changes depend on elevation: unveiling 50 years of moth observations

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Along elevational gradients, such as those found along mountain ranges, environmental conditions are changing in small space, reflected in distinct changes in arthropod communities. However, the susceptibility of arthropod communities at different elevations to global change remains poorly studied due to the lack of long-term data covering large elevational gradients. For example, many studies on insect decline originate from intensively used lowland landscapes. Here, we studied a vast dataset on moth communities collected by a highly committed naturalist in Switzerland over a span of 50 years (1972–2021), comprising over 35,000 sampling nights and more than 2.5 million moth individuals. The dataset covers an elevational gradient of over 2000 meters, allowing us to examine the response of moth communities to environmental changes across different elevations.

Our findings reveal a decline in moth abundance, biomass, and species richness in lower elevational sites, while higher elevations exhibited increases in all three parameters. Particularly cold-adapted species have been shifting to higher sites. The observed trends in moth communities at different elevations were linked to the substantial increase in summer temperatures during the study period, and the effect of increasing summer temperatures was partly dependent on land use in the surrounding of the study sites (e.g., cover of forest). While no relation to changes in winter temperatures were found, trends differed considerably between moth species with different overwintering strategies, indicating that different ecological strategies make species vulnerable to different global change drivers.

Our study highlights the importance of considering large environmental gradients when assessing the decline of insect biomass or species richness and emphasizes the context specificity of long-term changes in arthropod communities. Thus, depending on environmental conditions, different drivers might need to be addressed to halt biodiversity loss.

Biodiversity trends in Germany: An analysis across taxonomic groups and habitats

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Biodiversity in Germany is under threat due to various factors such as habitat destruction, increasing land use intensity and climate change. While conservation efforts have helped to restore degraded ecosystems and improve biodiversity of specific taxa and habitat types in recent years, a comprehensive evaluation of the state of biodiversity is currently lacking also due to the lack of long-term monitoring data.

As part of the German national biodiversity assessment "Faktencheck Artenvielfalt" we analyzed trend data of biodiversity across different taxa and habitats, covering the period from 1950 until today. We conducted a systematic literature review with focus on temporal trends and additionally calculated trends from available raw data on species richness, abundance and biomass. We summarized trends across studies with weighted vote counts, a method that gives more weight to studies with more observation years, and thus, trends with higher confidence. We used a moving window approach for aggregating data points to visualize the changes over time.

Our analysis reveals that mean biodiversity trends vary significantly across taxa and habitat types. With regard to abundance and species richness, the situation in inland waters has improved, while vertebrate populations, especially birds, in agricultural habitats have decreased. For some taxa, our results contradict the trends reported in red lists. A higher number of positive trends might be explained by the large proportion of study sites from protected areas. Especially shorter time series did not show clear biodiversity trends, highlighting the need for long-term monitoring data.

This incomplete knowledge of biodiversity trends in certain taxa can hamper effective conservation strategies and policies. Therefore, it is important to establish long-term monitoring programmes across a wide range of taxonomic groups and habitat types to gain a comprehensive understanding of biodiversity trends.

Long-term population trends for freshwater fish in German rivers – What do data, traits, and experts tell us?

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Freshwater biodiversity is declining globally, with one-third of all known freshwater fish facing the threat of extinction. For setting conservation priorities, it is important to estimate long-term changes in populations and understand the variation in species' trends. However, data are often fragmented or scarce. Other less data-intensive approaches, including trait-based approaches or expert opinions, are important to identify target species for conservation, e.g. for red list assessments. In our study, we compared three approaches for identifying long-term population trends of freshwater fish in German rivers and conservation priorities: (i) based on an almost German-wide high-quality abundance dataset, (ii) trait-based approaches and (iii) expert knowledge, namely knowledge from recreational anglers across Germany. Our study highlights the advantages and challenges of employing different sources of information to set conservation priorities for freshwater fish species.

Taxonomical and functional changes in dry grassland vegetation after 30 years

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Dry grasslands on porphyry outcrops in Central Germany are part of the Natura 2000 habitat network and extremely rich in plant species, but have suffered from increasingly frequent drought events, variation in grazing management and intensification of agricultural use of the surrounding landscape.

To explore how plant diversity has changed in the last decades we resurveyed 156 plots that were originally recorded in 1993. We analysed taxonomic and functional changes (species richness, community composition, community-weighted mean traits) and related micro-topography (aspect, slope) and soil variables (depth, pH, C/N, P, Ca, Mg, K) to the changes observed between the vegetation surveys.

On average, we found increased species richness with lower mean vegetation cover, as well as a considerable shift in species composition, brought about by the increased number of therophytes. Trait composition showed a clear shift in flowering phenology, ecological status and reproduction type, benefitting early bloomers, generalists and seed dispersal, while locally restricted grassland specialists decreased. Changes at the landscape scale were mainly related to habitat area, as species and trait composition were less affected on larger outcrops. In contrast, local scale changes were more related to micro-topography and soil characteristics, pointing to the importance of microsite conditions on mitigating large-scale impacts.

Climate change has significantly affected the composition of grassland communities on porphyry outcrops in Central Germany. While dispersal of species with certain characteristics seems to have be promoted by the phenological shifts, the spread of rare characteristic grassland species seems to have be impeded. This resulted in maintenance of plant diversity at the local scale but declines at the landscape scale. These findings highlight the importance of biodiversity change assessments at different spatial scales.

Biodiversity Monitoring South Tyrol: A multi-taxon monitoring scheme in an Alpine region

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The need for long-term regional data on biodiversity population trends has grown rapidly in recent decades. This is particularly true for mountain regions, which are considered global hotspots for biodiversity. Local politicians, representatives of stakeholder organizations and the public, all have a growing interest in sound and reliable data on biodiversity. This data is needed to provide the scientific basis for political decisions, especially those concerned with spatial planning, agriculture, and nature protection.

In 2019 a permanent biodiversity monitoring program was started in South Tyrol, Italy, as an initiative of the local provincial government with Eurac Research experts responsible for the project mapping, data collection and dissemination of the results.

The aim of the Biodiversity Monitoring South Tyrol is to survey species groups which are sensitive to climatic and land use changes. The study sites are distributed evenly over the region and include a representative selection of near-natural habitats, such as high-mountain grasslands, alpine brooks and forests, as well as habitats which have been strongly influenced by humans, such as meadows, vineyards and residential areas. Since 2019, a total of 320 sites will undergo investigation for a total of 5 years as part of the project's terrestrial monitoring. The surveyed taxa cover vascular plants, bryophytes, birds, bats and insect groups, such as grasshoppers and butterflies. For the aquatic part of the monitoring, a total of 120 individual areas of running water are being surveyed over a period of 4 years for water insect larvae. In addition, data on abiotic factors as well as on the surrounding landscape is also being collected.

Another major focus of the initiative is the constant dialogue between the project experts and the local authorities. In addition, further activities in the field of biodiversity are also regularly promoted both within the framework of special projects and in the fostering of networks between biodiversity experts. Finally, the medial communication of the results to the public is a crucial point of the monitoring program. The presentation gives an overview of the project and reveals the findings of the project's first four years.

Linking trends of habitat types and plant species on a regional scale

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Habitat change represents one of the main drivers of species declines worldwide. Changing habitat conditions especially affect habitat specialists, while they might favor more generalist species. To link trends between habitat change and species change, data are needed that combine information on both habitats and species from the same locations across large areas, which so far are scarce. In Germany, habitat mapping programs have been carried out on the level of the federal states over the past decades, mapping all protected habitat types while also recording plant species occurrences inside those habitats.

Here, we make use of these habitat mapping data from the federal state of Baden-Württemberg to derive temporal trends of (1) habitat types, (2) plant species across the state, and (3) plant species inside different habitat types. We tested the consistency between trends of the extent of every protected habitat type with trends of those species that prefer that particular habitat type, as well as with mean trends of all species that occur inside that particular habitat type.

We found that, on average, most protected habitat types decreased in area, with the exception of forests, which showed positive trends. Species analysis showed positive trends especially for those species that preferred the habitat types scrubs, copses and field hedges, and bog, carr, swamp and alluvial forests. Negative trends were found for species preferring the habitat types heaths and semi-natural grasslands, meadows and pastures and for species that are considered endangered. Generally, a species' trend across Baden-Württemberg mostly followed the trend of the preferred habitat type of that species. However, the mean trend of all species inside a habitat type did not necessarily follow the mean area trend of the respective habitat type. While especially the species preferring the respective habitat type were decreasing in their occurrence probability, other species showed more positive trends.

This points to ongoing turnover of floristic composition, and thus, to changes in habitat quality within habitat types. Our study implies that future monitoring programs should track temporal trends of both habitat types and the species occurring in these habitats, as they can show diverging trends.

Where peat disappears, specialists go first:

An ecological analysis of historical and recent distribution sites of *Liparis loeselii*

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The cultivation of fens in Europe has led to massive anthropogenic degradation of these complex ecosystems over the past centuries. These changes have led to a massive loss of biodiversity and in some cases to the local extinction of species. This includes the yellow widelip orchid (Liparis loeselii), which is typical for alkaline fens and is strictly protected in the European Union. Habitat preferences and threats to central European populations have been poorly studied, which makes effective habitat management difficult. In this study we aim to show habitat preferences of the species and try to identify main drivers for the ongoing decline. Therefore in this study we researched 17 recent sites and 11 historical sites of Liparis loeselii in Germany. We used a nested-plot design of random and selected placed plots to tackle the heterogeneity of the sites or possible observer effects. For each plot, the entire vegetation and a selection of abiotic parameters was recorded. To examine the ecological changes between site and plot categorys, we used linear mixed models. In addition we analysed species composition with a redundancy analysis (RDA) followed by a permutation test with restricted permutations. The results show that the historical sites are characterised by a high degree of humification of peat, higher nutrient availability and higher litter cover. At recent sites, Liparis loeselii prefers habitats with low humification of peat, high PAR radiation and lower graminoid cover. Furthermore species composition differs between recent and historical sites, but also on researched plot categorys. The results suggest a persistent water deficit for the historical sites, which leads to extensive eutrophication in the fens and thus promotes high growing, competitive species. Populations at recent sites, which often only exist in small scalled areas, suggest a narrowly realised ecological niche for the species.

Long-term data indicates positive effects of habitat size and ambiguous climate effects on population growth of the endangered wetland orchid *Dactylorhiza majalis*

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Central European semi-natural wet grasslands are known for their high nature value and diversity of rare and endangered species. However, they are experiencing deteriorating habitat quality and species losses, a problem that may aggravate with climate change. Identifying key factors that jeopardize wet grassland species is an urgent task for effective conservation.

To this aim, we studied the endangered orchid Dactylorhiza majalis, a characteristic species for Central European wet grasslands of high biodiversity and habitat quality. We compiled long-term monitoring data (1993 – 2020) for 84 populations located within the species' range center (NE-Germany) and analyzed i) long-term trends in population size and ii) immediate and time-lagged effects of six climatic variables and habitat size on population growth.

Situated mostly within nature reserves, the majority of populations remained stable (51%) or increased (31%) in population sizes. However, 18 % declined despite suitable habitat management. Small habitat size negatively affected population growth. The effect of climatic variables on population growth was rather small and ambiguous, while asynchronous variation among populations was strong. Population growth increased with higher spring temperatures but decreased with lower spring precipitation; lower spring precipitation and late frost events had positive time-lagged effects in the next season.

We conclude that D. majalis may withstand moderate levels of climate change, provided that future conservation practice can ensure suitable management and water tables sufficiently high for wet grassland species. Our results highlight the vulnerability of small wet grasslands and that large habitat size promotes effective conservation of one of the most diverse semi-natural habitats in Central Europe.

Key words

Orchidaceae, semi-natural grasslands, long-term monitoring, conservation, climate change, habitat size

Linking diversity with metabolic activity of bacterioplankton in four subalpine lakes

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Lakes and their plankton communities respond highly sensitive to global warming. Their resilience in response to stressors should be connected to the biodiversity of their communities. Lakes that are geographically closer to each other should show higher biodiversity than remote ones, based on island-biogeographic-model.

In order to link the functioning of bacterial communities to their diversity and their resource environment, we combined metabarcoding of bacterioplankton with bioassays and a characterisation of organic resources in the lake water. We compared the functioning of the communities among four different lakes in Austria, which are situated in different regions (Eastern Calcareous Alps and Salzkammergut). Two of them are rather isolated within the landscape and two are part of a large lake network, representing the two connected lakes in this survey. We used BiOLOG EcoPlates © bioassays, where lake water was incubated with 31 different organic test substrates. Diversity of bacterial communities was determined by amplicon sequencing. In addition, we characterize resource diversity by amino acid analysis.

We found that the diversity of resource use scales negatively with the availability of resources – resources that were abundant in the water were used least in the bioassays. This points at processes linked to resource use that are activated by resource limitation.

Assessing the spatial patterns of potential functional connectivity across multiple species and taxonomic groups in Switzerland.

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Functional connectivity defines the potential connection between two localities through species dispersal. It relates to the ability of a species to move and settle in new habitats and plays a key role in sustaining metacommunity processes. Here, we aim to quantify the probability that two communities are functionally connected through species dispersal using a new index that incorporates geographic distances, environmental distances and functional trait similarity. We considered functional traits related to mobility, reproduction, environmental niches and diet. We tested this approach on bees, birds, carabid beetles, grasshoppers and butterflies across Switzerland. We present spatially explicit, nationwide, connectivity networks for five different taxonomic groups. We show that the structure of these networks relates to individual species distribution and community, taxonomic and functional composition. Modularity analyses revealed clear clusters of ecological communities with high probability of being functionally connected. The spatial organisation of these clusters reflected Swiss ecoregions. The new index can help identifying highly connected or isolated sites that are likely to play a key role in species dispersal. This can strengthen our understanding of the role of species dispersal for metacommunity dynamics and biodiversity maintenance. It can also guide and help prioritize countrywide current and future conservation efforts.

Tracking changes in genetic diversity of endangered plant species using herbarium specimens

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Intraspecific genetic diversity is a key element of plant biodiversity because it determines the potential of populations to adapt to changing environmental conditions. Recent anthropogenic activities can lead to dramatic habitat change and fragmentation which may reduce population sizes and increase the isolation of plant populations. Together, these interactions may negatively affect the genetic diversity, reproductive success, and ultimately increase the extinction risk of endangered plant species (i.e., extinction vortex). Comparisons of current vs. historical population genetics offer promising opportunities to test these relationships by tracking genetic changes through time and space.

This study focuses on three highly endangered plant species from Central Germany (*Antennaria dioica*, *Omphalodes scorpioides*, *Viola pumila*). In our field surveys, we could only find 30% of the populations that had been recorded 20 years ago in the study region. As such, these remaining populations are crucial for the survival of the three species in Central Germany. In order to assess the urgency of endangerment status of the species, we investigated population sizes, fitness proxies and the genetic diversity of the current populations of the studied species. Furthermore, we sampled leaves from 300 herbarium specimens to estimate how much genetic diversity has been irreversibly lost through time (e.g. due to climate change, habitat fragmentation, and land use changes). Genetic data have been obtained by applying MIG-Seq, an effective method for SNP genotyping of degraded DNA (such as old herbarium samples). The resulting data will be used to develop indicators of biodiversity change and extinction risk. Our study emphasizes that herbaria are invaluable, though underestimated sources to inform conservation and restoration measures.

Which site conditions enhance natural recruitment in D. majalis - a characteristic orchid of Central European wet grasslands.

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Dactylorhiza majalis is a characteristic orchid of Central European semi-natural wet grasslands and is considered to indicate high habitat quality and biodiversity.

Despite various conservation efforts, the species is endangered in many European countries and extant populations are frequently further declining.

While flowering individuals of *D. majalis* are frequently monitored, natural recruitment and establishment niches of the species have been investigated less often.

Here, we aim to provide insight in conditions suitable for successful recruitment, to strengthen long-term viability of species´ populations.

In 96 populations located within the species' range center (NE-Germany) we investigated, which environmental factors affect recruitment rates of the terrestrial orchid *Dactylorhiza majalis* *u*sing both generalized mixed models and multivariate analysis.

Our results indicate, that recruits react more sensitive to certain environmental parameters in comparison to adult plants.

To enhance successful species conservation, management of semi-natural wet grasslands should focus on provisioning site conditions within the recruitments niche.

Elevational changes in canopy Collembola community composition are primarily driven by species turnover

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Forest canopies harbor an unparalleled biological diversity, with Collembola being one of the most abundant taxa. However, much of the research on canopy biodiversity focused on tropical and subtropical regions, leaving a gap in understanding canopy communities of temperate and boreal forests. To better understand and conserve biodiversity, studying canopy Collembola biodiversity along elevational gradients of natural forest is needed. In this study, we used canopy fogging to sample canopy Collembola along four elevational sites (800-1700 m a.s.l.) on Changbai Mountain, northeastern China, representing three forest types. We examined changes in species richness, abundance and composition of canopy Collembola, and partitioned beta diversity into nestedness and turnover to identify processes driving changes in community composition of canopy Collembola. We identified 53 morphospecies among 10,191 individuals, with Entomobryidae and Hypogastruridae being the dominant families. Abundance and species richness of these families increased gradually with increasing elevation. Species turnover was the main driver of community compositional changes with elevation. The results provide first insights into canopy Collembola communities across an elevational gradient in temperate and boreal forests allowing to better understand their response to future global climate change.

SESSION 24:

Stressors and Sensory Pollution

Combined effects of insecticide and poor quality food on health and foraging behavior of pollinators

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In agricultural landscapes, pollinators are facing a variety of stressors including exposure to insecticides and a reduction of floral resources. These stressors were frequently investigated separately, but studies investigating interacting effects are rare. A further key question is whether such stressors, which are known to affect health traits in pollinators, also affect the provision of pollination services e.g. by changing pollinator behavior.

In our study, we wanted to investigate whether interacting stressors affect not only pollinator health but also the potential delivery of pollination services by measuring health traits and conducting behavioral observations of two common pollinator species, Bombus terrestris (B. t.) and Episyrphus balteatus (E. b.) in a fully-factorial, semi-field setup. The pollinators were treated with either field realistic doses of the widely used neonicotinoid Acetamiprid, low quality food (polyfloral honeybee pollen mixed with pollen exines in a 70:30 ratio), or both. The pollinators were released in large flight cages and foraged on selected plant species, while we observed their foraging pattern, flight duration and flower handling time. As health traits, we measured overall colony development (B. t.), survival (E. b.), ovarian development (E. b. & B. t.) body size (B. t.) and asymmetric wing development (B. t.).

In both pollinators, we found that low food quality was the main factor in reducing pollinator health by decreasing bumblebee body size and ovarian activation of both pollinators, and that the effects were strengthened by the insecticide. Bumblebee behavior, however, was mostly affected by insecticide, with significantly increased flower handling times and increased flight durations. Syrphid fly behavior did not respond to insecticide treatment, but to low quality food, leading to shorter flower handling times. Our study demonstrates that different pollinators can react differently to various stressors of land-use.

Combined effects of warming and pharmaceuticals on freshwater ecosystems from an individual to ecosystem level: a mesocosm study

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Global warming and chemical pollution cause rapid environmental change and pose a major threat to biodiversity and functioning of freshwater ecosystems. We investigated the combined effects of +4°C warming and a mixture of commonly used pharmaceutically active compounds (PhACs) on a pelagic invertebrate community in outdoor mesocosms mimicking small freshwater ponds. The experiment was conducted twice (in winter and summer). The effects of warming and PhACs differed greatly between seasons and across scales and trophic levels. The PhAC mixture reduced phytoplankton biomass and altered individual development of odonate larvae in summer, while it had only marginal effects on the community in winter. Warming reduced the survival of predatory aquatic insects in winter and accelerated their development in summer, partially releasing large zooplankton from top-down control. Finally, phytoplankton biomass increased with warming in the summer, but not in the winter experiment. Our results show that (1) warming can either mask or amplify the effects of anthropogenic pollutants on freshwater communities and (2) the effects of combined stressors on freshwater communities are context-dependent and differ across scales of biological organisation.

Impacts of multiple anthropogenic stressors on the transcriptional response of *Gammarus fossarum* in a mesocosm field experiment.

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Freshwaters are exposed to multiple anthropogenic stressors, but the combined effects of stressors are difficult to predict as they can interact in complex ways. Furthermore, stress responses may remain undetected if only the abundance changes in ecological experiments are considered, as organisms have physiological protective pathways to counteract stressor effects. Since physiological coping mechanisms are ultimately controlled at the transcriptional level, gene expression data can be used to detect stressor effects which do not immediately translate in structural alterations of biological communities. We used transcriptome-wide sequencing data to quantify single and combined effects of elevated fine sediment deposition, increased salinity and reduced flow velocity on the amphipod Gammarus fossarum in a mesocosm field experiment. Stressor exposure induced a strong transcriptional suppression of genes involved in cell metabolism, indicating that G. fossarum responds to stressor exposure by directing energy to vitally essential processes. Treatments involving increased salinity induced the strongest transcriptional response, contrasting the observed abundance patterns where no effect was detected. Stressor interactions at the transcriptional level were mainly antagonistic, such as the combined effect of increased fine sediment and reduced flow velocity. A compensation of the fine sediment induced effect by reduced flow velocity is in line with observations based on specimen abundance data of gammarids. Our findings imply that transcriptomic data can be used to detect stressor effects that similarly propagated to higher ecological levels but additionally provide new mechanistic insights in multiple stress responses. An assessment of stressor effects at the transcriptomic level and its integration with stressor effects at the specimen abundance level significantly contribute to our understanding of multiple stressors in freshwater ecosystems across biological scales.

"Multiple-stressor effects on litter decomposition in freshwater ecosystems: A meta-analysis"

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Freshwater ecosystems are subject to multiple stressors, including flow modification, land use change, pollution, invasive species, and climate change. Different stressors often occur simultaneously in freshwater ecosystems, posing risks to ecological integrity and ecosystem services. Multiple stressors have gained increasing attention due to the difficulty of predicting the magnitude and direction of their interactions, leading to unexpected outcomes in restoration efforts. However, multiple-stressor research has primarily focused their effects on species performance or community structures. Ecosystem functions, which provide a more comprehensive measure of ecosystem health, have received limited attention. We conducted a meta-analysis to investigate multiple-stressor effects on litter decomposition in freshwater ecosystems. We analyzed 67 responses to two-stressor combinations and identified their interaction types. Additionally, we explored the influence of various moderator variables on the magnitude and direction of interactive effects. The most frequently investigated stressors included hydrological and morphological alterations, nutrients, heavy metals, and temperature. Although vote counting showed that the majority of the stressor interactions was additive, the weighted random-effects model revealed an antagonistic interactive effect. We also demonstrated the influence of moderator variables, such as the presence of macroinvertebrates, dispersal, habitat type, and litter type, on the direction and magnitude of stressor interactions. Our findings emphasize the importance of including various components of freshwater ecosystems when investigating the effects of multiple stressors on ecological functions.

Shifting the spotlight: A bird's eye view on light pollution

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One of the most dramatic changes occurring on our planet in recent decades is the ever-increasing extensive use of artificial light at night, which drastically altered the environment nocturnal animals are adapted to. Unlike animals moving exclusively on the ground, flying animals can move vertically in addition. One parameter considerably changing with altitude is the visual range and thus the light environment perceived by an individual. To demonstrate this, we performed measurements at the Watzmann, the central massif of the Berchtesgadener Alps.
At this special location, it was possible to use ground-based all-sky photometry at different altitudes due to the steep incline, demonstrating the crucial differences depending on altitude.
Moreover, our recent findings revealed by harmonic radar indicate that flight altitude is decisive for the attraction of moths towards an artificial light source. We therefore propose to extend the attraction radius of a light source, which is conceived only in two dimensions to date, by the third dimension. Since the disturbance of natural light patterns by artificial light is altitude dependent, we emphasize the need to include altitude as a vital parameter in the study of ecological light pollution and encourage further research to determine its role as a predictor of light-related effects on airborne organisms.

Reducing harmful effects of light pollution through customised lighting technology protects aquatic and terrestrial insects

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Artificial light at night (ALAN) is a rapidly growing, globally relevant sensory pollutant. Previous studies have shown that particularly (1) aquatic insects, and (2) nocturnal pollinators are negatively affected by this emerging pollutant. As these two groups provide (1) critical across-ecosystem linkages of biomass and energy flow, and (2) essential ecosystems services, respectively, ALAN has a high potential to disrupt vital ecosystem functions and contribute to ongoing insect declines. Here, we present an ongoing project that not only investigates the effects of ALAN on behaviour and populations of insects, but also integrates solutions that aim at reducing negative environmental effects in cooperation with lighting engineers, industry, community administrations and citizen scientists. To this end, we developed a customised lighting geometry for road lighting luminaires that reduces the amount of light shining into adjacent areas beyond lit roads and bicycle paths. We installed road lighting luminaires with the novel light geometry in an experimental facility in a dark-sky reserve, at which we test the impact of different luminaire types since 2012, as well as in four municipalities in central and north-eastern Germany. The effects of the customised light geometry on insects are being investigated in a Before-After, Control-Impact (BACI) insect monitoring with flight-interception-traps. Here, we present first results showing that the novel light geometry is highly effective in attracting less insects, especially vulnerable groups of aquatic insects (e.g. Chironomidae, Ephemeroptera) as well as terrestrial nocturnal pollinators (e.g. Lepidoptera). Compared to conventional luminaires with the same illuminance and lighting colour our novel luminaires with their customised lighting geometry present a practical solution to the growing problem of light pollution and are suitable to substantially reduce the contribution of ALAN to ongoing insect declines.

Combined effects of warming and a pesticide mixture on freshwater invertebrates

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Warming climate and chemical pollution are two widespread stressors of freshwater biota. Warming, predicted to be up to +8°C by 2100, can impact freshwater biota through a range of mechanisms such as increased individual growth rates and altered nutrient cycling. Pesticides are usually not intended for direct use in water bodies; however, they enter the aquatic compartment via spray drift, runoff, and leaching, are widespread in freshwater habitats, and usually reach surface waters as mixtures. Many freshwater organisms, unable to readily migrate between habitats when facing adverse conditions, are particularly threatened by these stressors.

We assessed the combined effects of warming and a mixture of pesticides on a freshwater community in a 2*2 factorial design (i.e. with/without pesticides and with/without warming) in heated outdoor mesocosms. We combined a single-pulse cocktail of 6 pesticides (herbicides and fungicides), at concentrations commonly measured in surface waters in the Czech Republic, with warming at +4°C above ambient. The experimental community was assembled from common macroinvertebrate and plankton taxa from different trophic levels (e.g., predators, filter feeders and grazers, detritivores, and primary producers). The experiment ran twice, during summer (June/August) and during autumn/winter (November/April). We repeatedly measured pesticide concentrations, environmental parameters (dissolved O2, conductivity, pH, turbidity, and temperature), chlorophyll-a concentration, zooplankton density and aquatic insect emergence (the latter occurred only in summer). At the end of the experiment, macroinvertebrates were destructively sampled.

While little effects were observed in winter, both warming and the pesticide mixture altered the composition of the invertebrate community and the patterns of insect emergence during summer. In summer, pesticide mixture negatively affected the predator emergence and the phytoplankton biomass, while warming negatively affected the community composition. These findings suggest that if warming primarily drives the disruption of the community, low and environmentally relevant pesticide concentrations may also negatively affect freshwater biota when combined with another stressor.

A functional response model accounting for information flow and decision-making - how the sensory information affects trophic interactions

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Accurately quantifying consumer-resource interactions is essential for understanding and predicting community dynamics, stability and ecosystem functioning. The functional response, which describes how the consumer's feeding rate responds to changes in resource density, has long been used to quantify such interactions. Importantly, foraging consists of a sequence of events, including but not limited to search, detection, pursuit and attack. According to this foraging sequence, the likelihood of completing each step is determined by species traits, environmental conditions, and the time required to complete each step. However, in commonly used functional responses, these probabilities and related uncertainties in completing the foraging sequence have often been underlooked. Here, we have revisited the derivation of the functional response according to the foraging sequence and developed a new functional response framework that can account for such uncertainties and that can be fitted to existing data. With this, we aim to provide a unified mechanism for the various functional response relationships observed in nature.

In ecological communities, every individual receives sensory inputs that are translated into information, which is then processed to detect potential prey and/or avoid predation by perceiving and analyzing cues in surroundings. Intuitively, stronger cues increase the amount of information received and lower the uncertainty in the foraging sequence. Therefore, these cues can regulate individual behaviour, interactions between consumers and resources and, ultimately, the dynamics of the community. To include such probabilistic processes that originate from information constraints, we developed a functional response framework based on the flow of information and the decision-making process involved in the foraging sequence. In particular, we explicitly modelled the probability of successful detection and identification of prey items and integrated these into the sequence. We show that this model, which is grounded in theory and based on ecological realistic assumptions of how animals perceive and process information from the environment, can accurately approximate the functional response observed in nature.

Disrupting Nature's Rhythms: Unveiling the Complex Effects of Artificial Light at Night on Ecological Networks

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Artificial light at night (ALAN) is eroding natural light cycles, thereby changing species distributions, activity patterns, and the way species interact. Yet, our understanding of ALAN impacts on ecological networks and ecosystem functions is still very limited, primarily due to the complexity of empirical assessments of community and ecosystem-level responses in nature. Modelling approaches offer the opportunity to deal with such complexity by reducing nature to a couple of fundamental processes, yet they have virtually never been applied in light pollution research.

Using an allometric-trophic network model, we test how an ALAN-induced shift in temporal activity patterns for diurnal, nocturnal, and crepuscular species impacts food web stability. The results indicate that diel niche shifts can severely impact community persistence by altering the temporal overlap between species, which leads to changes in interaction strengths and rewiring of networks. ALAN can thereby lead to biodiversity loss through the homogenisation of temporal niches. This provides a first step into unveiling the complex effects of ALAN on ecological networks and ecosystem functioning.

Impacts of multiple stressors on New Zealand freshwater invertebrate communities assessed in a streamside mesocosm experiment via DNA metabarcoding

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Stream ecosystems are under unprecedented pressure: the increased likelihood of extreme weather events, rising atmospheric CO2 levels and impacts of agriculture expose stream ecosystems to multiple stressors. Unlike single stressor effects, multiple stressors often interact resulting in synergistic or antagonistic effects on stream communities. To understand these interactions and enable adequate management decisions, there is a need to investigate multiple stressor effects. DNA metabarcoding is increasingly used in ecological research, but scarcely applied in multiple stressor research. This study investigated multiple stressor effects and the possibilities and constraints of DNA metabarcoding in this research field. Specifically, we studied the effects of four common stressors resulting from climate change and agricultural land use in a streamside mesocosm experiment using the “ExStream system” at the Kauru river in New Zealand. The effects of heat waves, fine sediment deposition, increased levels of dissolved CO2 and high variability of flow velocity were tested in a full-factorial experiment. The composition of the invertebrate community was investigated via DNA metabarcoding, which allowed for the analysis of stressor effects on macroinvertebrates with a high taxonomic resolution. Our study found that individual stressor effects rather than stressor interactions determined community composition, while stressor interactions affected single operational taxonomic units (OTUs, species proxies). The taxonomic resolution achieved through metabarcoding enabled the evaluation of ecological responses in taxa without reference sequences or species assignment. The data acquired through metabarcoding offered robust results but were limited by a lack of reference sequences and abundance information. In summary, the use of DNA metabarcoding is a promising tool to complement multiple stressor research and all stressors applied in this study impacted the invertebrate community.

SESSION 25:

Land-Use Related Modulation of Climate Change Impacts

Investigating the consequences of climate change under different land-use regimes: the Global Change Experimental Facility

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Climate change and land use are interrelated in many different ways creating versatile feedbacks between them. Thus, basic information is needed on the influences of climate and land-use change as complex pressures on ecosystem services. Manipulative experiments are essential for the assessment of ecological key processes which trigger ecosystem transformations. However, field experiments manipulating the complex influence of land use and climate change on ecosystems are urgently needed to better understand and quantify the underlying processes, to develop and validate models, to deduce indicators, to develop strategies for sustainable land use, and to steer key processes.

The vast majority of global change experiments, however, is not only conducted in different biomes and land-use systems but also under different regional settings and employing different methodologies what makes the assessment of key processes difficult. Here, we introduce the GCEF, a large field experiment to assess the consequences of climate change on agroecosystems differing in land-use type and intensity. Its design and set-up allow to investigate ecosystem functions on relevant temporal and spatial scales.

Land use and intensity strongly affected abiotic and biotic soil characteristics. We further found significant impacts of the climate treatment on the soil communities and related ecosystem processes, whereby extent and direction depended on land-use type and season. Across years, plant community diversity and productivity only showed minor responses to the climate treatment. However, if there were changes in plant community diversity and productivity those were strongest in the highest land-use intensity, suggesting extensive land management may govern resilience to climate change. The enhanced summer drought showed severe negative effects on the majority of biological soil and vegetation parameters, with significant legacy effects in subsequent seasons.

Climate and land-use interactively affect the flowering phenology of grassland species

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Phenological shifts due to changing climate are frequently reported to be highly species and context specific. Land-use practices such as mowing or grazing directly affect the phenological dynamics of grassland species, but it is unclear if plants are similarly affected by climate change in differently managed grassland systems (i.e. meadows and pastures). Functional traits show a high potential in explaining phenological shifts and might help to understand species-specific and land-use specific phenological climate responses.

In a large-scale field experiment on climate and land-use change (the Global Change Experimental Facility; GCEF), we monitored first flowering day, last flowering day, flowering duration and day of peak flowering, of 17 herbaceous grassland species under ambient and future climate conditions, comparing meadows and pastures. Climate responses of the flowering duration differed between land-use types i.e. meadows and pastures. In most cases climate effects were stronger pronounced on pastures leading to shorter flowering durations under future climate. This may be mainly related to different microsite conditions on meadows compared to pastures as future pastures were overall warmer and drier. Functional traits explained species-specific and land-use specific phenological climate responses. Long flowering species and species with an acquisitive strategy (high SLA, high mowing tolerance) stronger shortened their flowering under future climate regardless of land-use type. Traits explaining land-use specific climate effects where of relevance only on pastures where species with a high SLA stronger advanced their flowering start, late flowering species advanced and long flowering species delayed peak flowering under future climate.

In this contribution we show that phenological shifts due to changing climate can differ between land-use types and that different sets of traits are of relevance explaining phenological shifts on meadows or pastures.

Multi-species grassland dynamics – how resources allocation affect interspecific competition outcomes

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European permanent grasslands represent a backbone for dairy and meet production, and are hotspots of biodiversity, providing important ecosystem services to society. Understanding how the form of land use and climate variability affect the botanical composition of these grasslands is therefore essential for adequate management adaptations to target sustainable development goals. Here, we present results of the DynaGraM modelling approach to understand short- and long-term changes in grassland biodiversity in response to various forms of land use and climatic variations. We question through this model the feedbacks and mechanisms involved in competitive exclusion or contrariwise in plant coexistence.

This study questions the role of a particular mechanism, the allocation of resources by plants into storage organs, on the issue of interspecific competition leading to the competitive exclusion by dominant species, mechanism often simulated in grassland models. This presentation explores how this allocation affects the issue of plant interspecific competition and promotes, by feedback loops, species coexistence by mitigating the mutualistic exclusion. We show that this mechanism acts as a buffering effect to environmental variations and management stresses factors. We apply the model to examine how joint stresses factors affects the species composition of pastures. Last, we compared the simulated outcomes to grasslands observations recorded by tele detection in a grassland experiment (Laqueuille, Massif Central, France).

Overall, this model introduces a novel and relatively simple approach to represent competition and adaptation processes in plant community dynamics, thus providing a response to the key challenge of modelling multi-species grasslands. This presentation points out the mechanisms involved in the emergence of coexistence within complex ecosystems.

Biodiversity dynamics in response to land use intensification in Swiss grasslands.

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In Switzerland, traditionally managed grasslands are part of the Alps' cultural landscape. However, lowland grassland management has intensified in the second half of the last century, and largely replaced traditional management. Fertilization to increase productivity, combined with high mowing frequencies and stocking densities decreased lowland grassland biodiversity and altered species assemblages towards homogenous communities. Contrary to the general perception that grasslands in mountainous regions are still traditionally managed and harbour a rich biodiversity, recent study indicate that land-use intensification is also increasing there. However, this process received only little attention by stakeholders, politics or the wider public, and parallels what has happened in the lowlands in the past. We assess the increase in land-use intensification, and its effect on biodiversity, using data from Swiss national diversity monitoring programs collected over the past two decades. We quantify land-use changes using shifts in vegetation related to mowing frequency, light tolerance and nutrient content. Using linear models and structural equation models, we then link this change to multi-taxon (vascular plants, bryophytes, butterflies, molluscs, birds) changes in alpha and beta-diversity along altitude and other environmental gradients. The first resuts indicate that land-use intensification is linked with a decrease in vascular plant species richness, and that this effect is stronger in higher altitude than in lowlands. The final results of this ongoing project will enable us to get a clearer picture of potential regional specificities in land-use effects and in the response of different taxa, and will help orientate conservation policies in the Swiss Alps.

Sensitivity of Central European ecosystems (temperate zone, Germany) to climate warming, extreme weather events and changing disturbance regimes.

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Climate change is rapidly altering the planet. Novel effects are currently arising worldwide, from melting ice in the Arctic via burning bushfires in Australia to droughted forests in Europe. Assessing the role of disturbance dynamics for biodiversity and ecosystem functioning, for wilderness protection and landscape management is crucial in the light of multiple unknown futures (Jentsch & White 2019).

We conducted a meta-analysis across all ecosystem types in temperate Germany - from lowland coastal via semi-natural mountainous to high elevation alpine - to assess the sensitivity of local biodiversity to severe weather events, shifting climate and altered disturbance regime.

The Federal Agency for Nature Conservation (BfN) lists about 700 ecosystem types (Finck et al 2017), all of which are prone to different natural or anthropogenic disturbance regimes (Wohlgemuth et al. 2022) and show different sensitivity or resistance to climate change and other global change factors. For each of these numerous ecosystem types we have compiled and evaluated the relevant stabilizing dynamics versus altering processes, which maintain or threaten current biota. An essential part of our analysis is understanding the impact of these dynamic processes on current biodiversity and ecosystem functioning and forecasting thresholds of transitions to future alternative states.

The goal is to develop a universally applicable ‘ecosystem sensitivity’ key, which is able to forecast ecosystem vulnerability or resilience to changing climate. This will allow to develop climate-smart management plans for maintaining ecosystem integrity and high levels of biodiversity - especially when either implemented at an early stage of restoration or managed for transition towards novel ecosystems.

Exploring the interacting effects of climate change and land use intensification on soil microbial community structure and nutrient cycling in agroecosystems

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Microbial communities essentially contribute to nutrient cycling in soils of agroecosystems through their decomposition activity. Even though it is undisputed that global change poses a serious threat to their diversity and therefore ecosystem functioning, the interacting effects of global change drivers on soil communities and related functions are still unclear.

At the Global Change Experimental Facility (GCEF) in Bad Lauchstädt, we investigated the interacting effects of two global change drivers, climate change and land use intensification. The GCEF comprises 5 land use types (2 croplands: conventional and organic, 3 grasslands: intensive and extensive meadow, pasture) and 2 climates (ambient vs. future with increased mean temperature and a changed precipitation pattern). We analyzed soil samples from three depths (D1: 0-15 cm, D2: 15-30 cm, D3: 30-50cm) for basic soil parameters, microbial community structure, respiration and the activity of enzymes involved in C, N, P, S element cycles.

Enzymatic activities differed significantly between land use types in the topsoil, with the lowest activity in organic farming. All activities decreased in deeper soil layers, but this decrease was less pronounced in organic farming, resulting in higher activity compared to other land use types in deeper soil layers. Bacterial community in organic and conventional farming was highly similar for D1 and D2, whereas we observed clear differences between D1 and D2 in the grasslands. Fungal community was highly similar in D1 and D2 in all land use types. For the topsoil, we identified pH as the main driver of bacterial community structure, partly masking significant, but less pronounced land use and climate effects. In contrast, climate as well as land use strongly affected fungal community in the topsoil, while pH played a subordinate role. With this study we contribute to reveal interacting global change impacts on microbial community structure and functions in agricultural soils.

Climate change and land use influence soil nematode community through modifications of the soil microstructure and properties

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[2]German Centre for Biodiversity Research (iDiv) Halle-Jena-Leipzig, GermanySoil microenvironment is of prime importance in determining and regulating soil food web structure and interactions in belowground communities. However, global climate change and agroecosystem management may alter the critical role of the soil structure and properties in belowground biodiversity, and change the relative importance between soil structure and soil properties. Here, in the framework of Global Change Experimental Facility (GCEF) in Germany, we used a field experiment to study the interacting effects between simulated climate changes and two types of land use consisting of conventional farmland and extensive grassland on nematode assemblage structure. We currently revealed that climate change and land use type induced shifts in the community composition of nematodes. Results are also expected to assess the correlations between soil microstructure, soil properties, soil nematode abundance, and trophic structure using structural equation modelling (SEM).

Soil microbiomes response to extreme summers in European cropland and grassland

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The increasing frequency of extreme climate events highlights the need to understand how soil microbiomes react to such disturbances. Here, metagenomics was used to analyze the effects of future climate scenarios (warming by +0.6 °C and altered precipitation) on soil microbiomes in cropland and grassland during the summers of 2014–2019. Unexpectedly, Central Europe experienced extreme heatwaves and droughts during 2018–2019, which significantly affected the community structure and function of soil microbiomes. Specifically, the relative abundance of Actinobacteria (bacteria), Eurotiales (fungi), and Myoviridae (viruses) was significantly increased in both cropland and grassland. The impact of extreme summers on the prokaryotic community structure was also reflected in the taxonomic profiles of 721 recovered metagenome-assembled genomes (MAGs). Furthermore, genes related to microbial antioxidants, cell wall biosynthesis, heat shock proteins, and sporulation were found to potentially contribute to significant increases in the drought-enriched lineages, and their activities were confirmed by metatranscriptomics. Genome mining suggested that Actinobacteria may have a competitive advantage in extreme summers due to the biosynthesis of geosmin and 2-methylisoborneol. The results suggest that soil microbiomes are more resistant to climate changes in grassland than in cropland. Overall, this study provides a comprehensive understanding of soil microbiome responses to extreme summers.

Climate-dependent plant responses to earthworm activity in two land-use types

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Plant nutrient uptake and productivity are driven by a multitude of factors that have been altered by human activities, such as climate change and the activity of decomposers. However, interactive effects of climate change and key decomposer groups like earthworms have rarely been studied. We conducted a field microcosm experiment to investigate the effects of future climate (combined treatment of warming and altered precipitation) and earthworms (anecic - *Lumbricus terrestris*, endogeic - *Aporrectodea caliginosa*, and both together) on plant biomass and stoichiometry in two contrasting land-use types (intensively-used meadow with four forage grasses and conventional farming). We found that projected climate change and earthworms interactively affected N content and C:N ratio of grasses. Earthworms enhanced the N content thereby decreasing C:N ratio in grasses, but only under ambient climate conditions. Future climate generally decreased the N content of grasses and winter wheat, resulting in an increase in plant C:N ratio. The projected future climate increased above- and belowground biomass of the grass community, which was mainly driven by production of the dominant *Festulolium* species during periods outside the projected summer drought, but slightly decreased the aboveground biomass of winter wheat. In contrast to previous studies, we found little evidence for earthworm-dependent effects on plant aboveground biomass. Our results suggest that climate change diminishes the effects of earthworms on plant growth and nutrition by inhibiting earthworm activity especially during summer drought.

Effects of climate change and grassland management on plant population dynamics are mediated by changes in reproductive success

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Climate change is one of the largest threats to grassland plant species, which can be modified by land management. Although climate change and land management can separately and interactively influence plant demography this has been rarely considered within one experimental set-up. We used a large-scale experiment to quantify the effects of grassland management, climate change and their joint effect on the demography and population growth rate of 11 native plant species. We parameterized integral projection models with four years of demographic data to project the population growth rate. We hypothesized, plants would perform better in ambient than in the future climate treatment that creates hotter and drier summer conditions and that plant performance in grazing vs. mowing would vary across species and depend on their traits. Due to extreme drought events, over half of our study species went quasi extinct. Of the persistent species, only one supported our expectations, and the rest either had higher population growth rates in the future climate treatment or showed no significant difference in population growth between climate treatments. Species with shorter flowering durations performed better in the mowing treatment while those with longer flowering durations performed better in the grazing treatment. The population growth rates of these species were sensitive to changes in vital rates related to reproduction and recruitment. Our study highlights how extreme climate events, can influence long term experimental results. Depending on the species we found effects of land management and climate change on population growth rates but we did not find strong support for interactive effects among both factors. Experiments combined with measuring plant demographic responses provide a way to isolate the effects of different drivers on the long-term persistence of species, and to identify the demographic vital rates that are critical to manage in the future. Our study suggests that it will become increasingly difficult to maintain species with preferences for moister soil conditions, that traits such as flowering duration might predict responses to management, and that vital rates such as reproduction and recruitment are disproportionately important.

Vineyard irrigation as response to climate change: what are the consequences for biodiversity?

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Global climate change will result in fundamental changes in land management. A common adaptation of agricultural practices to increasing evaporation and subsequent drought is the set up of irrigation systems. Mediterranean vineyards of South-Eastern France were traditionally managed without irrigation. In our study area, the Luberon mountains, irrigation has increased from nearly 0% of the vineyards in 2000 to more than 30% nowadays. Irrigation has an eutrophisation effect on non-crop vegetation with potential negative effects on biodiversity if plant growth is water limited. On the other hand, irrigation may reduce the competition between grapevine plants and inter-row vegetation facilitating the establishment of high-diversity plant mixtures. In the framework of the EU project Life VineAdapt, we analysed the effects of vineyard drip irrigation on inter-row vegetation and arthropod populations involved in biocontrol (predators, parasitoids) and pollination. Eleven irrigated and 11 non-irrigated vineyards were compared. We analysed the cover of all vascular plant species and additionally estimated the flower cover of nectar producing plants at flowering peak before irrigation started. At the same time, we counted ladybirds (larvae, adults), hoverflies (larvae, adults), parasitic wasps, crab spiders and wild bees using direct observation and net hunting. Parameters of grapevine performance (chlorophyll fluorescence) and yield were measured early September.

We did not find significant changes in plant community composition and species richness but a reduced cover of nectar producing flowers in irrigated vineyards. At the same time, the abundance of parasitic wasps, ladybirds (adults, larvae), crab spiders and wild bees was reduced suggesting a causal relationship with reduced flower cover in irrigated vineyards. Structural equation modelling confirmed this causal relationship for ladybird larvae, parasitic wasps and wild bees but not for the remaining groups. Irrigation had no effect on chlorophyll fluorescence and increased yield only in one out of two study years. Further studies are planned to analyse effects of intra-row soil biota and arthropods in the grapevine canopy.

SESSION 26:

Traits and Stability

Between and Within Species: A trait-based approach to identify assemblage mechanisms in nocturnal Lepidoptera in Forests

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How insect species assemble in different habitats is especially important in forests, which strongly vary in canopy structure and density, directly influencing microclimatic conditions. Catalysed by climate change, trait-based approaches have increased in the last decades, describing the cohesion of functional traits and climatic parameters. However, variation within species has been largely neglected in the community composition research field. We aim to gain a more mechanistic understanding of how insect species respond to microclimatic variation in forest gaps. Thus, we investigated the responses of body size and colour lightness of both, the whole community, and single species to variation in forest canopy density. Therefore, we used nocturnal Lepidoptera data from a large-scale canopy experiment covering four temperate forest regions across Germany and additionally measured traits of several individuals belonging to four species. We predict that (i) the body size of moth communities increases while the colour lightness decreases with increasing canopy openness, that (ii) the response of single moth species will follow the same pattern, and that (iii) responses in body size and colour lightness to variation in canopy openness are more pronounced between than within single species.

Canopy cover is an important characteristic influencing forest insect communities and single species, while strongly affecting local climate. As climate change impacts canopy cover through higher and more frequent disturbances, the understanding of ecological mechanisms is increasingly important to predict variation in responses of insects affected by climate change. Species with a high variation in intraspecific functional traits have a higher probability that their comprising specimens persist in fluctuating environmental conditions. This is particularly relevant regarding the ongoing loss of biodiversity. Therefore, studies on intraspecific trait variation should receive more attention.

Spatio-temporal dynamics of herbivore communities in a subtropical forest of China

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Understanding how insect herbivore communities are affected by plant community changes and the consequences of their interactions on ecosystem functioning remains a challenge in ecology. Although overall herbivore diversity has been shown to be significantly promoted by increasing plant diversity, we still lack a clear understanding of how changes in plant diversity influence the dynamics of herbivore communities and plant-herbivore networks across temporal scales. Insect herbivore populations fluctuate over time and variability in climatic conditions might interact with plant-regulated bottom-up effects to structure herbivore communities. Using comprehensive dataset of Lepidoptera caterpillars collected in the world's largest tree diversity experiment (BEF-China) from 2017 to 2022, we intend to unravel how intra- and interannual spatio-temporal herbivore community dynamics are affected by tree diversity, tree growth and climatic factors over time. Overall, the current results suggested that tree diversity stabilized interannual variability of herbivore diversity. Moreover, stability of tree growth rates and microclimate factors partly determined spatio-temporal stability of herbivore communities.

Time-lags in parasite-host interactions promote phytoplankton bloom formation in plankton communities

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Food web theory has largely neglected the presence of pathogenic species. However, predictions on food web response to environmental change will differ for food webs ignoring versus including host-parasite interactions. The inclusion of host-parasite interactions increases food web complexity and influences food web dynamics. In freshwater systems, parasites of phytoplankton are dominated by chytrids, a fungal parasite. Empirical studies show that chytrid infection being critical for phytoplankton bloom control and energy flow to higher trophic levels, with chytrid zoospores contributing › 50% to zooplankton diet. Previous theoretical studies on a corresponding food web, consisting of an edible nonhost (insusceptible) and an inedible host phytoplankton, a parasitic chytrid and a zooplankton species, implemented the host-parasite interaction like a predator-prey interaction. Unsurprisingly, the community response to eutrophication was qualitatively identical to predictions from classic food web theory. Yet, a parasitic interaction usually lasts longer than a predatory interaction (referred to as a time-lag), which is reflected by the distinction between "susceptible" and "infected host" in established SI models. We theoretically investigated the influence of this time-lag on community dynamics by implementing the host-parasite interaction either as a predator-prey interaction (no time-lag) or using an SI model (emerging time-lag), where parameters and initial conditions were derived from empirical data. We found that a time-lag allows uninfected host to form a dominant bloom, while parasite development is delayed. Furthermore, the fungi-zooplankton feeding link stabilizes longterm community dynamics. This study provides a novelty that pathogens could support host bloom formation, thus, highlights the distinct role of parasites, which should be considered if assessing the response of communities to environmental change.

Aridity dependence of grasslands' resistance to climate extremes regulated by species turnover

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Extreme dry and wet events are becoming more intense on global scales. Grassland ecosystems along a global aridity gradient might differ in their capacity to cope with extreme events. Local climatic history could shape grassland's response. For example, the species occurring in dry grasslands might have stronger drought adaptation strategies than those in mesic grasslands, and thus extreme dry events may have a weaker effect on ecosystem resistance in dry grasslands. The unpredictable nature of extreme events makes them difficult to study. In addition, nutrient availability can be greatly affected by site aridity and can interact with superimposed climate extreme events, such as when arid conditions hinder the availability of essential nutrients for plants. Here, we used the historical water balance data (SPEI) to classify site-based standardized extreme weather events (95th percentile, dry or wet) and selected 35 globally distributed grassland sites which experienced extreme events during the experimental years. Our results show that ecosystem biomass resistance increased with site aridity only under extreme dry events, which was due to the high species gain and low loss, which related to the increased abundance of annual species. In turn, the significant effects of nutrient addition on ecosystem biomass resistance across the aridity gradient only happened in response to extreme wet events and increased with site aridity, which was due to the increased abundance of non-graminoid species. In the face of increased global nutrient deposition, these findings are crucial for improving our understanding on how global grasslands across aridity gradients respond to extreme events.

Thermal niches of local pollinator communities along a gradient of biodiversity promotion areas and its effects on cherry yield

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Both wild and manged pollinators provide vital pollination services crops, thereby contributing to sufficient and stable food production. Diverse wild pollinator communities are predicted to provide important insurances functions against environmental change, such as buffering pollination services against ongoing climate change increased weather variability, through functional redundancy and complementarity. However, empirical evidence for this hypothesis remains scarce, and the effectiveness of management options, such as agri-environmental measures, to promote the buffering capacity of wild pollinator communities and its role for crop yields remains largely unexplored. We investigated how agri-environmental measures such as grassland extensification and the establishment of hedgerows in agricultural landscapes around cherry orchards contribute to pollination service delivery and crop yield of cherry. In particular, we examined the contribution of predicted enhanced thermal niche breadth and complementarity of diverse pollinator communities, and the role of agri-environmental measures and other landscape features to foster predicted climatic resilience and crop yield and its stability along with the role of managed pollinators. We identify pollinator groups and species that play key roles for cherry pollination under variable weather conditions, i.e. species that pollinate cherry also under suboptimal weather conditions, and discuss applied implications of our findings for pollinator conservation and pollination management of cherry.

Global change effects on the diversity-stability relationship in tundra ecosystems

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The effect of diversity on stability is a long-standing question in ecology. Understanding the diversity-stability relationship in tundra ecosystems is crucial due to the pronounced global change impacts in these regions. Changes to the stability of the tundra vegetation cover may have important knock-on effects on the global carbon cycle due to potential permafrost thaw-related release of greenhouse gases contributing to a strong positive feedback in global warming.

Empirical research shows that high diversity is often linked to high stability through several mechanisms which are increasing the mean productivity, decreasing its variance or both.

Our study aims to answer:

a) Do species and functional richness of vascular plants enhance tundra ecosystem stability?

b) Which functional group has the strongest impact on ecosystem stability?

c) How does temperature and precipitation change affect the relationship between species richness and stability?

To answer these questions, we analyze the relationship between the temporal stability of productivity and species richness from › 3000 vegetation surveys for which we will also calculate the functional diversity.

Since cryptogams are abundant and have a critical function in tundra ecosystems, we hypothesize that they will also play a crucial role in stabilizing the tundra ecosystem. First results show that increased lichen diversity positively affects the temporal stability of the tundra ecosystem while vascular plant species richness has no effect.

The role of functional diversity in ecosystem regime shifts

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Biodiversity may increase the resilience of ecosystems facing environmental change. However, we have limited understanding if this applies to ecosystems that respond to gradual environmental change with abrupt regime shifts. Here we used a mathematical model to investigate if diversity in functional traits influences the resilience of ecosystems that abruptly transition between alternative ecosystem states. The model describes anoxic-oxic regime shifts of aquatic ecosystems mediated by cyanobacteria and two groups of sulphur bacteria. Within each of the three groups of bacteria, we modelled multiple strains that varied in environmental tolerance and maximum growth rate. We measured the effect of trait diversity on resilience and the effect of the combination of functional groups that contained trait diversity. We found that trait diversity did not always increase resilience: higher diversity in two of the groups increased but in one group reduced resilience of their preferred ecosystem state. We also found that simultaneous trait diversity in multiple groups often led to smaller or erased diversity effects. Taken together, our findings suggest that higher trait diversity can increase resilience but can also promote collapse when diversity occurs in a functional group that negatively influences the state it occurs in. We propose this mechanism as a potential management approach to facilitate the recovery of a desired ecosystem state. Collectively, our findings highlight the importance of considering multiple interacting functional groups when predicting the effect of functional trait diversity on ecosystem resilience.

Biogeographic context mediates multifaceted diversity-productivity relationships in island and mainland forests

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Growing evidence suggests that impacts of biodiversity loss on ecosystem functioning and nature's contributions to people are usually negative, yet the magnitude and direction of these impacts can be quite variable across naturally-assembled ecosystems. A potential driver of variation in diversity-productivity relationships is the biogeographical context, which may alter these relationships via processes acting at the species pool level like dispersal limitation, environmental filtering, speciation, and invasibility. However, the extent to which the relationships between biodiversity facets on forest productivity are shaped by the biogeographic context remains uncertain. Using plot data from a national forest inventory, we examined the effects of taxonomic, phylogenetic, and functional diversity on aboveground productivity in forest ecosystems across the Canary Islands and climatically similar areas in mainland Spain. Using linear models and structural equation models, we assessed the influence of multifaceted diversity on aboveground productivity and how environmental conditions, non-native species, and the number of trees affect that relationship. Our results show that environmental conditions and the number of individuals increase productivity in both island and mainland forests. In island forests, non-native species increased productivity via their effects on phylogenetic diversity, while they decreased productivity via functional diversity. Our results suggest that multifaceted diversity, by capturing the diversity of evolutionary history and unique trait combinations present in a community, contributes to elucidating diversity-productivity relationships in island forests that could not be detected by taxonomic diversity alone. By filling empty niches in island forests, we find that non-native species are fundamentally altering ecosystem functioning on islands.

Tree diversity increases forest temperature buffering

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The increasing frequency and intensity of extreme climate events make the stable provision of ecosystem functions and services a crucial objective for forest management. An important but often neglected forest function is the buffering of temperature extremes, that is, the cooling of hot and insulation against cold macroclimate temperatures below the tree canopy. This temperature buffering – or microclimate stability – may be increased by tree diversity and may itself maintain forest biodiversity and functioning, for instance, by stabilising functions responding non-linearly to temperature, such as photosynthesis. However, despite its relevance, the effect of tree diversity on temperature buffering is largely unexplored. Here, we show that tree species richness consistently increases forest temperature buffering (assessed as the temporal stability of microclimate temperatures) across daily, monthly, and annual time scales in a large-scale forest diversity experiment covering a species richness gradient of 1 to 24 tree species. We found that species richness strengthened both components of forest temperature buffering, the cooling of hot and the insulation against cold macroclimate temperatures, with the cooling effect being more pronounced. By disentangling the ecosystem traits responsible for the buffering effect, we show that species richness effects are mediated by vegetation density and structural diversity, assessed as leaf area index and stand structural complexity index, respectively. Our results demonstrate that forests with high tree diversity have a stronger buffering effect on temperature fluctuations than forests with low tree diversity. Safeguarding and planting diverse forests may thus protect below-canopy communities and functions against global warming and climate extremes.

Above- and belowground biomass stability of shrub- and grass- dominated communities in response to precipitation changes in desert steppe

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Community stability is important to provide reliable ecosystem services under precipitation changes. Efforts have been made to explore the aboveground biomass stability of grass community in response to changes in precipitation, but how it affects belowground biomass and community total biomass stability of grass community as well as shrub community stability remains elusive. Here, we explored the response patterns and drivers of the stability of aboveground biomass, belowground biomass and community total biomass in grass- and shrub dominated communities that are situated side by side, through a precipitation manipulation experiment conducted in the two plant communities. The results showed that the stability of community biomass in response to precipitation changes depends on the community type as well as on different hierarchys of biomass. Species stability and species asynchrony contributed most to the variation of AGB stability under precipitation changes in both grass- and shrub- dominated communities, while soil properties were the main drivers of BGB and CTB stability in shrub- dominated community. This study will promote our current understanding of the stability of desert steppe ecosystems under precipitation changes and be beneficial in sustainably delivering ecosystem functions in the context of global precipitation change.

Temporal stability of grasslands under climate change and underlying mechanisms

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A better understanding of how climate change affects the stability of grassland biomass production is important to ensure future food security. Since 2015, data on grassland biomass production have been collected in the Global Change Experimental Facility (GCEF) – a large field experiment in Bad Lauchstädt (Saxony-Anhalt, Germany) with different land use types under future and ambient climate treatment. We divided the time series of grassland biomass data into six overlapping time windows of three years (2015 – 2022) to capture short-term variations in community stability, identify biotic stability mechanisms and relate them to prevailing environmental conditions. For each time window, we determined the temporal stability of the community biomass production as inverse of the coefficient of variation and different potential biotic stability mechanisms such as species asynchrony, species diversity, and the population stability of dominant species. In addition, we will identify extreme dry years (e.g., 2018, 2019) to quantify the resistance and recovery of community biomass production. After an establishment period of a few years, grassland community production was found to be less stable under the future climate treatment compared to the ambient climate treatment. This might be due to the more synchronous species dynamics under the future climate treatment than under the ambient climate treatment. Overall, temporal stability of community biomass production increased with increasing species asynchrony. We will use structural equation models to determine the relative importance of the different biotic stability mechanisms.

Does connectivity affect zooplankton diversity and ecosystem stability in subalpine lakes?

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Ecosystem stability is of growing concern with climate change. Regarding freshwater ecology, trophic interactions in lakes could impact ecosystem stability. An understanding of species involved in these interactions and how the abundance and diversity of these organisms is affected, could facilitate better management of freshwater ecosystems. Zooplankton and their role in the trophic food web makes them of particular interest when studying stability of lake ecosystems. Many studies consider zooplankton as crucial indicators of climate change, due mainly to their short generation time and central position in the aquatic food web.

This study proposes that well connected lakes are more likely to be stable ecosystems and have a quick recovery time. Diversity and abundance of zooplankton from 4 subalpine Austrian lakes – 2 remote and 2 well-connected – are used to assess the seasonal and spatial variations in communities to see if this can be used as an indicator for what determines stability. Sampling took place once a month from June 2020 to June 2021. Zooplankton was collected by vertical net hauls; the composition of the communities was analysed by microscopic analysis. A depth profile was established with a probe measuring dissolved oxygen, turbidity, chlorophyll a, temperature, pH and conductivity.

Preliminary results indicate that rotifers are the most abundant group in all 4 lakes, particularly in spring months in the more remote lakes. Grundlsee, a well-connected lake, had the largest number of copepods, however the remote lakes have higher overall diversity than the clustered lakes. Taxon data will be compared to abiotic data to determine environmental changes and further analyses to assess differences between remote and clustered lakes will be carried out.

Elucidating the Floral Economic Spectrum (FES) and the Effects of Changes in Soil Nutrient and Water Availability on Floral Traits

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As human activities continue to alter the global climate, ecosystems are facing new challenges such as increased drought events and altered nutrient availability from soil. Understanding how plants respond to such changes is crucial for predicting how ecosystems will respond to future global change. To understand the effect of global change factors, there is rapidly growing literature around functional trait variation that has enhanced our mechanistic understanding of how plants interact with their environment. Flowers which act as the primary means of reproduction in plants attribute to the long-term survival of ecosystems and yet, the effect of environmental factors on floral traits are far less studied compared to leaf and root traits. Therefore, this study aims to investigate the effect of soil quality (nutrient rich vs nutrient poor) and water availability (normal vs water scarcity) on floral traits. We will also study how floral traits coordinate among each other and with leaf, root, and seed traits in order to understand floral economic spectrum and also the whole plant economic spectrum. To achieve the study's objectives, 60 insect-pollinated species from Central European grasslands will be selected and grown under four experimental conditions. We expect that reduced water availability will result in smaller flowers with shorter longevity, reduced rewards and fewer volatiles, making them less attractive to pollinators. Conversely, increased soil nutrient availability is expected to result in plants producing larger flowers with increased longevity, greater rewards and more volatiles to attract pollinators. Additionally, we expect that the effects of water scarcity and poor nutrient availability will synergise with the effects of water scarcity being more pronounced under reduced nutrient availability. Finally, the effects are also expected to be species specific with species having larger flowers and adaptation to nutrient rich environments to be affected the most. In conclusion, this study will advance our understanding on the importance of nutrient and water availability on the population dynamics of plants and pollinators and provide new perspectives on the allocation of plant resources during reproduction and how it is influenced by global change factors.

Direct and indirect effects of climate change on functional traits and composition of insect communities

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Insects and plants comprise a large amount of biodiversity in terrestrial habitats and provide important functions to our ecosystems. However, climate change is predicted to alter plant-insect interactions through several mechanisms. Climate may directly affect insects by changing their physiology and metabolism. In addition, climate may indirectly affect them via changes in the plant community. Enhancing our understanding of those direct and indirect effects is crucial to predict how plant-insect interactions and the functions they provide might change in the future. The use of trait-based approaches has increasingly gained attention, as it can enhance our understanding of the mechanisms by which climate change affects communities and species interactions. However, our knowledge on how the functional composition of insects is affected by climate is very limited. This Postdoc project therefore aims to deepen our understanding of how climate change directly and indirectly affect the diversity and functional composition of insects. I will take advantage of available insect samples from more than 60 sites in Europe, collected for an ongoing global research network, the BugNet. On those, I will measure functional traits that respond to changes in climate or plant community characteristics. Using modern statistical tools will allow me to disentangle the relative importance of direct and indirect effects of climate. This project will substantially contribute to our understanding of how anthropogenic climate change impacts insect community assembly and related ecosystem functions.

The role of small and connected grassland fragments in maintaining high arthropod functional diversity in human-dominated landscapes

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Due to agricultural expansion and intensification, grassland ecosystems went through dramatic habitat loss and fragmentation worldwide. By having relatively short generation times and representing a diverse group, grassland arthropods are particularly sensitive to this process and, therefore, are exposed to considerable risk. Although studying functional diversity provides accurate insights into ecosystem processes, studies often focus on taxonomic diversity and neglect trait-mediated functional responses. We assessed the effect of fragment size and connectivity on the functional composition and diversity (RaoQ) of spiders and true bugs collected from 30 sandy steppe (forest-steppes) and 30 loess steppe

fragments (kurgans) in the southern part of the Hungarian Great Plain. We observed higher functional diversity in well-connected fragments for spiders and in small fragments for both groups. We collected small, humidity-preferring, and web-builder spiders in small fragments and more ballooning species with moist habitat preferences in well-connected fragments. Furthermore, increasing grassland connectivity resulted in a significantly higher proportion of polyphagous and humidity-preferring species in the true bug communities. Our results highlight the importance of small and connected grassland fragments in maintaining high arthropod functional diversity. Even small fragments in a well-connected grassland network can promote ecosystem functioning and associated services within highly modified landscapes.

Trait-environmental relationships and community assembly in a sub-Mediterranean forest of Central Spain

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The Iberian Peninsula represents one of the largest boundaries between Mediterranean and Eurosiberian vegetation. This sub-Mediterranean region harbors species from both Mediterranean and Eurosiberian regions, as well as many endemic species and unique plant communities being thus zones of special conservation interest. The Iberian sub-Mediterranean regions are particularly sensitive to changes, and even small climatic variations can significantly alter the composition of their plant communities. Future climate change projections for the Mediterranean basin predict a rise in temperature and droughts, making the sub-Mediterranean zones a priority for biodiversity research and conservation. A trait-based approach to studying the functional structure and composition of plant communities can provide valuable insights into the processes that drive community assembly. The functional composition of communities is closely related to the provision of ecosystem services. Therefore, understanding which environmental factors influence functional traits can improve our understanding of how climate change and other anthropogenic drivers may impact the delivery of ecosystem services. Our goal is to comprehend how trait-environmental relationships model the functional assembly and composition of plant communities in the sub-Mediterranean forest of Hayedo de Montejo (a UNESCO World Heritage Site). This understanding will allow to assess the potential impacts of climate change on the functional structure of these transitional regions. Preliminary findings show different functional plant community composition as a result of the environmental variability within Montejo.

SESSION 28:

Evolution in Biodiversity Research

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Fossil leaves are an abundant type of plant macroremains. They are used in many paleobotanical studies to reconstruct terrestrial climate evolution throughout the Cenozoic (common era, from 66 million years ago to today). Some methods are based on functional and morphometric leaf traits such as leaf area, leaf mass per area (i.e., inverse of specific leaf area), or leaf type of margins (toothed vs entire), which are sensitive to environmental conditions and may reflect more acquisitive or conservative ecological strategies in plants. In these studies, trait variation between assemblages is often interpreted as an adaptation to different environmental conditions and, when assemblages of different ages are compared, related to ancient global changes. Yet, other parameters such as the taxonomic composition of communities and the type of depositional environment (e.g., lacustrine, riparian, marine) might also explain part of the differences among assemblages.

While databases on present-day vegetation are well developed, little has been done to document the functional diversity of fossil assemblages through time and space. These data are important for fully comprehending the evolution of leaf traits and angiosperm radiation, and their intricate dependence on the abiotic environment. In this talk, we introduce the first data of a new database dedicated to angiosperm fossil leaf traits. We analyze leaf trait variation within and between several European assemblages (including Germany, Czechia, France, Spain, and Switzerland), from different ages (between 56 and 5 million years ago), in light of climate evolution, type of depositional settings and assemblages composition.

Genome sizeand trait flexibility affect the adaptability and evolution of tropical plants

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Functional traits may affect the adaptability and hence diversification of lineages, leading to present-day biodiversity patterns. However, it is unclear how ‘trait flexibility’, i.e., the evolvability of traits over macroevolutionary times, affects diversification rates, and whether genome size evolution underlies trait flexibility, influencing adaptation. To address these questions, we integrated genome size, functional trait, distribution, and phylogenetic data for palms (Arecaceae)- a pantropical plant family comprising ca. 2600 species. We used macroevolutionary and structural equation models to show that diversification rates of palm lineages increased approximately 20 million years ago, concordant with increased rates of genome size and trait evolution. However, rates of genome size evolution were not directly associated with diversification rates, but with fruit size and stem diameter evolutionary rates. Instead, fast diversification rates were found for species with relatively large genomes, small fruits, and fast rates of stem height, fruit length, or leaf size evolution. This suggests that genome size evolution acts as a potential driver of trait flexibility, and fast evolution of traits provides the adaptability for lineages to persist and diversify. This may explain some of the most enigmatic evolutionary radiations across angiosperms and their distribution across the globe.

The evolution of plant defense traits is shaped by megaherbivores

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The evolutionary arms race between plants and herbivores has led to many adaptations and counter-adaptations in both organismic groups. Plants possess numerous analogous morphological structures, such as prickles, thorns, and spines, that deter predation from herbivores, especially large mammals. However, whether these traits have evolved in response to herbivory, or whether they evolved in response to environmental factors other than herbivory, such as temperature and aridity, remains unclear. Here, we use a macroecological approach and hypothesize that the evolution and distribution of plant defense traits is convergent and was shaped by the interaction with medium- to large-sized (i.e., more than 10kg) mammalian herbivores. We focus on 1835 species of mimosoid legumes (64% of total species), a pantropical lineage that shows a wide diversity of herbivory defense or escape traits, such as armatures (e.g., on leaves, trunks, and branches), extrafloral nectaries, distinct leaf types (e.g., pinnate, bipinnate leaves and phyllodes), and variation in plant architecture/height. We integrated these with morphological, phylogenetic, and geographical data on 235 extant and 185 extinct species of medium- to large-sized mammalian herbivores, fire regimes, and climate, and applied phylogenetic and structural equation models at global and continental scales. Results illustrate the repeated evolution of defense traits, and that the global proportion of armed species across assemblages is strongly associated with species richness of extant and extinct mammalian herbivores and extended periods of drought, whereas fire and temperature affect armature indirectly, via effects on herbivore richness. Furthermore, we detected biogeographical differences in drivers of armature: climate (drought and temperature) was the most important driver in African assemblages, whereas herbivores explained most of the variation in the Americas. Our findings suggest that the environmental correlates of plant defense traits are scale-dependent and that current ecosystems cannot be properly understood without considering interactions with extinct species.
We argue that the complex interaction between fire, drought, and temperature, the expansion of savanna habitats, and the evolution of mammalian herbivores have influenced the evolution and distribution of plant defense adaptations.

Exploring adaptation across a precipitation gradient in a Neotropical legume tree species (*Enterolobium cyclocarpum*)

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Neotropical seasonally dry forests are one of the most threatened and fragmented ecosystems on earth and they will probably continue to lose biodiversity due to climate change and habitat degradation. Here, we explored the adaptive potential of plant populations across a precipitation gradient in Neotropical dry forests. We focused on the lowland Neotropical tree species Enterolobium cyclocarpum, a common legume tree found in dry forests from Central and Northern South America, but also in human disturbed and open landscapes such as cattle ranches and agricultural fields. We collected leaf samples from individuals across an annual precipitation gradient in Colombia, ranging from the Caribbean, Inter-Andean valleys and across several savannas. We sequenced 123 individuals across 12 populations using RADseq. We tested whether isolation by distance, topography (i.e. the Andean mountains) and/or climate explained genomic differences among populations, and if non-neutral among population differences showed signatures of selection due to climate (i.e., single nucleotide polymorphism variants associated with precipitation regimes according to changes in allelic frequencies). Our results suggest a clear genomic division across the different regions and genetic loci potentially linked to distinct precipitation regimes. This suggests that both complex topography and climate are shaping the genomic architecture of dry forest plant populations across heterogeneous landscapes. Our results contribute to the understanding of molecular evolution in Neotropical tree species and their adaptive potential under ongoing and future climate change, important for preventing future biodiversity loss.

Genomics of plant adaptation to the harsh Arctic-alpine environment

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Plants with an Arctic-alpine distribution are challenged by extreme temperatures, low water availability and short favorable seasons, and can be used as models to study adaptation to harsh environments. Further, these species experience fast rates of climate change, and studying their evolution and genomic diversity can reveal possible responses to a warming climate. We use a large-scale collection of more than 1000 individuals of the perennial plant Arabis alpina collected across Europe to study its biogeography and genomics of adaptation to the extreme Arctic-alpine environment.

Our demographic reconstruction reveals the ancient spread of this plant across Europe, dating back 0.5 to 1 Million years ago. Further, we detect a widespread population decline since the last glacial maximum (20 thousand years ago), likely driven by warming temperatures in the present interglacial. This trend can further our understanding of the responses of Arctic-alpine species to a warming climate, and their potential to adapt to future environmental challenges.

During its expansion across Europe, A. alpina occupied contrasting environments, from Mediterranean mountains with long, dry growing seasons, to high altitude peaks in the Alps, to the high latitude Scandinavian Mountains with very short growing seasons. Simultaneously, A. alpina evolved variable mating strategies ranging from obligate outcrossing to mixed mating to selfing. We integrate population genomics across space, mapping life-history traits from crosses, and environmental variation, to uncover the genomic consequences and the molecular basis of mating system variation, and of adaptation to extreme environments.

Rapid adaptation of recombining populations on tunable fitness landscapes

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How does standing genetic variation affect polygenic adaptation in recombining populations? Despite a large body of work in quantitative genetics, epistatic and weak additive fitness effects among simultaneously segregating genetic variants are difficult to capture experimentally or to predict theoretically. In this study, we simulated adaptation on fitness landscapes with tunable ruggedness driven by standing genetic variation in recombining populations. We confirmed that recombination hinders the movement of a population through a rugged fitness landscape. When surveying the effect of epistasis on the fixation of alleles, we found that the combined effects of high ruggedness and high recombination probabilities lead to preferential fixation of alleles that had a high initial frequency. This indicates that positively epistatic alleles escape from being broken down by recombination when they start at high frequency. We further extract direct selection coefficients and pairwise epistasis along the adaptive path. When taking the final fixed genotype as the reference genetic background, we observe that, along the adaptive path, beneficial direct selection appears stronger and pairwise epistasis weaker than in the underlying fitness landscape. Quantitatively, the ratio of epistasis and direct selection is smaller along the adaptive path (≈1) than expected. Thus, adaptation on a rugged fitness landscape may lead to spurious signals of direct selection generated through epistasis. Our study highlights how the interplay of epistasis and recombination constrains the adaptation of a diverse population to a new environment.

Microbiota and complete metamorphosis in insects

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Metamorphosis, the change (meta) in form (morphe), is a widespread phenomenon in the animal kingdom, where it has evolved several times independently. The most dramatic metamorphic changes occur in the most successful group of animals: the insects, which comprise 50-70% of all living animal species. More than 80% of all insects are holometabolous and undergo complete metamorphosis. The larval anatomy is radically remodelled in a unique pupal stage, leading to distinct larval and adult forms. In contrast, the second major group of insects, the Hemimetabola, undergo incomplete metamorphosis, with the adult form resembling the larval stages. Complete metamorphosis is considered a key trait explaining insect diversity.

However, how this radical remodelling is related to the astounding insect radiation is unclear. The remodelling gives holometabolous insects the unique opportunity to change their microbiota. A change in microbial composition throughout development may facilitate niche shifts by allowing the insect to acquire specialised symbionts for a life-stage-specific diet, ecology and physiology. We showed a strong microbial turnover between larvae and adults in holometabolous insects, presumably driven by the intercalated pupal stage. However it is not clear how strong this effect is compared to the impact of changing environments throughout development. Many aquatic insects undergo a strong habitat shift from an aquatic to a terrestrial life stage throughout development, but systematic studies of changes in the microbiota are rare in aquatic insects.

Using 16S rRNA gene metabarcoding, we investigate whether (i) changes in the gut microbiota during the adult moult differ between aquatic hemi- and holometabolous insects; and whether (ii) an aquatic-to-terrestrial habitat shift influences the microbiota. The results shed new light on the importance of microbial symbionts for their host's adaptation to life-stage-specific challenges.

Studying Evolution at the German Centre for Integrative Biodiversity Research (iDiv)

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The German Centre for Biodiversity Research (iDiv) Halle-Jena-Leipzig aims to provide a scientific basis for the sustainable use of our planet's biodiversity and to develop the new research field of integrative biodiversity research. Biodiversity arises through evolutionary processes and an evolutionary perspective is therefore essential in addressing these missions of iDiv. Many people at iDiv study evolution and are distributed across various working groups. evoDiv is a newly founded forum for this interest group that aims to bring together people from different fields to discuss evolutionary research, methodology, and applications.

This poster will showcase the diversity of evolutionary research at iDiv, including micro- and macroevolution, trait evolution, evolutionary modelling, population and conservation genetics, molecular ecology, genomics, animal-plant and host-symbiont interactions, wildlife epigenetics, and others. Our aim is to introduce the researchers behind evoDiv and highlight evolutionary work using case studies. We further hope that our poster will spark discussions on the role of evolution in ecology in general.

Intra-specific genetic variation and adaptation in Hordeum murinum

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Intraspecific genetic variation between plant populations is common and can reflect local adaptation. Yet, local adaptation can be disrupted by climate change. Phenotypic and genetic investigation of plant populations along a geographical gradient might give us insights into adaptive abilities within species, a knowledge needed for predicting species adaptive ability and assessing its vulnerability to climate change. While phenotypic studies of local adaptation are common, genetic underpinnings of local adaptation in most wild plant species have rarely been studied, mainly because the necessary tools are readily available only from few model species. In this ongoing project, we study genetic variation in *Hordeum murinum*, a common wild annual. As it is related to cultivated barley, there are genomic resources available that will allow us to study genetic underpinnings of adaptive traits and how they vary along gradients. We score the species in wild across Europe to define its ecological niche and sample seeds. We combine common garden experiments with genetic tools to identify adaptive variation and underlying genetic regions. First preliminary results from four populations suggest that *H. murinum* grows in a great variety of environments. Its populations are differentiated from each other, for example in winter hardiness or content of anthocyanins. Individuals growing within each location are extremely related to each other, or even a single genotype, which suggests high level of selfing. Over the next three years, we will expand our study to accessions from at least 100 sites across Europe.

iCONNECT - integrative CONyza NEtwork for Contemporary Trait evolution

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Rapid evolution is a common occurrence in plant invasions. However, our understanding of rapid evolution is limited because most studies underestimate among-population variation (APV) within native and non-native ranges and/or do not disentangle how population histories drive APV. Furthermore, integrative frameworks of APV-focused research are lacking but could help identifying molecular mechanisms of rapid evolution.

We here present the integrative network iCONNECT. iCONNECT is an open collaboration of researchers who contribute to the sampling of *Conyza canadensis* populations across the Northern hemisphere and researchers who investigate APV in their particular research field using these sampled populations.

The first study within the iCONNECT framework will be a greenhouse experiment in which 120 native and 150 non-native *C. canadensis* populations will face a competition × drought treatment combination. For the study populations, we collected field data as proxies for population history in terms of plant competitive regime, drought regime and fungal interactions in the rhizosphere. The samples will be analyzed in a coherent manner for 1) phenotypic APV (competitive ability under dry vs. mesic conditions), 2) eco-metabolomic APV (mass spectrometry analyses of root exudates), 3) APV in root-fungal interactions (amplicon sequencing), and 4) population genomics (ddRADseq).

Our experiments will shed light on the principles of rapid evolution by investigating how population history dictates biotic interactions across large spatio-environmental scales. Moreover, studying correlations between the investigated APVs may unravel how belowground mechanisms determine competitive ability and may identify metabolites and genomic regions that are associated with competitive ability and root-fungi interactions.

Thermal plasticity of resurrected and contemporary populations of *Hypericum perforatum*

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Climate change is applying pressures to plant populations, which must adapt or move to retain fitness. A changing climate highlights the need for us to understand the potential that species possess to evolve in addition to any plastic responses. Approaches that allow the study of contemporary evolution, such as resurrection studies, have the capacity to provide insights into the responses of populations to these changes. In this resurrection experiment, seeds from seven populations of *Hypericum perforatum* collected from the UK and France, and their historic counterparts, were grown and subjected to four temperature treatments. Three traits were measured and compared between historic and contemporary populations: date of flowering, average seed weight and flower abundance. We found that temperature influenced date of flowering and flower abundance, leading to an overall earlier flowering time and an overall decrease in flower abundance with increase in temperature. The only significant difference between historic and contemporary populations was found in flower abundance. Whilst flower abundance declined with increasing temperature, contemporary populations produced proportionally more flowers than historic populations per degree of temperature increase. Seed weight remained similar across temperatures and between the historic and contemporary populations. These results suggest that plasticity allows this species to adjust its flowering phenology but that evolution during the past decades may have selected for an increased flower abundance at higher temperatures. These findings contribute to our overall understanding of how species have and will react under climate change, as we try to disentangle the roles that plasticity and evolution play in enabling populations to retain fitness under changing conditions.

ADAPT - Upcoming project on the role of rapid evolutionary adaptation in altering the response to multiple stressors in a changing environment

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Rapid climate change and severe anthropogenic impact result in a multitude of environmental stressors that have a profound impact on global freshwater biodiversity. Those stressors often interact, sometimes in unexpected ways, making it difficult to accurately predict biodiversity responses. What likely contributes to the combined stress response, is the sensitivity of an organism to various stressors often resulting from evolutionary adaptations. Prior exposure to stressors can affect organisms' stress response and thereby, challenge our understanding of the effects of adding novel as well as reducing established stressors in an ecosystem. Thus, the aim of this upcoming project is to evaluate the role of rapid evolutionary adaptation on multiple stressor responses of freshwater amphipods, aquatic keystone species. Here, we plan to investigate multiple stressor responses of *Gammarus pulex* populations adapted to elevated levels of pesticides. We will perform a series of indoor experiments using combinations of a stressor they are adapted to (pesticide) and additional environmental stressors related to changing environment: temperature, salinity and an invasive species, all applied in a full factorial design. We aim to evaluate the sensitivity of the pesticide-adapted *G. pulex*populations towards a gradient of stressors by investigating a set of functional (leaf consumption), behavioural (activity patterns) and physiological (gene expression) endpoints. We also plan to investigate trait divergence using high-resolution morphometrics and genomics to explore eco-evolutionary signatures of adaptation. With that, the aim of this project is to provide a novel insight into our understanding of ecological responses to multiple environmental stressors in the light of organisms' evolutionary adaptation, performance trade-offs as well as stressors' modes of action.

Experimental evolution of inherited symbionts in novel hosts

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Symbiosis is present in almost all animals, and endosymbiotic bacteria, such as *Spiroplasma*, are commonly found in terrestrial arthropods. These inherited symbionts are not necessary for host survival but are highly prevalent and exhibit various phenotypic traits, including "male killing," "feminization," or provide selective advantages to their hosts. Despite the stability and efficiency of host-symbiont associations passed from mothers to offspring, the lack of co-cladogenesis suggests that many symbiont-host associations are temporary over evolutionary time. Therefore, hereditary symbionts must regularly establish themselves in new hosts, a process known as "host shifting," to survive. Host shifts are significant evolutionary events for both hosts and symbionts.

Our study aims to investigate the factors encoded by symbionts that are crucial for host shifts and how environmental interactions impact host shifts. We will use model host-symbiont systems, such as the *Drosophila/Spiroplasma* system, to conduct host-shifting experiments and characterize the molecular evolution of inherited symbionts in response to experimental host shifts. Furthermore, we plan to incorporate genomic features associated with successful host shifting in natural populations of inherited symbionts.

This study will provide insight into how host shifting impacts symbiont evolution in novel hosts and explain the remarkable diversity and abundance of inherited symbionts in arthropods.

SESSION 29:

Evolutionary Response to Global Changes

The effects of thermal evolution on consumer-resource interactions

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Species traits can evolve in response to rising temperatures, possibly affecting trophic interactions and their stability. However, we have a limited understanding of how thermal evolution influences trophic interactions. Here we used protist microcosm experiments to investigate the effects of thermal evolution on a consumer-resource system. We selected a microscopic alga and a ciliate consumer for six months at 18°C and 28°C and measured how their growth rates, cell morphology and trophic interaction changed as a result. Selection at higher temperatures reduced the growth rate of the consumer but had no effect on resource growth rate. Resource cells became rounder and consumer cells more elongated at higher selection temperatures, but cell size was not affected by selection temperature. The trophic interaction (measured as ingestion rate of the consumers) was affected by thermal evolution of the resource but not of the consumer: resource cells selected at 28°C were consumed more compared to the ones selected at 18°C. These results suggest that thermal evolution could influence how global warming affects trophic interactions and species traits. This motivates further research into the mechanisms behind thermal evolution and highlights the need to incorporate evolution into predictive ecological models of global warming.

Demographic history of Malagasy palms: have humans replaced past dispersal by megafauna?

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Past and ongoing global change, such as paleoclimate change, and human impact such as deforestation and defaunation, may lead to extinctions and dispersal limitation of populations and species. Madagascar, a biodiversity hotspot with alarming rates of biodiversity threat, has experienced such severe change since the Quaternary, but whether it has led to population size declines and the loss of migration between populations remains unknown. Here, we test this hypothesis by using double-digest restriction-site-associated DNA sequencing (ddRAD) across 38 populations of 12 species of Malagasy palms (Arecaceae). We used Stairway Plots and the diffusion approximation method implemented in dadi to explicitly test alternative demographic models consistent with climate, deforestation or defaunation impacts on populations. We revealed that all species experienced a decline in effective population size compared to historical conditions, but migration rates declined in some species, whereas they remained constant or indicated secondary contact in others. Interestingly, human use and rainforest habitat (linked to human effects, e.g., deforestation) or fruit size (linked to defaunation effect) did not consistently explain differences in demographic histories between palm species. However, human-used savanna palms in the west (Hyphaene coriacea and Crysalidocarpus madagascariensis) did not show a disruption of migration, whereas megafruited, rarely human-used rainforest species Orania longisquama and Satranala decussilvae showed a recent migration disruption, consistent with the loss of seed dispersal by nowadays extinct megafrugivores, such as giant lemurs and elephant birds. We conclude that Quaternary global changes linked to paleoclimate and anthropogenic impacts have led to the consistent decline of Malagasy palm populations, but human-use and assisted gene flow may safeguard populations for some species.

Evolutionary history of a range-limited rodent indicates interplay of environmental change and human presence

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Late Pleistocene environmental changes influence species divergence, genetic diversity, and demographics. Additionally, early hunter-gatherers modulate the evolutionary history of many species. Subfossil remains of the giant root-rat (Tachyoryctes macrocephalus) evidence that this endemic fossorial rodent species was a key food resource for early hunter-gatherers in the afro-alpine Bale Mountains in southeast Ethiopia. To investigate the species' evolution in relation to the interplay between human presence and environmental change, we combined ancient biomolecular techniques (radiocarbon dating, ancient mitochondrial DNA, stable isotopes) of subfossils and modern specimen data (modern mitochondrial DNA, stable isotopes). We found that the species diverged into a northern and a southern subpopulation approximately ~220,000 years ago, likely due to a topographic barrier. Demographic analyses indicate that the northern subpopulation declined during the period of human occupation (47,000-31,000 years ago), presumably as a response of intensive hunting, while the southern subpopulation decreased during the last glaciation of the region (48,000-16,000 years ago) which aligns with environmental changes indicated by stable isotopes. Our findings provide valuable insights into the interplay between human activities, environmental changes, and species dynamics. By studying the history of species, we can gain knowledge to inform conservation strategies in the face of the present biodiversity crisis.

Epigenetic responses to changing environments

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The world's environmental conditions, including its temperature and nutrients, are changing rapidly, causing a loss of biodiversity. While living beings have to cope with these changing conditions, we still know little about the underlying molecular mechanisms. Epigenetic mechanisms flexibly regulate gene expression and can provide rapid short-term and stable longer-term physiological adjustments to environmental changes. Here, I will address the question, whether epigenetic changes are identified in specific gene pathways in response to an environmental factor or whether responses are in common gene pathways for different environmental factors. We will include temperature increase and diet alterations within and across species, and discuss the potential of epigenetic biomarkers to improve conservation strategies.

Population genetic diversity is driven by species dispersal and environmental complexity

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In the context of global changes, assessing the current and future state of species and biodiversity distributions, as well as their responsible drivers, is essential to assess the consequences of anthropogenic threats on our ecosystems and established adequate conservation strategies. Although less studied due to a certain lack of data, populations within species must also be part of this assessment to understand whether similar threats impend their genetic stability, and coordinate conservation efforts at both inter- and intra-species levels. Here, by employing a large compilation of research studies (~1,500) and populations (~20,000) for ~850 species, (1) we globally assess how natural, anthropogenic environments and their grains drive population genetic diversity (PGD or expected heterozygosity), and for each species, (2) whether their population genetic stability relates to their IUCN conservation status. Across all studies, we found that when PGD is positively driven by environmental complexity, the inverse relationship applies with human footprint, and vice-versa. Furthermore, the optimal spatial resolution of the relationship PGD-complexity was found across all species to be strongly related to their dispersal capabilities. Therefore, we here show that, on top of being driven by environmental complexity and human factors, PGD is also determined by species dispersal and their ability to adapt to their surrounding environments.

Evaluating common conservation tools for genetic diversity

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Protected areas and the IUCN Red List are widely used conservation tools for protecting and monitoring wildlife in their natural habitats. Protected areas can be designated based on geological, cultural, and ecological significance, and Red List extinction risk is based on abundance and the quality and size of species ranges. Although genetic diversity affects population resilience and ability to persist in changing environments, it is not typically considered in Red List status assessment or protected area decision-making. However, both tools could, in theory, be indirectly related to genetic diversity. Species with lower extinction risk are predicted to have higher genetic diversity, while low levels of human disturbance and fragmentation in protected areas should also safeguard genetic diversity by supporting large, well-connected wildlife populations. Yet, the effectiveness of these conservation tools for monitoring and maintaining genetic diversity is not well tested. Using publicly available genetic data for hundreds of species sampled in >1000 locations, we find that neither Red List status nor protected area status is consistently related to genetic diversity across species. We discuss the reasons for this lack of effect and implications for global conservation genetics policy.

Two common, often coexisting grassland plant species differ in their evolutionary potential in response to experimental drought

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For terrestrial plant communities, the increase in frequency and intensity of drought events is considered as one of the most severe consequences of climate change. While single-species studies demonstrate that drought can lead to relatively rapid adaptive genetic changes, the evolutionary potential and constraints to selection need to be assessed in comparative approaches to draw more general conclusions.

In a greenhouse experiment, we compare the phenotypic response and evolutionary potential of two co-occurring grassland plant species, *Bromus erectus* and *Trifolium pratense*, in two environments differing in water availability. We quantified variation in functional traits and reproductive fitness in response to drought and compared multivariate genetic variance-covariance matrices and predicted evolutionary responses between species.

Species showed different drought adaptation strategies, reflected in both their species-specific phenotypic plasticity and predicted responses to selection indicating contrasting evolutionary potential under drought. In *T. pratense* we found evidence for stronger genetic constraints under drought compared to more favourable conditions, and for some traits the plastic and predicted evolutionary responses to drought had opposing directions, likely limiting the potential for adaptive change.

Our study contributes to a more detailed understanding of the evolutionary potential of species with different adaptive strategies in response to climate change and may help to inform future scenarios for semi natural grassland ecosystems.

SESSION 31:

Changing Forests

Changes in forest structural complexity and its landscape-level heterogeneity after Enhancement of Structural Beta Complexity (ESBC) interventions

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Management practice of Central European broadleaf production forests has led to large-scale predominance of structurally homogeneous forest landscapes. This, in turn, contributes to low landscape-scale beta diversity and beta ecosystem multifunctionality.

To test whether artificially increased structural heterogeneity can enhance beta diversity and beta multifunctionality in forest landscapes, a large-scale field experiment was established in beech-dominated production forests throughout Germany, where forest structure was altered through ESBC (Enhancement of structural beta complexity) interventions. The applied ESBC interventions combine the creation of different standing and lying deadwood structures by tree removal with two variations of spatial arrangement of the intervention (aggregated and distributed), leading to a total of 15 treatments. We compare the heterogeneity of forest structure in Enhanced forest districts, where all plots received the same treatment, with Control forest districts, where all plots received a different treatment. To assess forest structure, we measured pre- and post-intervention stand structural complexity (SSCI), canopy openness, and understory complexity (UCI) with Terrestrial Laser Scanning in a yearly time series starting in 2018.

The ESBC interventions severely decreased SSCI and increased canopy openness especially in the gap-like aggregated treatments. As time went on, natural rejuvenation emerged quickly where the interventions had increased light availability, which led to a rapid increase of SSCI and UCI. On the scale of forest districts, applying different treatments to different forest patches could significantly increase the structural heterogeneity of Enhanced districts, which might have promising implications for beta diversity and beta ecosystem multifunctionality.

Effects of natural and managed canopy gaps on soil microclimate, decomposition and their relationship in a hardwood floodplain forest in Central Europe

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Forest canopies buffer macroclimatic changes sustaining a distinct microclimate in the forest interior. Canopy gaps can affect soil microclimatic conditions and dependent ecosystem functions such as decomposition. In addition to silviculturally induced gaps, there are increasing numbers of canopy gaps resulting from increased tree mortality due to climate change related disturbances such as droughts or infestations. Especially under accelerating climate change, it is unclear, whether the thermal buffering capacity of forests with canopy gaps is still sufficient to mitigate macroclimatic changes. We therefore investigated soil microclimate and decomposition along a gradient of differently structured and sized forest gaps (from patchy single tree gaps up to 0.72 ha cuttings) in the drought year 2022 in a Central European forest. In all experimental periods of our study between May and October, mean soil moisture and temperature were on average 4.9 % and 1.1 °C higher in plots with open-canopies and removed or thinned understorey than in plots with closed vegetation. Under open conditions soil temperature fluctuations were over the whole season on average 3.4 % stronger than on plots with denser vegetation. Three different decomposition experiments with tea bags, wooden spatulas and bait-lamina stripes showed each no significant differences between the levels of canopy and understorey openness. We found a positive significant effect of mean soil temperature on invertebrate feeding activity over the whole season whereas soil moisture decreased in this time, but only very few relationships between microclimate and decomposition during single experimental periods. Although it was a very dry growing season, there were still high decomposition rates. We therefore suspect that temperature has a stronger influence on soil biological activity than soil moisture under the given climatic conditions. We conclude that the microclimatic differences within the gap gradient of our experiment were not strong enough to affect soil biological activity.

Higher tree water deficit under intra- vs. interspecific competition – insights from mature stands of European beech, Norway spruce and Douglas fir

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Mixed forests are, for multiple reasons, a promising option for forest management in Central Europe. However, it is not clear to what extent interspecific competition affects tree hydrological processes. High-resolution dendrometers capture sub-daily variations in stem diameter, presenting a valuable tool to monitor growth and water status of individual trees at the same time.

To evaluate the effect of intra- vs. interspecific neighborhood on tree growth and water status, we deployed >100 sensors in pure and mixed forest stands of European beech, Norway spruce and Douglas fir on four different sites in north-western Germany, measuring stem diameter at 10-minute resolution for a period of four years (2019-2022). Using normalized minimum tree water deficit as a daily indicator for water stress, we found that throughout the growing season, beech trees growing in pure stands exhibited higher water deficit than those in mixed stands. An exception was 2021, the wettest year of the study period, where all trees showed low water deficits, while the largest differences were observed during the driest year (2022).

We assume that these differences may arise from belowground complementarity in interspecific neighborhoods, since results from water stable isotope analysis on a subset of plots show small but consistent differences in water uptake depth of the tree species in the mixed stands, suggesting a broader access to belowground resources. Still, environmental variables (mainly VPD and soil matric potential) were the strongest predictors of tree water deficit, and annual growth was substantially impaired by drought on all plots.

Overall, our data suggests that mixed beech-conifer stands seem to be less affected by severe droughts than pure stands, making them indeed a valid option for the adaptation of forests to climate change.

LINKING SAP FLOW TO STEM CIRCUMFERENCE CHANGE OF EUROPEAN BEECH, SYCAMORE MAPLE AND COMMON ASH DURING THE SUMMER DROUGHT 2022.

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Drought events have become more intense and frequent in recent years and the resulting effects on forests in Central Europe in general and in Germany in particular are remarkable. Understanding how uneven-aged mixed temperate forests experience the stress period through eco physiological studies can contribute to the development of strategies to limit drought-related tree mortality. Studies combining the monitoring of hydraulic tree properties in high resolution with hydraulic properties of the atmosphere and the soil are very limited. An experimental plot at the Hainich National Park located at vicinity of an Eddy-covariance tower offers a unique opportunity to examine these eco physiological patterns at different levels (soil, tree, below- and above-canopy). In fact, assessing the physiological responses of trees to changing environmental conditions during dry summers would help to better understand their responsiveness to drought.

We assessed the effects of drought on stem circumference change and sap flow density of 12 European beeches (Fagus sylvatica, dominant species), 4 sycamore maples (Acer pseudoplatanus) and 5 European ashes (Fraxinus excelsior) in the Hainich National Park during the exceptionally dry summer 2022, using state-of-the-art measurement techniques. We observed between July and September, a higher but not significant ($p > 0.05$) sap flow reduction in F. sylvatica and A. pseudoplatanus compared to F. excelsior. The tree water deficit response was however stronger in F. excelsior compared to F. sylvatica and A. pseudoplatanus. While the tree water deficit was mainly affected by soil water content and very less by vapor pressure deficit and net radiation, sap flow density responded significantly to the three climate variables. Our efforts contribute to understand the implications of species-specific physiological responsiveness to drought with respect to future extreme climate events.

Long-term alterations in leaf traits of Central-European beech and oak trees and effects of severe drought: results from ICP forest monitoring

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During recent decades, Central-European forests have experienced hot and dry summers that resulted in severe damage to trees. We used results of the ICP Level-II monitoring network in south-western Germany from 2004 through 2021 to detect drought effects on leaves (morphology, nutrient relations, injury) as well as long-term trends of foliar traits in stands of the European beech (Fagus sylvatica) and oak (Quercus petraea or robur), the ecologically and economically most important deciduous tree species of Central-European forests.

Across all beech (but not oak) stands, leaf size and specific leaf area (SLA) were significantly lower during the extreme 2018—2020 drought stress, whereas foliar injuries (chloroses, necroses, herbivory, fungal infection) were largely unaffected by drought. In both tree genera, the foliar N concentrations were significantly reduced during the drought. This resulted in significantly increased N/P ratios in the beech. In this species, the concentrations of Ca, K and Mn were lower during the drought but were not reduced to deficiency levels. In the oaks, this was true for P and Mg. Whilst the supply with N was good to luxurious at all sites and to both tree genera across the years, the P supply was scarce almost throughout — independently of drought — and even deficient in some stands and years, resulting in elevated N/P ratios. Similar relationships, but less severe in the oak, were found for Mg and the N/Mg ratios. Long-term trends in leaf morphology, injury and nutrient concentrations were only detected for few traits in individual stands and followed no general pattern.

In conclusion, the severe drought of 2018—2020 reduced the foliar concentrations of macronutrients in some instances, but not below deficiency thresholds. In the beech, a decrease in leaf size and SLA might be used as an indication of drought stress effects in regular monitoring programs.

Are temperate tree species able to adjust root-water uptake depth in response to drought?

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Temperate trees are facing a growing challenge due to limited water supply and increased atmospheric demand resulting from an extreme trend in drought events. Traits such as root-water uptake depth (RWUD) are crucial for determining a species' performance during drought. The objective of this research is to determine the ability of species to adjust their RWUD during drought. For this purpose, we analyzed ∂^2H and $\partial^{18}O$ isotope data from xylem water samples obtained from nine co-occurring temperate tree species over three growing seasons (2020-2022) at the Swiss Canopy Crane II site in Switzerland. Additionally, we analyzed bi-weekly water samples collected from precipitation, throughfall, and soil water at different depths. The years 2020 and 2022 were comparatively dry when compared to the reference period of 1991-2021, whereas 2021 experienced a wet summer. This provides an opportunity to observe the dynamics of RWUD across a broad range of soil water supply. The hydrological model LWFBrook90.jl is applied to assess RWUD dynamics in response to soil moisture and soil water potential variations in high temporal resolution.

The initial results show species-specific differences in the summer ∂^2H and $\partial^{18}O$ isotopic signals. While xylem-water ∂^2H and $\partial^{18}O$ values for Quercus sp., Fraxinus excelsior, and Sorbus torminalis suggest RWU in deeper soil, Carpinus betulus, Picea abies, and Abies alba signal a predominant RWU in the top soil. Fagus sylvatica and Pinus sylvestris exhibit variability in their values, indicating RWUD adjustment. These initial findings reveal different rooting strategies and resource partitioning within the rhizosphere. The final results of this study are expected to have significant implications for understanding the mechanisms behind drought vulnerability of temperate trees and improving the prediction of tree species' responses to a changed hydrological regime.

Biodiversity conservation in the Leipzig floodplain forest - using a demographic forest model to support conservation planning

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The Leipzig Floodplain Forest (LFF) is a biodiversity hotspot of national significance. Much of this biodiversity is associated with characteristic hardwood floodplain forest tree species, especially pedunculate oak (Quercus robur) and European ash (Fraxinus excelsior) trees. However, the share of oak and ash has been declining over the last decades due to regulation of the hydrological regime, recurrent droughts, and invasive pests and pathogens. In particular, it is unclear whether the planned revitalization of the hydrological regime (higher groundwater table, more floods) will be sufficient in ensuring the conservation of oak, or whether active oak planting is required. To answer this question, we apply the Perfect Plasticity Approximation (PPA) forest model. The PPA model is a demographic forest model which simulates changes in forest dynamics according to growth and mortality rates in discrete canopy layers, as well as recruitment rates. We use forest inventory data from the 'Lebendige Luppe' project, including approximately 8000 trees growing in either ambient conditions or artificially flooded plots, to quantify demographic rates for eight focal tree species and characterize their dependence on the hydrological conditions. In addition, we take data from small-scale oak plantations ("femel" in German) with differing sizes to model potential management scenarios.

In the baseline scenario (no revitalization of the hydrological regime, no active management), the basal area of oak trees is projected to decline by half in the next 50 years, indicating that natural regeneration alone is insufficient. Likewise, a scenario where the hydrological regime is revitalized does not ensure sufficient oak recruitment. Therefore, we compare the long-term impacts of different active management scenarios on the tree species composition of the LFF. Our results can support the design of an optimal biodiversity conservation strategy for the LFF.

Assessing the importance of timing of drought for the survival and growth of temperate tree species under warmer climate.

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The timing of drought events during the growing season is crucial for predicting the future vulnerability of temperate tree species to climate change, as it may significantly affect seedling establishment, growth, and survival. Understanding the impact of drought timing is especially important given the seasonality of growth and water availability in temperate latitudes. In this study, we investigated how drought timing, warming temperatures, and their interactions affect the survival and growth of seedlings from four European tree species (Fagus sylvatica, Sorbus aria, Picea abies, and Pinus sylvestris) with contrasting drought tolerances (high vs low) and leaf traits (deciduous vs. evergreen). We conducted a controlled climate chamber experiment, exposing 790 seedlings to drought of equal duration at different times of the growth season (spring vs. summer), under three different warming scenarios (current, +2 Cº, +4 Cº). We replicated the development of temperature, water availability, humidity and photosynthetically active radiation (PAR) at 10-minute temporal resolution in the climate chambers, representing the current conditions at 800 m.a.s.l in Berchtesgaden National Park in the northern Alps, Germany. Over five months (April to August 2022), we monitored seedling growth, survival and soil moisture. We found that under current temperatures, drought treatments had negligible effects on seedlings. However, under warmer temperatures, drought impacts were considerable. Spring drought had a greater impact than summer drought on both the survival (with up to 85% reductions in survival under the warmest treatment) and growth of all species. The two species with low drought tolerance (F. sylvatica and P. abies) were most impacted by spring drought. Deciduous species (F. sylvatica and S.aria) were more affected by summer drought than evergreen species (P. abies and P. sylvestris). Our findings highlight the importance of considering the timing of drought when predicting the future success of temperate tree species under a warmer climate.

The performance of beech, sessile oak, silver fir and Douglas fir along an experimental gradient from hot-dry to cold-moist climate in Switzerland

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A warmer climate with dryer summers affects the suitability of tree species in their current habitat. Changing disturbance regimes amplify the consequences of climate change on forests and subsequently on future ecosystem services. Climate smart forestry includes the assisted migration of tree species into new habitat. Solid tree species recommendations are needed to help forest managers select species adapted to future climates from extant tree species and where those are currently missing, plant species for better mixture.

In two complementary experiments we test the growth performance of beech, sessile oak, silver fir, Douglas fir, Turkey oak and Atlas cedar along a climatic gradient. In the Swiss common garden experiment (Testpflanzungen), those tree species (among 12 others) are tested on 57 sites throughout their current habitat, as well as in higher altitudes, where the climate is supposed to suit them towards the end of the century. In three of the lower altitude common gardens, we expand the climatic gradient towards a hotter and drier climate using polytunnels. In the Polytunnel Greenhouse Experiment we test how the native trees species perform in a future climate compared to non-native species from a warmer climate and how this will affect their competitive ability in future, novel forest communities.

Both experiments are running since 2021. We will introduce the experimental set-up, encourage collaboration, and share first results on survival of the tested tree species across a large climatic gradient, and their growth performance in a warmer environment on contrasting soils.

Further information: www.testpflanzungen.ch, https://www.wsl.ch/de/projekte/polytunnel-greenhouse-experiment.html.

Patterns of early natural tree regeneration after wildfire in a Central European Scots pine forest

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In the past years, several severe wildfires destroyed large areas of forests in Germany and the risk for wildfires is predicted to further increase in this region. However, only few research about the effects of wildfires on Central European forests was conducted until know. We have studied how a large (334ha) burned Scots pine forest stand in Brandenburg (NE Germany) was recolonized by natural tree regeneration in the second year after the fire. We have counted individuals of the most dominant tree species, Populus tremula (aspen), Betula pendula (birch), Pinus sylvestris (pine) and Salix sp. (willow), on 200 plots on a 100x100m grid. We analysed the effects of fire severity, post-fire forest management (different levels of salvage logging and soil disturbance) and distance to the next potential seed tree on regeneration densities. We found less aspen, pine and willow on plots with high fire severity. Post-fire management was an important factor which influenced natural tree regeneration. Birch and pine regeneration decreased with increasing distance to the next potential seed tree, while aspen and willow showed no dispersal limit in our study area. Reforestation of large forest areas which were disturbed by wildfires is a major challenge. Our study area was recolonized quickly and effectively by natural tree regeneration (mainly aspen), which provided a cost-effective and easy way of reforestation and may form a more diverse and less fire-prone forest in the future. However, natural tree regeneration is affected by several factors and most species show distinct patterns regarding post-fire forest management. We recommend having seasonal patterns of seed set and germination of tree species in mind when planning forest management activities to avoid seedling disturbance. To provide sufficient potential seed trees as sources for regeneration, surviving trees should be at least partially left on site as "green islands" even if they will later subsequently die back.

Limited influence of air temperature and precipitation on early survival and growth of non-native tree species in a Central European multi-site common garden experiment

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The biggest challenge for forest management in the near future will be the silvicultural adaptation of forests on sites where climate change is going to increase the risk for drought induced calamities of trees. One option is the diversification of the local species pool by promotion of non-native tree species. Currently, we have in depth experience with cultivation of only a few non-native species that were successfully introduced to Central Europe more than a century ago such as Douglas-fir or red oak. Other tree species that may complement the species pool in Central Europe need to be carefully selected by a range of criteria. Amongst other aspects, the suitability of species to grow well under expected future climatic conditions as well as a good performance already today should be tested before establishing larger silvicultural experiments at stand-level. We present results of a multi-site common garden experiment where growth and survival of five non-native tree species and one local native reference species per site are tested in five sites in Austria, Germany and Switzerland along a temperature and precipitation gradient. Satisfactory early survival and growth rates of all tested species indicate their high potential for being considered for further trials. Contrary to our expectations, survival and growth rates were mostly equally high on the two sites at the opposing ends of the temperature and humidity gradient and lower on all other sites. Growth and survival were only marginally affected by the strong summer drought in 2018 in all except one test site. This indicates that the tested tree species grow well in a wide range of weather conditions. However, other site conditions than temperature and precipitation seem to influence the performance of the trees and have to be considered when discussing the suitability of these tree species.

Functional traits explain shoot growth reductions resulting from successive hotter droughts across a wide set of European tree species

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In many regions of the world forest suffer from extreme drought events, such as hotter droughts caused by climate change. Beside studying the tree mortality, it is crucial to understand changes in tree growth pattern during such hotter droughts, since thus far, we still have a limited understanding of how physiological responses to intense drought events translate into growth reduction across a wide range of species. We further lack knowledge on how we could employ knowledge on functional properties of tree species to parametrize models predicting growth responses and eventually mortality risks.

Therefore, we examined the effects of the three consecutive drought years 2018–2020, on a large set of 57 planted tree species, replicated at least three times in the research arboretum ARBOfun, Großpösna, Germany. Me measured the lateral branch growth per year and calculated the growth resistance as the growth during the drought in relation to the pre-drought growth. We further used gap-filled trait data from the TRY database to explain the growth resistance.

We found that growth resistance decreased in the hotter drought year 2018 compared to pre-drought conditions. In addition, growth resistance decreased even further in the consecutive years 2019 and 2020 compared to 2018. Further, we found that the trait P50 (xylem pressure at which 50% conductivity has been lost and indicating embolism resistance), showed a significantly interaction with the drought years, thus with lower P50 the lateral resistance increased in 2018 and 2019, while the trend turned around in 2020. We also found significant effects on resistance over all year, for SLA (specific leaf area) and the C:N ratio for the confers species.

Overall we found strong evidence for significant growth reduction during the hotter drought with legacy effects over this large set of 57 species at the same site and identified single hydraulic traits and traits related to resource acquisition to predict growth response.

Structural changes of individual trees after a storm event

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Storms represent one of the most serious disaster for German forests, and are prone to happen more often with climate change. Tree movement is correlated with the passage of wind gusts of small spatial scale. Previous studies showed that to explain the sensitivity of a forest stand to storm, timber removal and selective thinning were more important than soil and site conditions or topographic variables.

This suggests that a finer scale of observation is necessary to understand the predisposition of a tree to storm damage. In particular, a tree can damp its own oscillation by friction with its neighbors or by transferring the energy to branches and twigs via higher frequency agitation.

From 16th to 21st of February 2022, North-Western Europe and in particular the Northern half of Germany was affected by a series of powerful winter-storm (Dudley – Eunice – Franklin). In some days, hurricane force winds were recorded, and wind gusts reached 100 km.h-1 at some stations.

Here we observe the effects of the storm on trees and in particular the role of structural traits of individual tree and neighbours in the response to this disturbance. We focus on two conifer species, Pseudotsuga menziesii, and Picea abies. The observations were made at four locations in Lower Saxony (Germany), each of them composed of four stand type: Pure P. menziesii, pure P. abies, and mixtures of P. menziesii or P. abies with native broadleaved Fagus sylvatica. In March 2021 and March 2022, all the sites were scanned with mobile laser scanner (LiDAR). The resulting point clouds were segmented into individual trees and paired with the forest inventory. For each tree, we compared the cloud matching, the changes in crown volume, number of branches and stem leaning. Indeed, even for trees not uprooted by the storm, changes in tree structure were observed, potentially affecting vitality on the long term.

Towards a better understanding of post-disturbance forest reorganization

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Forest ecosystems are changing profoundly because of changing climate and disturbance regimes. Theory suggests that change happens in pulses that interrupt phases of relative stability. The reorganization phase is a relatively short window of time after disturbance in which "the deck is reshuffled", either resulting in the renewal of the system or in a transition to a different trajectory leading to an altered ecosystem. Once the ecosystem has reorganized, the propensity for fundamental change declines rapidly – the system is increasingly locked into its trajectory. This process of reorganization and lock-in is particularly pronounced for ecosystems dominated by sessile, long-lived species, such as trees: individuals that establish in the first years after disturbance often determine forest structure and composition for decades and centuries to come. Thus, the reorganization phase is a critical window determining the occurrence, direction and magnitude of forest change. Here, I present a research agenda towards a better understanding of post-disturbance forest reorganization in a changing world. I introduce a framework for characterizing forest reorganization, proposing five major pathways of reorganize following disturbance: resilience, restructuring, reassembly, replacement, and regime shift. I identify fundamental processes underpinning forest reorganization which, if disrupted, deflect ecosystems away from resilience. Based on these conceptual considerations I illustrate how we can learn about forest reorganization from experimental, empirical, and simulation-based studies, drawing on examples from an ongoing European Research Council project. I conclude that studying post-disturbance vegetation development provides early indication of forest change, and offers a window into the future of our forests.

Unlocking Forest Reorganization: How Disturbances and Forest Management are Shaping Germany's Future Forests

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Increasing tree mortality due to climate change is raising questions about future forest development and the impact of forest management. To understand how post-disturbance forests may reorganize in structure and composition, we surveyed dominant forest types in Germany affected by mortality from drought and bark beetles in 2018-2020.

Across 120 patches and 1,244 sample plots, we compared disturbed and managed (salvage-logged), disturbed and unmanaged (remaining deadwood on site) forests to their reference, undisturbed conditions. We used six indicators for forest structure and composition to understand if post-disturbance forests: remained resilient (no change compared to reference conditions), changed in structure, composition, or underwent forest loss. As drivers, we considered forest management and patch size.

We found that 63,7% of disturbed patches showed indication of post-disturbance reorganization. Replacement (change in both structure and composition) was the most common pattern (43.1%), followed by a change in composition (33.4%) and structure (23.5%). Regeneration density on disturbed sites was high (median of 11,897 stems/ha) with no evidence of forest loss. Norway spruce (Picea abies (L.) Karst.) forests reorganized most strongly due to reduced stem density when harvested after disturbances. Unmanaged sites maintained high resilience, while forest management facilitated reorganization, and particularly a change in species composition. The strength of forest reorganization increased with larger patch sizes.

Our study indicates that disturbances are strong drivers of forest reorganization in Central Europe. Non-management of post-disturbance sites represents a viable option to maintain stand resilience, while forest management can assist changes in tree species composition in secondary Norway spruce forests. Studying early post-disturbance vegetation development provides early indication of forest change, and offers a window into the future of our forests.

No stabilization of species diversity despite conspecific negative density dependence in global forests?

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A long-held ecological hypothesis suggests that local tree species diversity is stabilized by specialized enemies that create conspecific negative density dependence (CNDD), prevent the dominance of individual species, and therefore promote coexistence. CNDD, however, only leads to stable coexistence when all species in the community have positive population growth rates when rare, and this requirement can be violated if CNDD varies strongly among species. Nevertheless, variation in CNDD among species has rarely been explicitly quantified or used to evaluate the diversity-enhancing impact of CNDD. Here, we use dynamic forest inventory data from twenty large, globally distributed forest sites to quantify CNDD and interspecific variation therein based on mortality models and meta-regressions. On average, an increase in local conspecific density negatively affected tree survival at almost all sites. The strength CNDD varied substantially between species and sites, and estimates for some species also indicate significant positive effects of conspecific neighbors. Variability in CNDD among species was considerably greater than what theoretical simulations suggest as the maximum for stable coexistence, casting doubt on the effectiveness of CNDD for maintaining tropical tree diversity. Empirical CNDD studies should rely more frequently on this additional evidence, underpinned by theoretical simulation studies that should examine in more detail whether and how fitness differences among species resulting from CNDD variation are compensated by equalizing mechanisms.

Exploring the last biological frontier: biodiversity of deadwood-dependent taxa in forest canopies

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Natural disturbances and forest harvesting alter the vertical and horizontal structuring of forests which determines habitat conditions for forest species. Microclimatic conditions depend on canopy cover and thus differ between closed and open forests and, similarly, change along the vertical axis from the forest floor to the upper canopy. Yet, it is unknown whether habitats in the upper canopy host similar communities as those near ground in forest gaps due to similar microclimatic conditions or whether other factors make the upper canopy a distinct habitat. We tested this question for saproxylic, i.e. deadwood-inhabiting, communities by sampling beetles, fungi and bacteria from 150 branch bundles comprising three tree species which were exposed along a vertical and horizontal gradient in microclimate: sun-exposed in the upper canopy and in gaps, half-shaded in the mid canopy and at the edge of forest gaps and shaded near ground under a closed canopy. Variation partitioning showed that species composition of all taxa was predominantly determined by tree species, followed by vertical stratum in beetles and spatial distance between sampling locations in fungi and bacteria. Beetle assemblages at upper and mid-canopy formed a distinct community compared to those near ground. Fungal assemblages in the upper canopy were similar to those in gaps, while bacteria assemblages in the upper canopy were different only from those near ground under closed canopy. Gamma diversity of all three taxa differed between tree species, but only few significant differences occurred between vertical and horizontal positions. Our results indicate that deadwood in gaps represents a distinct habitat compared to deadwood in the canopy for beetles, but not for fungi and bacteria. Hence, for the conservation of saproxylic biodiversity, sun-exposed deadwood in gaps cannot fully substitute deadwood in the upper canopy. This highlights the need to protect standing deadwood and large, old trees with dead branches in the canopy.

Trophic levels and functional guilds are differentially susceptible to management of forests

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Forests play a crucial role in the global conservation of biodiversity, but the effects of forest management on biodiversity have not been sufficiently studied so far. In four study regions, representing typical forest communities of Central Europe, the effects forest structure on selected groups of organisms were investigated along a management intensity gradient on 50 plots in each region.

Our results showed that species groups were affected differently by management, depending on their habitat requirements and the specific characteristics of the organisms studied. A general decrease in abundance or species richness with increasing forest management intensity could not be found. However, species composition changed significantly along the management intensity gradient. Species turnover was mainly caused by the dominating tree species, stand age and the resulting forest structure.

In unmanaged old beech and oak stands, for example, cavity-nesting birds, such as woodpeckers, were found in higher abundances. In managed stands, bird communities often benefited from the opened canopy and the structurally rich shrub layer, and thus consist mainly of species that breed in shrubs or dense vegetation. While carnivorous beetles (e.g. carabids) showed only little variation between the stands, saproxylic beetles were more influenced by forest management: For this group the amount of dead wood but also the main tree species played a crucial role. In spruce stands, heavy drought events since 2018 tremendously affected the beetle community.

Our results show that forest management and biodiversity are not mutually exclusive. At landscape scale forest management may even contribute to differently structured forests that provide appropriate habitat for a broad variety of taxa. Nevertheless, the particular value of old growth, dead wood-rich stands especially for saproxylic organisms became also clearly visible in our study.

Impact of forest management intensity and abiotic site conditions on carbon sequestration

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The impact of management intensity on the carbon sequestration potential of forests is currently a heavily debated issue. To contribute empirical evidence to this discussion, we analyzed above- and belowground organic carbon stocks of forest ecosystems along a gradient of forest management intensity. To cover regional environmental variation, research was done in four ecoregions of north-Western Germany that differ significantly in site conditions and natural forest community. Within each region 50 plots were established along a gradient of forest management intensity ranging from forest reserves where management ceased ca. 30-50 years ago to conifer plantations. C-stocks in living tree biomass increased on average from ca. 120 t/ha to 150-170 t/ with decreasing forest management intensity. Top values between 200 and 300 t/ha were almost exclusively found in unmanaged forest reserves. Carbon storage in dead wood was largely insignificant in managed stands and only in unmanaged forest reserves it reached values between 10 and up 20 t/ha. There were no significant differences in aboveground C-storage between the four study areas. In contrast soil organic carbon (SOC) stocks were strongly influenced by abiotic site conditions that varied considerably between study regions While in beech dominated forest on Cambisols in low mountain areas on average 100-110 t/ha of SOC could be found these figures were on average 80 t /ha higher in lowland Oak forests with temporarily wet Stagnosols and reached maximum values of 300 to 400 t/ha on strongly acidic groundwater influenced soils. At such sites, thick organic layers under planted conifers strongly contributed to the high carbon sequestration potential. Overall, there were only minor effects by forest management intensity on SOC stocks. Based on our results we conclude that the aboveground carbon storage potential is strongly influenced by forest management intensity, while SOC sequestration is predominantly controlled by abiotic site conditions such as soil texture and humidity. Especially hydromorphic soils may exhibit a more than three times higher carbon sequestration potential than average well-drained mesic sites, which makes them particularly valuable and a major target for restoration measures such as rewetting.

Belowground coenosis reacts on forest management intensity

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The activity of soil fauna plays an important role for several ecosystem services in forest ecosystems. Their diversity and abundance depend particularly on the soil conditions, which are influenced by forest practices in different ways. The BiCO2-project investigated the effects of forest management on soil fauna on 200 plots in north western Germany (North-Rhine Westphalia), representing the main German forest types. The overall goal of the BiCO2-project is to analyze the effects of forest management intensity on biodiversity and carbon turnover processes. As part of the BiCO2-project, earthworms and springtails were investigated as important players in decomposition processes and for the distribution of organic matter in soils. Their occurrence was linked to the intensity of forest management. To characterise the forest management intensity, the ForMI index was calculated. It uses, among others, the present deadwood and harvested biomass to objectify the forest management intensity.

The overall occurrence and abundance of earthworms and springtails seemed to be independent from the forest management intensity at all. In contrast to this, the general site conditions such as soil pH proved to be of particular importance for the distribution of the mesofauna. For example, anectic earthworm species could not be detected in three of the four forest areas studied due to low soil pH. The missing of the deep-drilling species causes losses of crucial ecological functions of the ecosystem that cannot be compensated for by other species. Special forest practices, such as skid trails, also showed a significant influence. Thus, the abundance of earthworms and springtails was significantly reduced on the skid trails compared to undisturbed control site. In order to maintain the important ecological functions of soil mesofauna in forests, it is particularly important to apply soil conserving management methods.

Positive tree diversity effects on elemental pools in tree foliage are mainly driven by selection effects and mycorrhizal association

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The positive effect of plant diversity on ecosystem functioning is hypothesized to depend on plant nutrient availability, uptake, and their temporal dynamics. However, empirical evidence is scarce. Nutrient supply of plants is greatly influenced by mutualistic soil fungi. Tree species predominantly associate with either arbuscular mycorrhizal fungi (AM; phosphorus provision) or ectomycorrhizal fungi (EM; mineral nitrogen provision). Thus, higher-diversity tree stands might enhance soil nutrient uptake by forming associations with different mycorrhizal types. In the tree diversity experiment MyDiv, three levels of tree species richness (monocultures, two- and four-species mixtures) were crossed with either AM, EM, or a mixture of both mycorrhizal types. Here, we investigated the effects of tree species richness and mycorrhizal type on elemental pools above- and belowground. For this, soil, soil microbial biomass, and tree foliage were analyzed for carbon (C), nitrogen (N), and phosphorous (P) concentrations and pools. We demonstrate that higher tree diversity results in larger foliage C and P pools for AM, EM, and mixed tree communities, and greater N pools in EM and mixed tree communities. Soil pools and soil microbial pools did not show any significant effects. The results for tree foliage pools also show that mixtures have additive effects, rather than complementarity effects. Analyses of the diversity effects (complementarity (CE), selection (SE), and net effect (NE)) confirmed this observation. The net biodiversity effects are mainly driven by strong selection effects, which are mostly pronounced for P pools. Our results indicate that tree diversity enhances aboveground nutrient storage. Contrary to our hypotheses, selection effects drive nutrient dynamics in young tree plantations.

Development of formerly managed forests on beech sites in Swiss forest reserves over five decades

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To study the long-term development of unmanaged forests, a network of forest reserves has been established by ETH Zurich in Switzerland since the late 1940s. Today, it is managed jointly by the Swiss Federal Research Institute WSL and ETH Zurich. It comprises 50 reserves spread throughout Switzerland, covering the most important central European forest types. Within the reserves, permanent plots were established on which all living and dead trees with a DBH ≥ 4.0 cm have been stem-tagged to allow their individual development to be tracked in inventories carried out ca. every 10 years.

We make use of data from multiple forest reserves in northern Switzerland established in the 1970s. In the absence of management, these forests would be dominated by beech (Fagus sylvatica). However, until after World War II they were managed as coppice with standards, which favoured light-demanding species such as oak (Quercus sp.) and birch (Betula pendula) over the more shade-tolerant beech and hornbeam (Carpinus betulus). With this dataset, we address two questions: (1) How has former management affected the species composition in these reserves, and how has it changed over time? (2) How has the carbon sequestration capacity of these forests developed 80 years after management ceased.

At the time of the first inventory, i.e. ca. 30 years after the last management, the forests still showed very high stem numbers of up to 2300/ha. With increasing time since the cessation of management, stand basal area increased whilst the number of stems decreased, resulting in darker forests. These conditions favoured shade-tolerant species and reduced the recruitment of light-demanding species, resulting in a change of species composition, a trend that is likely to continue in the future. The basal area of these forests continues to increase, i.e. they continue sequestering carbon. This highlights the importance of unmanaged forests in mitigating not only the biodiversity crisis, but also the climate crisis. It is not clear, however, how these forests will fare in a changing climate, as beech competitiveness is expected to be reduced by increased summer droughts.

How structural complexity of forests might relate to their adaptability- new insights from applying thermodynamic theory

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Managing forests for increased structural complexity as well as acknowledging them as 'complex adaptive systems' has become a paradigm in modern silviculture. However, primary forests usually show greater structural complexity than managed forests since forest management often aims for several reasons at less complex but specific structures, e.g. for the production of desired wood assortments. Therefore, the question arises why natural forests seem to gravitate towards large structural complexity. Here we argue that the consideration of thermodynamic theory in forest ecosystem research holds great potential for a deeper understanding as to why structural complexity is beneficial to forests. We bring together several existing theories and highlight how structural complexity relates to thermodynamic principles. Correspondingly, we suggest a causal link between structural complexity, forest productivity, and forests' adaptive capacity to environmental stressors.

Multi-objective forest management - an ecological-economic optimization approach

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How to meet economic objectives of timber harvesting while maintaining the functioning of diverse forest ecosystems? Answering this question requires ecological-economic models that can be easily applied and generalized for uneven-aged mixed-species forests.

Here, we develop a dynamic ecological-economic optimization model, which integrates a state-of-the-art demographic forest model with a continuous cover forestry harvesting model to optimize efficient and sustainable timber harvesting.
As a proof-of-concept, we apply the model to a beech-dominated forest in the Hainich National Park, Germany, with the goal of optimizing multiple objectives such as timber yield and the biodiversity value of the forest.

The ecological module is the Perfect Plasticity Approximation (PPA) demographic forest model that simulates forest dynamics based on individual tree growth and survival rates in the overstory and understory canopy layers, respectively, as well as recruitment rates. We used repeated forest inventory data from a 28-ha forest plot to quantify these demographic rates and validated the predictions of the ecological module against the structure of old-growth beech forests in Europe. The economic module includes constant marginal harvesting costs and timber prices, and the number of retained habitat trees (>70 cm diameter) as an indicator for the biodiversity value of the forest.

The forest model delivered reasonable predictions of the size distribution, basal area, and maximum diameter of old-growth beech forests. When only timber yield was maximized, trees were harvested when they reached 55 cm in diameter. This is similar to current management practices in beech forests. There is a trade-off between maximizing timber harvest and biodiversity value. Yet, there was a threshold of the number of retained habitat trees, below which losses in timber harvest only increased modestly with the number of additional habitat trees. Beyond this threshold economic losses increased sharply with each additionally retained habitat tree.

We established a generic ecological-economic modeling framework that reliably represents forest dynamics as well as optimal forest management. The framework can be extended to mixed-species forests and support forest management for diverse ecosystem services.

The occurrence of tree-related microhabitats is influenced by forest management intensity

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Tree-related microhabitats such as cracks in the bark or different kinds of cavities have a high relevance for the protection of biodiversity as such structures facilitate for example food gathering and breeding and can provide shelter for a multitude of species. In the past, good indicator properties of certain microhabitat types for species diversity of deadwood beetles and breeding bird communities have been demonstrated for oak-hornbeam forests. This indicates their suitability as an explanatory variable for the diversity and abundance of particular species groups. The occurrence of a variety of different microhabitat types in a forest stand might allow statements about its habitat potential.

We investigated the influence of forest management on the distribution of tree-related microhabitats in forest types representative of northern Germany on a total of 200 sample plots. Preliminary results demonstrate that the proportion of trees with microhabitats in a stand decreases significantly with increasing management intensity. In particular, the proportion of harvested wood and the proportion of non-native tree species, two of the management factors studied, affect the occurrence of microhabitats. Comparing the different surveyed forest types with varying tree species composition, management intensity has a stronger influence on the abundance of microhabitats in mixed oak or oak-hornbeam forests compared to pure beech stands.

This relationship between management intensity and tree-related microhabitats can be used as a key factor in the development of forest management strategies in which biodiversity conservation should play an elemental role.

Skid trails enrich the forest habitat by wetness indicators and ruderal plant species.

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Managed forests are filled with forestry infrastructure (skid trails), which accounts for a significant proportion of the total forest area and thus also influences their biodiversity. Nevertheless, the effects of skid trails on biodiversity are still not sufficiently understood. We carried out vegetation sampling on a total of 85 skid trails in four study areas and on control plots in adjacent undisturbed forest stands. At the same plots soil samples were taken to determine physical and chemical soil properties.

On the skid trails, we found significantly higher plant species richness, with on average two more species than in the adjacent undisturbed forest. Indicator Species Analyses revealed 15 species that were specific for skid trails, while no indicators for closed stands could be found. Between the study areas, however, different trends emerged. The effects of skidding were clearly visible in low mountain areas with beech forests, while lowland areas with predominant oak forests showed almost no effects.

In low mountain areas, skidding on slopes leads to more heavily disturbed topsoils, which was reflected in soil analysis by a narrower C/N-ratio and higher soil pH. In the ground vegetation these improved growth conditions were reflected in a higher number of nitrogen-demanding ruderal species as indicators. Furthermore, soil compaction by heavy machinery leads to a pronounced increase of plants indicative of wet site conditions. Surprisingly, all these effects were hardly visible in lowland forests on plane sites where topsoil disturbance on skid trails is obviously much less severe.

Skid trails, with their modified plant communities, can provide an additional structural element in the forest. However, detected plant species on skid trails are ubiquitous, so that the increased plant diversity does not necessarily go in parallel with a higher nature conservation value.

A simple model for the plasticity and ontogeny of the tree hydraulic architecture in response to water availability - a new perspective for exploring life history-shaped drought sensitivity

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Trees are adaptive organisms, challenging to abstract at the individual level for ecological models. To limit model complicatedness, some physiologically relevant traits such as the stem hydraulic conductivity are usually considered to be invariant, both in terms of tree genotype and life history. The work presented here addresses this gap and links data and patterns from wood anatomical studies to a framework for a new physiological tree growth model describing the response of xylem formation to environmental conditions and its feedback to hydraulic conductivity, which in turn influences tree growth and drought sensitivity. In particular, the modelling framework relates radial stem growth to the number and diameter of conduits formed and uses the associated diameter distribution to estimate the hydraulic conductivity as a proxy for tree growth performance and water use efficiency. The continuous, self-regulated build-up of the hydraulic architecture poses both chance and risk to tree fitness, known as the safety-efficiency hypothesis: forming larger water-conducting cells increases the hydraulic conductivity of a tree and can facilitate its growth, but, on the other hand, also increases its drought sensitivity. Tree species or their varieties can be distinguishable by their diameter distribution and thus, represent different trade-offs that best fulfill the requirements of certain ecological conditions or strategies. In addition, they can also vary in their plasticity, i.e. how strongly individuals can adapt during their lifetime when confronted with environmental conditions that differ significantly from the recent eco-evolutionary history of their genotype. Considering all this, the modelling framework presented offers an avenue to address a number of questions taking an individual's perspective, e.g. how long does it take for a given adaptability to have an, potentially resiliencing, impact under climate change?

Stronger drought sensitivity on warmer sites and aboveground growth decline across sites in four temperate forest tree species in Germany

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Rising temperatures, changing precipitation regimes and more frequent extreme weather events like hot droughts have exposed forests to stress and reduced vitality while increasing mortality. Therefore, understanding the climate–growth relationships of different tree species is crucial for predicting the impacts of climate change on forests.This study compares the climate sensitivity of growth of four common temperate tree species (European beech, Sessile oak, Scots pine, Douglas fir). In a space-for-time approach, the Rhine Valley, as one of the hottest regions in Germany, is compared with the only moderate warm Lüneburg Heath region in northern Germany in order to provide information about the growth patterns and the climate-growth relationships in future forests. We took cores from 500 trees at 24 plots, analysed the long term growth trends (basal area increment), and related the ring-width data to monthly climate data of the last four decades. From the late 1990s onwards, there was a noticeable decline in growth on almost all plots. The growth decline was consistent across both regions and all species. Spring and summer droughts (SPEI) emerged as the primary factors determining ring width, while the negative influence of summer temperature was not as strong as expected. Although the southern region exhibited greater drought sensitivity than the northern, no differences in growth patterns were observed between the two regions. We conclude that growth trend analysis provides valuable insights that complement information gained from climate–growth relationships. Our results indicate that even tree species that were thought to be drought-tolerant (i.e. Douglas fir, Scots pine, and Sessile oak), are suffering from the recent deterioration of the climatic water balance caused by climate change and this is particularly true for the southern region in Germany.

Rapid radial growth decline in four main timber species in Northern Germany linked to summer drought sensitivity

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Recent vitality losses in many forest tree species and local forest die-back caused by climate change in Central Europe highlight the need for locally appropriate species selection to enable stable, drought-resilient forests in the future. However, current studies often focus on the growth performance of single species over various climatic or edaphic conditions, making climate change-adapted timber species selection difficult by neglecting direct comparisons.

In this dendroecological study, we investigated long-term radial growth trends (basal area increment; BAI [cm^2]) and climate-growth relationships for the four timber species *Fagus sylvatica*, *Quercus petraea*, *Pinus sylvestris* and *Pseudotsuga menziesii* along a precipitation gradient in central Northern Germany (MAP: 830 – 570 mm year^{-1}). The study employed a space-for-time approach, encompassing 5 regions (20 stands total) to compare the species' adaptive potentials to drought stress.

We found that BAI strongly decreased in all species since the early 2000s. These findings were consistent for all sites along the precipitation gradient. Among broadleaved trees, *Q. petraea* did not outperform the drought-sensitive *F. sylvatica*, with early spring drought conditions playing an increasing role in determining the species' growth. For *F. sylvatica*, summer drought in the previous year turned out to be the most important factor influencing radial growth. We found that temperature had a less consistent effect than climatic aridity (SPEI). For the conifers, the rapid growth decline in the last 20 years was linked to an increased sensitivity to summer drought and could not be compensated by an extended growing season.

Our findings suggest severe losses in future timber production in Northern Germany. Despite the hope to find more drought resistant species, we found vitality losses and associated mortality risks in all studied species.

Modelling land-use change impacts on carbon and water fluxes of forests and grasslands under climate change

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Interaction of land-use change and climate change scenarios can lead to complex changes of carbon and water cycle dynamics of grassland-forest landscapes. This study uses the process-based model LandscapeDNDC to simulate carbon and water cycle dynamics of grasslands, broadleaved, coniferous and mixed forests for a landscape of southwest Germany. The model was evaluated with satellite gross primary production and evapotranspiration products. We utilized a novel hydraulic module that considers drought stress impacts on senescence and thus indicates differences in the vulnerability of different species and stand structures. In addition to simulations of climate change responses in the region, we also run a variety of land-use change scenarios, which represented a possible transformation of mono-specific forests to more diverse ecosystems with multiple tree species. We also tested how deforestation and afforestation would affect the carbon and water balance within the landscape. The results suggest that land-use change will have significant impacts on carbon sequestration and groundwater supply but that forest management may have considerable possibilities to increase the resilience to increasingly frequent and intense drought events. The findings also highlight the importance of accounting for the interactions between land-use change, climate change, and ecosystem dynamics when assessing the impacts of environmental change on terrestrial landscapes.

Impact of earlier leaf-out and drier summer on growth performance in three temperate tree species at the juvenile stage

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Temperate tree species are expected to lenghten their vegetation period by both advancing spring leaf-out and delaying autumn leaf senescence. However, adverse weather conditions such as severe droughts could counterbalance increasing tree growth and carbon sequestration caused by longer vegetation periods. A potential solution to attenuate negative effects of a future dryer climate during the vegetation period is the promotion of more diverse forests as recent research revealed that diverse ecosystems are more resilient than monocultures regarding various stresses. For this reason, we are investigating the performance of three temperate deciduous tree saplings (i.e., European beech, sessile oak and small-leaved lime) from 2021 to 2023 in experimental mesocosms in order to assess how spring phenology and summer drought impact species competitiveness. In detail, our experiment is consisting in: altering spring phenology with a passive warming treatment during spring, decreasing precipitation with rain-out shelters, and manipulating species diversity by letting tree species either grow in two-species mixtures or in monocultures. In spring 2022 the passive warming treatment increased air temperature by about 1°C and advanced leaf-out by about 4 days for all species, while the interaction between drought and species composition advanced or delayed senescence of beech and oak during autumn. Beech saplings exposed to passive warming during spring grew more in 2022, whereas oak saplings exposed to drought grew less in 2022. However, we expect the severe drought of 2022 to become more evident in the years following the drought. Thus, a long lasting effect of 2022 in combination with the rain-out shelter treatment is expected to decrease growth of all species in 2023.

The influence of environment on the development of *Abies alba* and *Quercus robur* seedlings

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Converting Norway spruce stands in Central Europe towards mixed species forests is one of the currently most demanding tasks to ensure the stability of forest ecosystems. Recently, direct seeding as a method of artificial regeneration and introduction of species in current monocultures is gaining increased attention in forestry practice. As environmental conditions have a large impact on the establishment success of plants originating from direct seeding, we examined how differences in soil and environment drive establishment success of *Abies alba* and *Quercus robur* seedlings in undisturbed and disturbed Norway spruce stands (canopy removal) in a low mountain forest in central Germany (Thuringia).

Our data suggests that the growth performance of *A. alba* and *Q. robur* seedlings (4-year-old) is mainly influenced by available photosynthetically active radiation (PAR) as well as soil pH and buffering capacity. Low soil pH appeared to negatively impact growth performance in both species. For *A. alba* photosynthetic performance described by Fv/Fm appeared to be negatively correlated with PAR, which was not the case for *Q. robur*. Because of this relation, the abrupt cutting of shelter trees, one year after germination, had a strong negative impact on the growth of A. alba and resulted severe diebacks, while *Q. robur* appeared to benefit from the increased light availability. The results suggest that *A. alba* reacts very sensitive to a sudden change in the light regime in this development stage, making the establishment success strongly dependent on the longevity of the canopy cover. *Q. robur* on the other hand appears to be well suited for sites that are under a high risk of losing its canopy to disturbances, or potentially even where the canopy already has been removed.

Development and promotion of natural mixed regeneration under the influence of pine canopy and small-scale precipitation

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In the pure pine stands of the Northeast German Lowlands, the establishment of naturally regenerated mixed tree species is of particular importance to strengthen these forests against climatic extremes. Natural regeneration of deciduous tree species is usually difficult on the mostly poor sites with low water supply and because of the low density of potential seed trees.

The research project VERMOS investigates the development of naturally regenerated mixed tree species considering: (a) local precipitation, (b) pine canopy, (c) associated vegetation, and (d) competition among regeneration plants. The spatial distribution of pines in the upper stand and all regeneration plants were recorded with positional accuracy. Intensive growth and quality measurements were made on the regeneration to document development and development potential. In the regeneration plots, small-scale recording of precipitation distribution (grid 1 m x 1 m) was carried out.

The spatial distribution of seed trees results in area-specific proportions of regenerated tree species with densities ranging from 3,200 to 32,700 per hectare. In dense pine stands, the proportion of pine in the regeneration layer is less than 5 %. This canopy effect is low for beech and oak regeneration density. Small-scale regeneration patterns are dependent on small-scale patterns of associated vegetation and precipitation. The spatial statistical analyses also show greater intraspecific aggregation of regeneration with increasing age. Tree species-specific analyses of annual shoot length increment demonstrate the direct influence of stand basal area as a regulating variable and the influence of precipitation. In years with particularly low precipitation, annual growth of regeneration plants is significantly reduced. The absolute differences in increment result in competitive shifts, which are of additional importance for silvicultural planning.

"Suitability" of the Swiss forest tree-species composition to future climate

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Climate change affects tree growth conditions; therefore, shifts in the tree species composition of the Swiss forest are expected in the long term. TreeApp is a tool for forestry practitioners to identify tree species expected to be "suitable" under future climate. Here, we compare the TreeApp recommendations with the species composition of stand trees (≥12 cm diameter at breast height [dbh]) and forest regeneration (10 cm height – 11.9 cm dbh) observed in the 4th National Forest Inventory NFI (2009-2017), also considering the presence of "suitable" seed trees.

We present a simple assessment scheme to classify the NFI sample plots into three levels of "future suitability" (degree of adaptation to climate at the end of this century). Across Switzerland, around 60% of the plots were rated as "suitable", 25% as "partially suitable", and 15% as "not suitable". "Not suitable" forests accumulated in two cantons with high-elevation forests. In protection forests, regeneration was assessed as "not suitable" in 25% of the sample plots and no regeneration was observed on nearly 20% of the sample plots. The proportion of sample plots with "not suitable" tree population increased with the proportion of spruce. When "suitable" seed trees were considered, the proportion of sample plots with "suitable tree population" was up to 16% higher than when only the regeneration was considered. These results underline the need to promote future climate-adapted regeneration in mountain forests, support the forest planning, and contribute to the forest management adaptation to changing climate.

Mapping potential future forests by predicting current forest regeneration

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Existing forest regeneration provides the basis for future forests and is of increasing scientific interest, particularly due to global change, associated disturbances, and the need for forest conversion. Nevertheless, there is a lack of maps characterizing the currently available forest regeneration in terms of density and tree species composition. Here, we assess the potential to map current species distributions in the regeneration using data of small trees from the national forest inventory of Germany. We calibrate and evaluate species-specific regeneration distribution models using current environmental information on topography, soil, climate, microclimate and stand structure, and interpolate the present tree species occurrence in the regeneration across Bavaria. Furthermore, we compare available tree species composition against targets for climate-adapted forests and analyse how browsing intensities influence the species composition in the regeneration.

What role plays adaptation in mountain treeline ecotones for responses in changing climates?

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Elevational treelines are expected to respond to current climate warming with an upward migration. Exceptional attention is paid to the Arctic region, since climate change is faster and more severe there than in other regions. If ongoing forest expansion keeps pace with future global change, vast areas of pristine alpine tundra habitats and its cold adapted species are threatened to recede or disappear completely additionally decreasing the albedo, which at least lead to regionally warmer temperatures. However, the rate of climate change may outrun a treeline advance. Furthermore, maladaptation to cold environments and poor genetic connectivity in the landscape may constrain necessary adaptation of local tree populations. The drivers and especially constraints and time lags that impact responses are unknown. Hence, to unravel the important factors for treeline migration and provide realistic predictions of the future treeline position we need to understand the role of genetic adaptation in forest dynamics.

The rate of structural changes in tree stands at the treeline will depend on the interplay amongst regional climate and site conditions and was dynamic over the last millennia. The advance of the treeline is not solely determined by warming temperature, but regionally constrained by abiotic features of, for example, microclimate, the topography of a mountain system, and soil conditions, and biotically by the tree species that dominate in the mountain forests. To obtain reliable estimates of tree migration rates, we need a better understanding of the complex processes involved in the establishment of forests, which are highly dependent on seed dispersal. Hence, the implementation of effective seed dispersal distances and trait adaptation in simulation models is important to provide realistic predictions of the future treeline position.

In this study, we combined data from fieldwork with a genetic survey to reveal details about short- and long-term migration processes of larches (*Larix* spp.) in mountainous regions of Siberia. The results were used to improve and apply the individual-based and spatially explicit model LAVESI (*Larix* vegetation simulator). LAVESI was designed to simulate the life cycle of larch species as completely as possible, especially seed-dispersal and subsequent establishment. We inferred the effective seed dispersal distances of larches in a complex mountain treeline system in the vicinity of Lake Ilirney (Far East Russia, 67°21'N, 168°19'E) from genetic parentage analysis using Single-nucleotide polymorphisms derived by Genotyping-by-Sequencing (GBS).

Multi-trait Point pattern reconstruction of plant ecosystems

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1) Plants interact locally in many ways and the processes involved (e.g. competition for resources, natural regeneration, mortality or subsequent succession) are complex. These processes give rise to characteristic spatial patterns that vary over time. The corresponding spatial data, i.e. the locations of individuals and their specific characteristics (e.g. trees of a certain species and their diameters), are known as marked point patterns, and their statistical analysis can be used to study the underlying processes and their changes due to environmental scenarios. A special application of point pattern analysis is their numerical reconstruction, which is classically used (a) to generate null models that can be contrasted with observed patterns, (b) to evaluate the information contained in observed data using various summary statistics, or (c) to initialise individual-based or agent-based plant models with realistic but artificially generated data.

2) Previous reconstruction methods of point patterns consider only one mark, or they consider several marks but neglect their correlations. We introduce a method that considers individual locations and two marks simultaneously (in our example information on tree species, and diameter at breast height). The method uses different summary statistics of the second-order point pattern analysis, such as the pair correlation function and the mark correlation function. By successively modifying the reconstructed spatial pattern, the distance (also called energy), measured in terms of differences in the summary statistics between the generated pattern and the observed pattern, is minimized and a high statistical similarity is achieved.

3) After testing the method on different datasets, the suitability of our method for reconstructing complex spatial forest stands, including the spatial relationships of all considered markers, is shown. The reconstructed forest stands thus represent plausible alternatives to the observed forests.

The presented method is a powerful tool for generating null models and data for initializing spatially explicit forest models based on point pattern data. With minor changes, it even enables the reconstruction of forest stands larger than those used to collect the inventory data; and although we used two marks only to demonstrate the power of the method, it is easy to include more marks.

Simulating tree growth with adapting size and count of water conducting cells.

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Trees do offer a variety of strategies to plastically deal with changing environmental conditions. Differences in size and count of water conducting cells, with consequences for water transport efficiency and risk of hydraulic failure as well as the whole-plant mechanical stability, are an important mechanism of adaption. Plenty of species specific water use strategies were derived from wood anatomical properties, like conduit diameter and density. However, since these properties are not static but dynamic within one individual tree, their are also intraspecifc differences due to different life histories of individuals.

The presented work will introduce a model of tree growth and its dynamics along an individuals lifespan, focusing on hydraulic architecture. It follows a simplified approach of plastic hydraulic conductivity, that is derived from changing count and diameters of water conducting cells under altered conditions of water supply. Drier conditions will impose smaller conduits to be build, also reducing hydraulic conductivity and finally growth. However it allows trees to reduce the risk of cavitation during reoccuring drought events.

These legacy effects ultimately may lead to an advantage over individuals used to well-watered conditions under future extreme drought events, since they are expected to show less embolisms and are less prone to hydraulic failure.

This simple model of tree growth provides a first step towards an advanced representation of dynamic hydraulic properties allowing to explain and predict intraspecific variations in physiological responses to climatic extremes on tissue to single tree scales.

A supra-regional field trial in Thuringia to test different management options for the reforestation of disturbed spruce areas

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The impact of extreme weather events such as droughts, heat waves, storms and the associated intensification of bark beetle outbreaks in spruce forests in recent years, has lead to a vast loss of spruce trees in Thuringia and other regions in Germany. There are various options for the management of disturbed areas, but their pros and cons are not clearly resolved. The ResEt-Fi consortium implemented a supra-regional field trial to test how specific practices for deadwood management affect the ecological conditions and subsequent reforestation dynamics of natural regeneration and planted trees. It aims at generating climate-stable mixed forests by an ecological valuable transition offering socio-economic benefits. For stakeholders and forest practitioners, it is planned to create guidelines and showcase scenarios for facilitating the selection of management procedures that fit optimally to the regional conditions and goals for mid- and long-term development.

The investigations focus on disturbed areas in three particularly affected model regions distributed across Thuringia, each characterized by specific ecological site conditions: 1. Southern Harz Mountains ('Südharz'), 2. Western Thuringian Forest ('Marksuhl'), and 3. Thuringian Slate Mountains ('Neuhaus'). A nested experimental design integrates different silvicultural strategies for dealing with disturbed areas, comprising (a) clearing, (b) high stumbs and (c) dead wood patches, which are compared with undisturbed sites as control (d). Furthermore, subplots with artificial regeneration and deliberately spread deadwood are additionally included in the investigations. Local climatic conditions of the treatments are recorded intensively, as are the comprehensive aspects of soil ecology, succession of vegetation, and effects on fungal communities, birds and wood-dwelling beetles. Taking all this information into account, predictions of the dynamics of various scenarios are derived by process-based simulations.

Late spring frost sensitivity of tree species – links to plant traits

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The frequency and severity of extreme events are predicted to increase with climate change. One such event is late spring frost, which is characterized by temperatures below freezing at the start of the growing season. Although tree species are adapted to late spring frost, advancing phenology due to climate warming has increased the risk of severe damage. This has significant implications at the economic and ecological levels. So far, studies have tried to identify the reasons behind differences in frost sensitivity using a limited number of tree species, but none have linked frost sensitivity to effects of phenology, life strategies, and plant traits. In this study, twigs from 31 tree species were exposed to two freezing temperatures (-5°C, -7°C) at 3 phenological stages. Using the electrolyte leakage method, the index of injury was compared to phenological and life strategy, as well as 11 plant traits from the TRY database. We address the following questions: (1) At which phenological stage are species most vulnerable to late frost? (2) Which plant traits act as indicator of frost resistance? (3) Are pioneer species more frost resistant than later successional stages? This information will contribute to an improved assessment of species suitability in a changing climate.

Shooting trees with lasers to safe the forests – Using terrestrial laser scanning to compare forest types in the context of the forest condition survey in Jena (Germany)

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Since 1984 in Germany the monitoring program "Waldzustandserhebung" (WZE) reports the forest health status annually. However, these grid-based measurements do not focus on the investigation of differences between habitat types. To overcome this limitation on a local scale, in Jena (Germany) we established a densified monitoring scheme to characterize six different forest types.

Traditionally the observations are recorded by hand, which is time-consuming and focusses on the investigation of the health status of the trees, without considering habitat and stand structure. We use a modern near sensing technology, namely terrestrial light detection and ranging (TLS) to extract stand metrics time efficient and of high quality in a semi-automated manner. A Leica RTC360 scanner is used, producing high point densities in a relatively short amount of time. A multi-scan approach with eight positions per plot results in a very detailed point cloud with low occlusion. We use automated tree segmentation and analysis tools to extract stand metrics. These cover classic metrics like tree height and DBH. Furthermore, non-destructive biomass estimates for trees, shrubs and herbs on the plot level will be possible.

The comparison between different forest types, stand properties and tree species performance will allow us to answer questions on best mitigation strategies in the context of the climate change. Furthermore, the TLS data can serve as basis for future monitoring of ecological seres.

Future development of ecosystem services in European forests and the role of small-scale forest owners

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Forests are one of the most important ecosystems to counteract today's challenges such as accelerated climate change or the biodiversity crisis. They provide a broad range of ecosystem services (=ES; e.g. carbon stock, wood and non-wood products, biomass for energy production, biodiversity), yet it is often unclear to which extent these ES might encounter trade-offs in multifunctional forest management. As around 60% of Europe's private forests are managed by small-scale forest owners, the impact of their decisions on future provision of ES should not be underestimated.

We used national forest inventory data from 5 European countries (Finland, Sweden, Germany, Austria, Slovenia) to simulate the future development of forests until 2100 under different climate change (no climate change, RCP4.5, RCP8.5) and management scenarios ("no management", "business as usual", "low intensity", "high intensity"). The simulations allowed us to analyze potential synergies and trade-offs among several ES and to better understand the role of small-scale forest owners.

Overall the simulated change (e.g. in growing stock or timber harvest) due to forest management was greater than that due to climate change scenarios. Further, we generally found limited synergies and trade-offs among different ecosystem services, e.g. carbon stocks did not correlate with forests' biodiversity indices. The great potential for/of small-scale forest owners was highlighted e.g. by the finding that their modeled timber harvest was above the overall average.

Our study shows the ability of adapted forest management to mitigate climate change-induced risks, without inevitably leading to conflicts of interest. Currently, we are working on 3D-visalisations of the future forest development to make these new scientific results accessible for (small-scale) forest owners. Their active participation in climate smart forestry is essential for securing the future of resilient and multifunctional forests.

Walddiskurs: Can biodiversity and climate change mitigation be achieved simultaneously?

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Forests can help to mitigate climate change and biodiversity loss. Because of this mitigation potential and forest dieback due to drought, sustainable forest management increasingly grows to an important topic in media and politics. In this process, different interests and positions from stakeholders (e.g. climate scientists, nature conservationists, forestry) not infrequently lead to conflicting goals. This calls for management approaches which increase potential synergies. In our interdisciplinary project "Walddiskurs" (including political scientists, linguists and ecologists) we want to contribute to the understanding of sustainable forest management so that daily action and political decisions can clearly focus on possible synergies between carbon storage and biodiversity. We also want to provide action-oriented guidance on how forest management for climate change and biodiversity loss mitigation can be communicated.

In the ecological sub-project, we examine potential trade-offs and synergies between carbon storage/wood volume and arthropod diversity (above- and belowground) across forest types and management regimes. To better understand the mechanistic links between wood volume and arthropod diversity, it must be clarified if there are correlations between wood volume (living and deadwood) and structural forest components, which are known to influence arthropod diversity. Using data across temperate forests, we found that wood volume over different forest types strongly correlates with different structural forest components. Effective number of layers, amount of tree related microhabitats and deadwood type richness are positively affected by increasing wood volume, whereas stand structural complexity decreases with increasing wood volume. These results show that there might be synergies between carbon storage and diversity. Further analyses on the shown correlations will focus on their dependence on forest type and forest management.

Scenarios of forest type change and resulting shifts in ecosystem service potential

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The prediction of ecosystem service changes is one of the striking challenges in the field of environmental research. In this study, we asked how the distribution of different forest types and subsequently their potential to provide different ecosystem services will change under different scenarios in the next decades. We combined a multi-step Delphi survey including a range of forest experts with a GIS-based simulation to determine changes in forest-based ecosystem service potentials in the German Federal State of Bavaria. Forest experts assessed future developments based on the most important influencing factors, resulting in three different scenarios describing how forests will change in the future under different assumptions: A *Status Quo Scenario* (representing constant influences), and two *Alternative Scenarios* (one under changing influences and one under optimal conditions). Those scenarios were translated into spatial scenarios by combining the experts' estimations on change probabilities of forest types and information on forest cover from the 2011 German federal forest inventory. Using information on forest related attributes like crown cover, deadwood volume or structural complexity, we estimated the ecosystem service potential across Bavaria in each of the scenarios. Among the considered ecosystem services, only few showed strong differences between forest types and most ecosystem services were provided at high levels throughout Bavaria. As forest experts assumed only small changes in forest cover composition (less than 10% change in cover for any forest type) across scenarios, changes in landscape-level potential of ecosystem service provisioning were small. Nevertheless, we found both synergies and trade-offs between ecosystem services and across scenarios. Our results can contribute to informed decision-making in forestry.

Skid trails impact carbon and nutrient turnover in managed forests

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Skid trails, which can account for 20% of forest areas in Germany, are subject to particularly intense topsoil disturbance in managed forests. Compaction associated with timber harvest alter soil physical properties, which subsequently leads to changes in soil chemical and microbiological processes. Soil microorganisms play a crucial role in carbon and nutrient cycling. Changes in their activity can have important effects on the ecosystem and, e.g. via soil respiration, also on greenhouse gas emissions.

Within the BiCO2 project, we analysed the topsoil of 85 skid trails across four study areas. In addition to physical and chemical properties, we investigated changes compared to the undisturbed control in parameters of soil microbial quality and quantity and examined nutrient turnover processes of C, N and P, reflected by readily bioavailable fractions, enzyme activities and soil respiration.

While bulk density generally increased, most of the other results cannot be generalized across the study areas because local factors such as substrate and slope determine the degree and, in some cases even the direction of the effects of skidding. Effects on C/N ratio and pH could only be found in low mountain beech forests while water-content was only affected in oak-dominated lowland forests. The microbial community composition (reflected in MBC:MBN) shifted, but in different directions depending on the study area. Skid trails in low mountain beech forests emitted more CO2 than control soils, whereas soils in skid trails of lowland oak forests showed reduced carbon turnover rates.

Our results underline that skidding should be limited to already designated skid trails. In low mountain regions with relatively steep slopes, where the soil structure is often more heavily damaged, carbon conversion processes and soil respiration are increased, which may lead to significant soil organic carbon losses. Here, even more care should be taken during timber harvesting.

The significance of forest biotopes for insect biomass and richness in normal landscapes

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Based on a stratified sample of 179 plots spread across normal landscapes of Bavaria/Southeast Germany and equipped with Malaise traps, we related insect biomass, composition and richness (based on metabarcoding) to landsacpe metrics and plant species composition and richness using mixed linear models and variance partitioning.

Compared to grasslands, arable fields and settlements, forest clearings had the highest insect biomass and richness. Plant species composition explained the major fraction of variance in arthropod composition, while land-cover composition was another important predictor. Habitat conditions as indicated by plant composition through Ellenberg-values appeared more relevant for arthropod composition than specific trophic plant-insect relationships.

Across trophic levels, arthropod richness showed a strong positive relationship with the richness of plants indicating legally protected biotopes (although those had negligible area), and butterflies and red-listed arthropods were related to the richness of red-listed insects and butterflies. Biotope-indicator plant species were more important predictors for arthropod richness than the amount of surrounding semi-natural habitat or landscape configuration. Plant species richness was mainly driven by local land use, with total species richness being highest in settlements and biotope-indicator richness being highest in forests.

The results highlight the importance of forests for the conservation of plants and arthropods as well as of preserving and restoring high-quality habitats in agricultural and urban areas.

Small-scale environmental variation in coniferous forests drives differences in functional traits in bryophytes

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The structure of forest ecosystems, as captured by tree morphology and canopy properties, generally affects the distribution of precipitation and light, hence, microbial activity, and consequently the small-scale availability of relevant resources for plants in the understorey. This knowledge especially becomes important in assessing forest vegetation responses to changing environmental conditions, and increasingly frequent disturbances such as drought periods or pest infestations. In temperate coniferous forests, bryophytes play a crucial role for ecosystem processes and biogeochemical cycling and are sensitive to changes in the environment. Yet, bryophytes are understudied in ecology and few studies have measured functional traits in bryophytes for temperate forests so far. Therefore, we established six small-scale environmental gradients in two temperate coniferous forests, consisting of five adjacent plots each, ranging from close to the stem to under a clearing. We weekly recorded bryophyte species composition and phenology and measured a broad set of functional traits for the most dominant species. To capture environmental variation, we measured a wide range of parameters per plot, such as temperature, light intensity, precipitation throughfall, and soil moisture. We found trait-, site, and growth form specific differences in functional traits, responding to the small-scale environmental gradient. Furthermore, we found differences in sporophyte occurrence and development with respect to the gradient. Our results suggest that bryophytes are functionally adapted to small-scale variation in environmental conditions. This way they might be able to cope with disturbances such as severe droughts or windthrow and therefore might even mitigate their severity on ecosystems.

Do leaf traits of tree canopies shape herbivory in tropical montane rainforests?

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Herbivory forces plants to evolve protection mechanisms affecting their palatability by influencing the composition and characteristics of leaf traits. These traits have consequences for the survival of tree individuals but also for processes controlled by the total tree community. Thus, measuring leaf traits is an important step towards understanding the dynamics of tree populations and communities. They can either be measured using conventional lab-methods or recently developed spectral techniques. We examined whether leaf traits of tree communities are related to herbivory and whether spectral leaf traits provide similar relations to herbivory as lab-based leaf traits. We established nine one-hectare plots evenly distributed over three different forest types in Ecuadorian tropical, montane rainforests where we estimated herbivory as the leaf area loss [cm^2] of 20 (± five) leaves per tree canopy of 390 trees belonging to 51 tree species (8 ± one individuals/species) using lab and spectral methods. For each methodological approach, we ran 100 linear mixed-effects models with all respective leaf traits as predictor- and herbivory as response variables for data subsets containing one randomly selected tree individual of each species to estimate the range of the regression coefficients for each trait. Automated stepwise backward selections determined the frequency of each trait having a significant influence on herbivory. We found no consistent relations between leaf traits and herbivory for neither lab- nor sensing-based traits. Sensing-based traits were erratically associated with herbivory showing positive and negative effects depending on the data subset selected for the analysis. A nested variance component analysis demonstrated that this variability was mainly due to the variation between tree individuals of a species. Our results suggest that herbivory was not driven by leaf traits of trees but by environmental conditions or processes along the food web.

SESSION 32:

Infrastructures and Networks in Biodiversity Research

Practical solutions and a grand vision: NFDI4Biodiversity as expert network and national research data infrastructure for biodiversity, ecological, and environmental data

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NFDI4Biodiversity is a consortium under the umbrella of the National Research Data Infrastructure (NFDI) dedicated to mobilising biodiversity and environmental data for collective use. Scientific institutions, IT service centres, and stakeholders in biodiversity conservation pool their expertise to provide a broad portfolio of data services. Our mission is to provide the community with access to modern technologies and a comprehensive stock of data. Our focus is on methods and tools for archiving, finding and analysing data that are suitable for everyday use and have been tried and tested in practice. Our vision is a cloud-based service platform which connects data providers and data users through a carefully constructed portfolio of software applications, semantic services, and storage infrastructure. Our helpdesk service is a single point of access for researchers and institutions alike. We will present instructive use cases and services which can already be accessed through our partners, ranging from taxonomy and field work to bioinformatics and data analysis pipelines. In a broader perspective, we will briefly introduce how we join forces with other initiatives to build a sustainable research data infrastructure for Germany, with support from the Federal Government and the Federal States (Länder), funded through the German Research Foundation - DFG.

A biodiversity portal for Germany: Lebendiger Atlas - Natur Deutschland (LAND)

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Biodiversity data can be messy, scattered and hard to come by - especially in Germany. As the national research data infrastructure for biodiversity (NFDI4Biodiversity) we set out to make biodiversity data FAIR and open. One of our products is the “Lebendiger Atlas - Natur Deutschland (LAND)”, a national biodiversity portal that provides species occurrence data in Germany to researchers, conservation authorities and the general public. To do so, we joined forces with the Global Biodiversity Information Facility (GBIF) as well as the national node GBIF.de and created the LAND-portal as a GBIF hosted portal (https://land.gbif.de/).

The portal integrates species occurrence data from different sources, including monitoring schemes, citizen science, natural history societies, museums and universities. To start with, we mostly stocked the portal with existing datasets from GBIF. Now we focus on mobilizing new datasets. To further develop the portal, earlier this year we held a community workshop with approx. 50 stakeholders from different institutions. In this talk we present the current state of the portal and its functionalities and discuss opportunities for data holders to join the initiative.

eLTER RI – A new European Research Infrastructure offering added value for researchers

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We live in a world of rapid social, economic and ecosystem change, facing major environmental challenges such as global warming, biodiversity loss and pressure on natural resources and the complex interactions between people and nature over the long term. Environmental sustainability can only be achieved on the basis of robust knowledge and empirical evidence needed to identify and mitigate human impacts on ecosystems. Addressing these issues in a transdisciplinary way requires world-class ecosystem research through a well-connected, extensive network of sites, facilities and experts, with openly shared and easily accessible data, tools and workflows supporting researchers. This is the goal of the pan-European Integrated European Long-Term Ecosystem, Critical Zone and Socio-Ecological System Research Infrastructure (eLTER RI, https://elter-ri.eu/) which is currently (2020-25) being built and developed. eLTER RI operates by catalysing scientific discovery and insights through state-of-the-art research infrastructure comprising about 250 high-level and well-instrumented facilities.

One of the main objectives of long-term ecosystem monitoring and research is to provide harmonised and standardised data sets based on the concept of eLTER RI Standard Observations in the near future, and additionally to mobilise legacy data to support evidence-based solutions. Alongside these data, several tools and services which are already in place or close to being available will help to serve multiple scientific communities. Some of these tools will be presented and we will show the links to NFDI4Biodiversity and NFDI4Earth by describing the workflows and tools foreseen for eLTER use cases serving as national nodes for eLTER data.

From Historical Biodiversity Data to Digital Long-Term Archiving - The State Archives of Bavaria in NFDI4Biodiversity

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The General Directorate of the State Archives of Bavaria (GDA) is involved in several NFDI consortia and contributes its expertise in long-term archiving, interface design, and data harmonization. The holdings of the State Archives, which date back to the Middle Ages, also contain historical as well as current biodiversity data, for example from agriculture and forestry. This paper, located within the section "Infrastructures and Networks in Biodiversity Research" (No.32), aims to shed more light on both contributions based on the activities within NFDI4Biodiversity.

On the basis of the Bavarian Archives Act, the State Archives of Bavaria are obliged to take over, secure, make accessible and make usable archival records of public authorities and other state agencies. This includes analog sources such as documents, files, and maps, various data carriers, as well as digital records, for example from state offices. Historical sources include a comprehensive survey of fauna in all Bavarian forestry districts in the mid-19th century, hunting statistics, and moorland maps. The GDA manages the import of data into the digital archive on behalf of state agencies and also provides indexing metadata in the archive subject information system ACTAPro. Cooperation is currently underway with the Bavarian Natural History Collections for the long-term archiving of the powdery mildew (the Erysiphales collection), both the data and the database structure. Other projects within NFDI4Biodiversity include a joint project with the Leibniz Institute for Ecological Urban and Regional Development. Automated processes are used to extract metadata from historical maps, which in turn are then linked to GBIF via an ABCD interface from the archival subject information system and can thus be made available to the biodiversity research community. The data archiving from two projects on forest fauna of the two national park administrations in Bavaria, Berchtesgaden, and the Bavarian Forest, is another example of data mobilization and the creation of new research infrastructures.

The Natura 2000 station network in Thuringia: implementing the European directive to protect threatened habitats and species.

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The Natura 2000 network consists of nature protection areas including Special Areas of Conservation and Special Protection Areas within Europe. The directive was introduced in 1992 to preserve threatened habitats and species. To reach the goals on maintaining, developing or restoring favourable conservation statuses various actors in the field of nature conservation, agriculture, forestry, and economics have to work together.

In Thuringia, a network of twelve Natura-2000 Stations was established in 2016 to preserve the nature heritage, which is governmental-funded by the Thuringian Ministry for Agriculture, Nature Conservation and Environment. The Free State is characterized by high natural richness within Germany having 212 Special Areas of Conservation and 44 Special Protection Areas covering 17% of the area.

The station network consists of ten regional and two supra-regional stations as well as a competence centre and works at the interface between governmental and voluntary nature conservation and land users. Mainly based on management plans of the nature protection areas, the stations initiate and conduct nature conservation projects, give advice on nature conservation, implement initial maintenance measures and much more. Moreover, the stations cooperated closely with universities to evaluate the implemented measures within some projects and monitored data are entered into the nature conservation information system of the Free State of Thuringia.

Due to their regional presence, years of work and the close cooperation with various local stakeholders the Natura 2000-stations is able to increase the success and acceptance of nature conservation measures. Knauber et al. (2023) states that the Natura 2000-Stations in Thuringia were generally evaluated positively and their success factors can give helpful advices for other federal states.

Luise Knauber, Sebastian Lakner und Tobias Plieninger (2023). „Umsetzungs- und Betreuungsmodelle der Fauna-Flora-Habitat-Richtlinie“ NATURSCHUTZ und Landschaftsplanung: 55 (05), DOI:10.1399/NuL.2023.05.03

The LifeGate-project and its Leipzig prototype

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The first map of all 2.6 Mio living organisms has been constructed to show the phylogenetic position and sizes of all major taxonomic levels (domain, phylum, class, order, family, genus and species). The map is available via a zoomable and searchable web application (www.lifegate.idiv.de). The data behind the map and its construction principles will be explained. A prototype of its use on the local scale within the City limits of Leipzig will be shown as well as an outlook to its use on the regional and global scale. LifeGate serves as a tool for researchers in all biological sciences and is especially useful for those dealing with thousands of species and across phyla.

Faktencheck Artenvielfalt - First National Assessment of Biodiversity in Germany

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"Faktencheck Artenvielfalt" is the first national assessment of biodiversity in Germany. It synthesizes available knowledge from scientific and "grey" literature. The main outcome will be a comprehensive report on the different habitats in Germany and a summary for policy makers highlighting the key messages. On top of that we will provide a literature database with detailed annotation, making it possible to trace our statements back to the sources and search for specific topics of interest.

The assessment focuses on the major habitats in Germany, i.e. forests, agricultural and open land, inland waters and floodplains, coasts and coastal waters and urban areas. For these habitats, we ask: What is the status and what are the current trends of biodiversity? What is the role of biodiversity for ecosystem services? How do direct drivers affect biodiversity? Which instruments and conservation measures actually work? We also ask these questions for the understudied area of soil biodiversity both in a separate chapter and within the other habitat chapters. In addition to gathering knowledge on responses and effects of biodiversity across habitats, we place a focus on the socio-economic system, which functions as an indirect driver of biodiversity loss through societal, economic/technological or political processes, but also provides the levers to achieve a transformation. These socio-economic questions are investigated within the habitat chapters and synthesized across and beyond in dedicated chapters: What is the role of indirect drivers for biodiversity change? What are examples of successful transformation processes to halt and reverse biodiversity loss?

Combining available knowledge on state, cause and effect of biodiversity change with societal processes allows us to identify research gaps and develop options for action to support programs for the protection of biodiversity.

SESSION 33:

Auenschutz und Renaturierung

Langfristige Entwicklung von Auenhabitaten nach Redynamisierung – wie resilient sind degradierte Alpenflüsse?

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Alpenflüsse sind mit ihrer großen Vielfalt an besonderen Habitaten und spezialisierten Arten von großer Bedeutung für die regionale Biodiversität. Diese einzigartigen Ökosysteme werden geprägt durch eine sehr hohe Abfluss- und Umlagerungsdynamik, welche im Zuge der flussbaulichen Maßnahmen der letzten Jahrhunderte massiv beeinträchtigt wurde. Der aktive Auenbereich wurde durch Uferverbauungen stark reduziert, die Hochwasserdynamik reguliert und Sedimentfrachten zurückgehalten. Besonders Pionierstandorte der offenen Kies- und Sandbänke gingen zurück und mit ihnen seltene frühsukzessionelle Arten.

Maßnahmen zur Redynamisierung von Flussabschnitten sind unabdingbar, um die Arten und Lebensräume vor Ort zu sichern. Die Entnahme von Uferverbauungen führte in verschiedenen Renaturierungsprojekten zu einer Entwicklung von Kies- und Sandflächen und somit zu einer verbesserten Auenstruktur für Pionierarten an den untersuchten Flüssen Isar und Inn. Hochwasserereignisse in den Jahren nach der Renaturierung unterstützten die Entstehung von Kies- und Sandflächen, sodass insgesamt eine Verbesserung der degradierten Flussabschnitte durch die Maßnahmen erreicht werden konnte. Dennoch wirkt eine fortschreitende Sukzession auf den offenen Flächen dem anfänglichen Erfolg der Maßnahmen für Pionierarten deutlich entgegen. An den untersuchten Abschnitten stellen sich nach wenigen Jahren wieder Zustände wie vor der Renaturierung ein, sie zeigen damit eine Art Resilienz gegenüber den Maßnahmen. Inwiefern sich ein verbesserter Zustand halten kann, hängt vom Auftreten von Hochwasserereignissen und dem räumlichen Umfang der Maßnahmen ab. Lokale Redynamisierung von Auenbereichen bleibt damit herausfordernd, insbesonder vor dem Hintergrund der veränderten übergeordneten Prozesse, wie Abfluss und Sedimentumlagerungen, und geringen Verfügbarkeit von Flächen entlang des Flusslaufs.

Was kann die Wasserwirtschaft für die Förderung der Artenvielfalt leisten? Untersuchungen aus dem EU-Forschungsprojekt MERLIN.

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Das EU-Forschungsprojekt MERLIN (https://project-merlin.eu/) untersucht anhand von 17 Fallstudien in Europa erfolgreiche und innovative Umsetzungsbeispiele von Süßwasserrenaturierungen auf systemischer und landschaftlicher Ebene. Eine dieser 17 Fallstudien ist das Generationenprojekt Emscher-Umbau in Nordrhein-Westfalen. Begleitend zum Bau eines Abwassersystems im gesamten Einzugsgebiet der Emscher begann in den 1990er Jahren auch die ökologische Verbesserung erster Fließgewässer. Da die biologische Vielfalt in und an Fließgewässer in hohen Maße abhängig von der Qualität des direkten Gewässerumfelds ist, werten Emschergenossenschaft und Lippeverband zusätzlich zur Renaturierung der Gewässer auch die gewässernahen Grünflächen biologisch auf. Extensive Grünflächen im urbanen Raum sind potenziell Hotspots der biologischen Vielfalt. Eine große Chance liefern Deich- sowie gewässernahe Grünflächen, da sie zusammenhängende Habitate für Tiere und Pflanzen darstellen. Im MERLIN-Projekt wird die Umstellung auf extensive Pflege von bestehendem Grünland sowie die Neuansaat mit Regio-Saatgut hinsichtlich ihres biodiversen Potentials untersucht. Durch das Monitoring von Vegetation und Fauna wird die Kurz- und Langzeitwirkung einer Pflegeumstellung von intensiver zu extensiver Mahd, mit und ohne vorheriger Einsaat, quantifiziert. Für die Kurzzeitwirkung wurden Flächen ausgewählt, auf denen die Pflegeumstellung innerhalb der letzten zwei Jahre durchgeführt wurde. Die Langzeitwirkung wird auf Flächen untersucht, auf denen die Pflegeumstellung vor mindestens fünf Jahren erfolgte. Auf insgesamt 32 Flächen mit jeweils vier Probestellen wurden Vegetationsaufnahmen und Streifnetzfänge durchgeführt sowie Barberfallen eingesetzt. Im Vortrag werden erste Ergebnisse vorgestellt und anschließend in Hinblick auf Übertragbarkeit und Skalierbarkeit der Maßnahmen und ihrer Wirkung diskutiert.

Gegenwart und Zukunft des Leipziger Auensystems: Auenrevitalisierung und Stadtentwicklung zusammen denken

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Flussauen sind Biodiversitäts-Hotspots und stellen zahlreiche Ökosystemleistungen bereit. Gleichzeitig sind sie durch anthropogene Eingriffe gravierend beeinträchtigt. Dies trifft auch auf das Auensystem der Flüsse Weiße Elster, Pleiße und Luppe im Raum Leipzig zu. Trotz schwerwiegender Flussregulierungen und der unmittelbaren Nähe zur Großstadt ist hier aber dennoch ein naturnaher Hartholzauenwald von mitteleuropäischer Bedeutung erhalten geblieben.

Als direkte Konsequenz der Regulierungen und fehlender Auendynamik hat sich die Artenzusammensetzung der Hartholzbestände allerdings bereits stark verändert mit zunehmender Dominanz überflutungsintoleranter Arten in Baum- und Krautschicht. Zudem bringen Kalamitäten und die extremen Dürreereignisse der letzten Jahre den Leipziger Auwald an eine Belastungsgrenze. Revitalisierungsmaßnahmen sind somit dringend notwendig. Erste diesbezügliche Bestrebungen gehen bis in die 1990er Jahre zurück. Eine besondere Herausforderung für die Umsetzung solcher Maßnahmen liegt unter anderem in der unmittelbaren Nähe des Auensystems zur Großstadt und den Restriktionen, die die städtischen Infrastrukturen mit sich bringen (Siedlungsentwässerung, Kläranlagen, Verkehrstrassen). Gleichzeitig können durch Klimaanpassungsmaßnahmen (z.B. wassersensible Stadtentwicklung) Synergien geschaffen, Restriktionen für den Naturschutz abgebaut und Potentiale eröffnet werden.

Derzeit erarbeitet die Stadt Leipzig ein gesamträumliches integriertes Auenentwicklungskonzept für das Leipziger Auensystem, das in eine langfristige freistaatlich-städtische „Rahmenstrategie Leipziger Auwald“ eingebettet und durch verschiedene Förderinstrumente (u. a. BfN-Naturschutzgroßprojekt, Aktionsprogramm Natürlicher Klimaschutz) schrittweise bis 2050 umgesetzt werden soll. Im Vortrag stellen wir den aktuellen Stand dieser Bemühungen vor und diskutieren Chancen und Hemmnisse bei der Planung und Umsetzung großskaliger Auen-Revitalisierungsmaßnahmen im urbanen Kontext.

Wissenschaftliche Begleitung und Wirkungskontrolle von Renaturierungsmaßnahmen im Leipziger Auenwald

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Flussauen-Ökosysteme sind Hotspots der Biodiversität und stellen zahlreiche Ökosystemleistungen bereit. Gleichzeitig gehören sie zu den Ökosystemen, die weltweit am stärksten durch anthropogene Eingriffe in ihrer Funktionsfähigkeit und ökologischen Integrität beeinträchtigt sind. Dies trifft auch für das Auensystem der Weißen Elster in Leipzig zu. Trotz der gravierenden Veränderungen des Auensystems blieb ein vergleichsweise großer Anteil des Hartholzauwaldes erhalten und ist auch heute noch in einem naturschutzfachlich wertvollen Zustand. Jedoch kann als direkte Konsequenz der wasserbaulichen Regulierungen und ausbleibender Dynamik bereits ein Wandel der Artenzusammensetzung beobachtet werden. Um langfristig eine auentypische Biodiversität wiederherzustellen und zu erhalten, sind Revitalisierungsmaßnahmen in diesem Auensystem zwingend erforderlich und werden aktuell im Projekt „Lebendige Luppe“ und weiterer Vorhaben geplant und umgesetzt (siehe auch Beitrag Seele et al. zur GfÖ). Im Rahmen der naturwissenschaftlichen Begleitforschung des Verbundprojektes Lebendige Luppe wurde ein Netzwerk von 66 Dauerbeobachtungsflächen (je 0.25 ha) im Hartholzauenwald eingerichtet, auf denen im Zeitraum 2013-2023 (vor Umsetzung und nach Umsetzung von Revitalisierungsmaßnahmen) kontinuierlich biologische und hydrologische Daten erfasst wurden. Untersuchungen zu Arten- und Lebensgemeinschaften auf den Dauerbeobachtungsflächen schließen die Vegetation der Kraut-, Strauch- und Baumschicht (inkl. Totholz) sowie teilweise faunistische Untersuchungen zu Laufkäfern und Mollusken ein. Trotz einer Homogenisierung der abiotischen Standortbedingung in Folge der Regulierungen und Auftreten von Eschentriebsterben und Rußrindenkrankheit, kommt es entlang des (verbliebenen) hydrologischen Gradienten oder in bereits umgesetzten Redynamisierungen zu einer deutlichen Differenzierung der Artenzusammensetzung der Vegetation und ihrer Steuergrößen. Erste Redynamierungserfolge für den Hartholzauenwald konnten dokumentiert werden.

SESSION 34:

Best Practice for Mainstreaming Biodiversity

Evaluating equivalency in a No Net Loss context using a key set of complementary biodiversity metrics

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Concepts of No Net Less (NNL) and Net Gain of biodiversity have been gaining momentum in the corporate world. With impact measurement tools now readily available and considering Target 15 of the Kunming-Montreal Global Biodiversity Framework (GBF), more businesses are prompted to achieve NNL despite negative impacts on biodiversity, through direct biodiversity restoration actions or by purchasing rapidly emerging biodiversity credits. This trend poses a need to define and quantify the equivalence of biodiversity losses and gains and how this depends on the metric(s) used to measure them. Here we evaluate and compare three biodiversity metrics in a global NNL context, using an optimization approach to identify the minimum number of sites to restore in order to compensate for biodiversity losses from corporate activities. The three metrics are Mean Species Abundance (MSA), persistence (P) and the Species threat abatement and restoration (STAR) metric. MSA quantifies ecosystem intactness, while P and STAR are species-level metrics of extinction risk. P measures the effect of habitat change on the probability of persistence of species through a non-linear relationship, while STAR quantifies the effect of habitat restoration and threat abatement on species' threat status. Our study illustrates how intrinsic properties of the metrics and conditions imposed on the location of restoration affect the identification of sites appropriate for restoration in order to achieve NNL. This research highlights the importance of using complementary measures of biodiversity in a corporate context, when considering global accounting of losses and gains.

The importance of residual structures in the agricultural landscape as habitats and stepping stones

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In our heavily used agricultural landscape there are small, sometimes highly isolated areas that are not used for arable farming. These are, for example, steep break-off edges in the terrain, terrain elevations, areas around wind turbines or manhole covers or areas under electricity pylons. These unused areas can serve as habitats for wild animals and plants or as stepping stones for their dispersal.

To determine the meaning and quality of such areas, a total of 15 isolated electricity pylons in the area of the Lommatzscher Pflege in Saxony as well as neighbouring farmland sites, which serves as reference area, have been investigated with regard to their faunistic and floristic species composition since summer 2021. In addition, calculation of the landscape connectivity index is carried out to determine the value of these residual structures for the biotope network and to develop measures for improvement in practice.

First results of the faunistic survey show significant differences in favour of species occurrences of bugs (Heteroptera) on the area under electricity pylons compared to those on the arable sites. The situation was different for hoverflies. No significant differences were discernible here. The evaluation of other arthropod groups (including Apoidea, Auchenorrhyncha and Coleoptera) is still pending. In an effort to improve the quality of these areas under electricity pylons, several are currently being redesigned and enhanced by the sowing of flowering mixtures. Others were including by flowering strips, which were planted by the cooperating farmers.

Using undersowing of diverse weed species mixtures against insect decline? Promoting weed diversity increases arthropod densitiy and biomass in cereal crops

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Land-use change has been identified as key driver of insect biodiversity loss worldwide. In central Europe, agricultural intensification resulted in habitat loss and degradation and in homogenization of agricultural landscapes. In addition, the widespread use of agrochemicals, such as herbicides or insecticides, is known to have direct negative effects on insects. In contrast, the indirect effects of herbicides, caused by the elimination of weeds, which serve as food sources or shelter for insects, have received little scientific attention. To tackle the possible impact of weed species richness on absolute arthropod densities and biomass, we conducted a field experiment in organically grown oat, barley, and maize crops that comprised the manipulation of weed diversity through undersowing. To establish a wide gradient of weed diversity, we applied three different treatments in plots at the field center: removing weeds, no further treatment, and additional undersowing of 12 weed species. We assessed arthropod communities using enclosures and suction sampling conducted with a modified garden vacuumer. To model the relationship between weed species richness and absolute arthropod biomass and densities, we used generalized linear mixed models. Our results show that weed species richness has a significant positive effect on both absolute arthropod biomass and densities. In particular, plots with more than 20 weed species had a mean insect biomass that was about 4.6-fold higher than plots with fewer than 10 weed species. Similarly, the mean arthropod densities were about 4.1-fold higher. The findings of our study suggest that diversified weed undersowing in crops may be an effective way for promoting arthropod fauna in agriculture, without pronounced yield losses in most crops. Further studies should include experiments on larger scale, the exploration of optimized weed mixtures, and the assessment of the acceptance of farmers for weed undersowing.

Can we expect improved ecosystem services when restoring plant diversity in agricultural and urban permanent grasslands? Can we expect improved ecosystem services when restoring plant diversity in agricultural and urban permanent grasslands?

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Enhancing biodiversity where it has been degraded is high on the agenda of nature conservation and sustainable ecosystem management. Lately, this has received increasing attention due to the current UN Decade on Ecosystem Restoration and the EU Green Deal, highlighting the need to improve biodiversity in both urban and rural landscapes. Experiments have shown plant diversity in sown grasslands to be positively related to several ecosystem functions and services. This has stimulated expectations to gain benefits beyond biodiversity conservation, e.g., higher yields, when restoring plant diversity in managed ecosystems. Yet, it has not been explored if the enhancement of plant diversity in semi-natural permanent grasslands will actually lead to improved ecosystem functioning.

To address this question, we conducted grassland restoration experiments in agricultural and urban permanent grasslands in Germany. While restoration treatments significantly increased plant diversity, especially in agricultural grasslands, subsequent effects on ecosystem functioning were marginal. Thus, even if restoration did not decrease important ecosystem services such as grassland productivity, it is important to notice that high expectations towards improved ecosystem services as a result of biodiversity restoration might not be fulfilled. Yet, there are also (anthropocentric) synergies arising from biodiversity restoration in grasslands, such as a higher aesthetic value, which is particularly relevant in an urban setting. Thus, when advocating the enhancement of biodiversity, we should carefully select the set of ecosystem functions and services for which we predict a positive response after restoration.

Biodiversity positive universities: the german speaking Netwerk Hochschulen für Biodiversität

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The Netzwerk Hochschulinitiativen für Biodiversität (HIB) is a German-speaking network of university initiatives, institutions, and actors committed to promoting biodiversity and nature at their universities. With currently 12 universities, pursuing the common goal of enhancing and showcasing biodiversity in their campus locations and cities, approaches vary profoundly. The three initiatives we present here have all been successful, but in very unique ways. Their ideas and experiences complement each other and can be exemplary for other universities within our network and beyond.

The university initiative Bunte Wiese Tübingen has been working with the city of Tübingen since 2010 to reduce mowing frequency to create biodiverse meadows throughout the city. Being the oldest initiative in our network, Bunte Wiese Tübingen has profoundly altered green space management in its hometown, and spread out towards other cities even before HIB was founded (Netzwerk Bunte Wiese). The initiative has conducted research on the effects of reduced mowing on different taxa, and compiled a vast amount knowledge, that other stakeholders can now benefit from.

Blühender Campus at Freie Universität Berlin initiated the HIB network in 2021. It was founded in 2019 with the goal of allowing more “urban wilderness” on campus and prioritizing biodiversity as part of the university’s sustainability strategy.

At Hochschule Anhalt, researchers are using their long-year expertise in grassland restoration and increasing biodiversity in the agricultural landscape. They are now applying their knowledge on their own campus and have been establishing flowering meadows using native seed mixes for several years.

Through HIB, these and other initiatives share ideas and knowledge and collaborate on solutions to the challenges they face. HIB seeks to build a supportive movement that ultimately inspires more universities to take responsibility in face of the immanent loss of nature and biodiversity.

Engaging urban neighborhoods in insect conservation interventions through participatory and transdisciplinary research

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The increasing densification of urban spaces can negatively impact biodiversity in the city, but the diversity of green spaces also offers new opportunities to mainstream biodiversity conservation interventions. Urban community gardens are social-ecological systems that support biodiversity, ecosystem services, and diverse human-nature interactions. In turn, community gardens can provide an ideal "living laboratory" to co-create, test and collectively implement biodiversity conservation strategies with gardeners that can be transferred to and mainstreamed across other urban ecosystems. This is important because the impact of biodiversity-friendly gardening strategies are not yet systematically researched, nor how this knowledge can be transferred to other urban ecosystems. In this transdisciplinary research, we are developing, implementing and testing insect conservation measures with gardeners and neighborhood residents in the city of Munich. Our aim is to activate and support city residents in biodiversity-based urban greening. To do so, we work at the nexus between civil society (gardeners, neighborhood residents, ecologically oriented organizations) and the relevant city actors (city council, district committees, city administration, business, science) to anchor the participation of civil society in the ecological transformation of the city. Here we will present our transdisciplinary research concept, participatory methods, and experience thus far in translating research to practice, and supporting the role of city residents to mainstream biodiversity measures in their neighborhoods.

The Potential of Outdoor Platforms for Nature Protection

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Sports activities in natural areas are playing an increasingly role in society, but they can also have diverse and often complex environmental impacts. To effectively manage visitors it is crucial to understand which information sources are used for planning and navigating outdoor activities.

Therefore, a total of 410 recreationists were interviewed in northeast Bavaria to determine how they plan and navigate outdoor activities. Additionally, 74 tour authors were interviewed to compare the motivations and attitudes towards conservation concerns of those who suggest tours that align or do not align with nature conservation regulations.

The study revealed that most people use digital tools for planning (86%) and navigation (73%) during outdoor activities. However, digital tools are used as a primarily tool for planning (69%) rather than navigation (25%). Moreover, many individuals (84%) utilize more than one tool for planning activities, whereas almost half (48%) rely on a single tool for navigation. The choice of tools is largely influenced by the type of activity. Trail running (93%), mountain biking (93%), and hiking (84%) are planned using primarily a digital tool, whereas sport climbing is mainly planned using an analog main tool (57%), with 87% of sport climbers relying on printed guidebooks. Although age has a relatively smaller impact on tool choice, 90% of 30-year-olds use a digital main tool for planning outdoor activities, compared to 73% of 60-year-olds.

Among the interviewed tour authors, 83% expressed a strong emphasis on nature conservation. 57% of those who shared tours compliant with nature conservation regulations were familiar with the expected behavior. Similarly, among those who shared tours that did not align with the rules, 64% knew the regulations.

This suggests that many violations of nature conservation regulations are unintentional and stem from a lack of adequate information. But the wide variety of tools used complicates the integration.

Inequity, Transformation and Talking Hope: Towards a New Discourse on Biodiversity and Climate Change

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Although the biodiversity agenda has been mainstreamed for years, discourses have not changed much: it continues to be represented as a battle against impending catastrophe. However, fear appeals affect change only to a limited degree. The emphasis in political and media debates on the costs of biodiversity conservation pits intra-societal and international stakeholders against each other. The failure to communicate the intersectoral benefits also undermines the ability to pursue intersectoral solutions to intersectoral problems, with biodiversity being one example. Most importantly, the failure to focus on alternative future scenarios which convey hope, self-efficacy and inclusiveness impedes public engagement for biodiversity and the equal participation of disadvantaged stakeholders. In light of these aspects, the current discourse on biodiversity loss is both counterproductive and inequitable: Its conceptual bias has social justice impacts which increase socio-political polarization and marginalize disadvantaged stakeholders even further. We present a new narrative for mainstreaming biodiversity, which is framed along the principles of social justice and highlights its social benefits. Drawing on psychological, communications and transformation research as well as NGO experiences, we offer a vision, which focuses on the opportunity for a new social contract afforded by the need to address biodiversity change. We posit the need for narratives of hopeful, alternative future scenarios to achieve sectoral and systemic change. We argue that communications approaches which derive the need for action from a commitment to social justice offer new potential to increase the social mandate for the future of biodiversity. Since engagement is inspired by the view of a more equitable tomorrow, this discursive shift also holds significant policy implications.

SESSION 35:

Dispersal in Macroecology and Macroevolution

Orphans of the past in contemporary ecosystems: the distribution, dispersal and evolution of plants with megafruits

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Plants with megafaunal fruits (›4 cm) have relied on dispersal by megafauna and other large-bodied vertebrates (› 40 kg) throughout their million-year evolutionary history. How megafruit plants have persisted in contemporary ecosystems after the Pleistocene extinction of most megafauna remains an evolutionary enigma. By integrating global data on traits, seed dispersal interactions, phylogenies and geographical occurrences, we show that many megafruit species (613 species, 40%) interact with contemporary dispersers, including megafauna (e.g., elephants), secondary dispersers (e.g., rodents), humans, or water, providing an explanation for their persistence. These megafruit species often have large geographical range sizes, strongly contrasting the 128 (up to 300) megafruit species that are currently threatened with extinction, suffer from small range sizes, and lack suitable co-occurring dispersers, primarily on isolated islands in Australasia, IndoMalay and Madagascar. Our results illustrate how the Pleistocene extinctions and ongoing defaunation limit seed dispersal of many plant populations with megafaunal fruit.

Macroecological patterns in potential avian seed-dispersal functions under current and future climatic conditions

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Frugivorous birds fulfil crucial seed-dispersal functions in most terrestrial ecosystems. While climate change is expected to reorganize the composition of bird assemblages at macroecological scales, it is largely unknown how these changes may affect the seed-dispersal functions frugivorous birds provide to plants. Here we used range and trait data for 1129 frugivorous bird and 8915 fleshy-fruited plant species to simulate how future climatic conditions will influence seed-dispersal function across the Americas. We used a trait-matching model based on fruit and beak size to estimate interaction probabilities between bird and plant species and weighted these with the similarity between ecoregion climate and the climatic niche of its occupant bird species. Based on this model, we estimated the current number of potential bird partners for each plant species at an ecoregion level and calculated log response ratios to quantify how this changed between current and future climatic conditions. The simulations predicted systematic decline in the diversity of potential bird partners per plant species across almost all ecoregions. However, the number of potential bird partners per plant species tended to increase in neotropical regions once we allowed for avian dispersal into an ecoregion and/or a higher generality in future fruit choices. We conclude that future projections of seed-dispersal functions rely on incorporating the capacity of frugivorous bird species to modify their ranges and/or future fruit diet. Moreover, differences in the trait diversity and composition of birds and plants at macroecological scales are likely to lead to contrasting responses of avian seed-dispersal functions to climate change in temperate versus tropical ecoregions.

The effects of Dispersal on the Diversification of the Emberizoidea superfamily

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Dispersal has been recognized as a crucial mechanism underlying the diversification of lineages. Dispersal enables organisms to colonize new areas and encounter novel ecological and evolutionary pressures which would lead to adaptation and ultimately, the emergence of new species. In addition, dispersal can also promote genetic diversity or facilitate the establishment of populations in geographically isolated areas, which can undergo unique evolutionary trajectories due to factors such as genetic drift, founder effects, and environmental stochasticity. Here, we evaluate the effect that both dispersal ability and biogeographic dispersal have had on the diversification patterns of Emberizoidea, a passerine superfamily native to the New World that shows faster-than-expected diversification as well as distinct dispersal abilities and colonization opportunities. To do so, we first evaluated the feasibility of a morphological proxy to describe dispersal ability. Then, using state-dependent diversification models and a rate correlation approach, we assessed the relationship between dispersal ability and diversification. Finally, using phylogenetic regionalization, ancestral area reconstructions, and stochastic mappings, we estimated the effects of biogeographic dispersal on the diversification of Emberizoidea. We found that the Hand-Wing Index (HWI) is an appropriate morphological proxy for measuring dispersal ability in birds. We also found that intermediate levels of dispersal may have benefited diversification, although dispersal ability appears to have decreased over evolutionary time, and speciation rates were not significantly correlated with the evolutionary rate of dispersal ability. Overall, our results suggest that speciation within Emberizoidea is associated with the range contraction within regions rather than dispersal between regions, implying that stable environments have facilitated the successful diversification of species within available geographical/ecological spaces.

Frugivores explain the pantropical variation in plant species richness and dispersal trait syndromes

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Tropical rainforests are the most diverse ecosystems in the world, but the underlying drivers of this diversity remain debated. Mutualistic interactions between fruits and frugivores (i.e., fruit-eating and seed-dispersing animals) are prominent in this ecosystem, and may influence diversification and diversity. These interactions are facilitated by the evolution of functional trait matching between plants and frugivores, and may explain the evolution of 'fruit dispersal syndromes' as the result of co-evolutionary selective pressures from interacting partners. Here, we integrate global occurrence and trait data for tropical plants (Annonaceae) and frugivorous birds and mammals with functional diversity metrics, structural equation models and fourth corner analysis to evaluate whether there is a match in the global distribution of plant and frugivore taxonomic richness and dispersal syndromes. We hypothesize that co-diversification and selection on co-evolving traits has shaped plant-frugivore interactions and co-occurrence across broad-scale assemblages. Our results evidenced that plant species richness is explained by richness of frugivorous birds and mammals, and that functional richness of frugivorous mammals is the unique biotic predictor of frugivory-related plant functional richness globally, both models showing additional or indirect effects of abiotic environmental variables. Our analyses also provide evidence for a close matching of frugivory-related traits of co-occurring Annonaceae and frugivorous bird and mammal species in the tropics (i.e., positive correlation between fruit length with bird hand wing index, and plant non-woody growth form with bird beak volume, mammal adult body mass and colour vision). In this way, our results provide evidence for co-evolutionary dynamics and reciprocal adaptations in morphological traits related to frugivory, which have therefore influenced contemporary patterns of plant traits across tropical realms.

Dispersal-related traits determine the relationship between species' evolutionary age and range size

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More than 40 thousand species are currently facing extinction worldwide. Species range size has been the most widely used proxy of extinction risk because species with small range sizes are more vulnerable to extinction than widespread species. Understanding the drivers of range size variation may help identify which species are at risk of extinction.

Species' ranges are shaped by ecological factors such as suitable habitat availability, environmental tolerance, and dispersal abilities of the species. Nevertheless, evolutionary factors such as adaptation, species age (i.e., time for range expansion), speciation, and range dynamics throughout evolutionary time (e.g., range fluctuations due to glaciations) also play a role.

Here, we investigated how dispersal, the geographical context (islands vs. continents) and species' evolutionary age influence the range size of more than 25,000 species, including birds, reptiles, amphibians, reef fishes, mammals and palm trees. We found that the species' evolutionary age has an overall positive effect on range size. However, the magnitude and the direction of the relationship depend on the evolutionary history, the geographical context and the dispersal capacity of the species. Disentangling the drivers of range size requires considering the evolutionary and ecological factors that modulate range size through time.

Africa as the evolutionary arena for large fruits

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Strong paleoclimatic change and few Late Quaternary megafauna extinctions make mainland Africa unique among continents. Here, we hypothesize that, compared to elsewhere, these conditions created the ecological opportunity for the macroevolution and geographic distribution of large fruits.

We assembled global phylogenetic, distribution, and fruit size data for palms (Arecaceae), a pantropical, vertebrate-dispersed family with >2600 species, and integrated these with data on extinction-driven body size reduction in mammalian frugivore assemblages since the Late Quaternary. We applied evolutionary trait, linear and null models to identify the selective pressures that have shaped fruit sizes.

We show that African palm lineages have evolved towards larger fruit sizes and exhibited faster trait evolutionary rates than lineages elsewhere. Furthermore, the global distribution of the largest palm fruits across species assemblages was explained by occurrence in Africa, especially under low canopies, and extant megafauna, but not by mammalian downsizing. These patterns strongly deviated from expectations under a null model of stochastic (Brownian motion) evolution. Our results suggest that Africa provided a distinct evolutionary arena for palm fruit size evolution. We argue that megafaunal abundance and the expansion of savanna habitat since the Miocene provided selective advantages for the persistence of African plants with large fruits.

A complex biogeographical history explains the spatial distribution of *Myrcia* diversity in the Atlantic Forest

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Speciation, extinction, and dispersal are the macroevolutionary processes influencing the spatial distribution of lineages, consequently, influencing diversity patterns. There are macroevolutionary methods to quantify these processes, but we lack methods that enable us to spatialize in situ speciation and lineage dispersal in grid cells. Here, we combined methods from macroecology and macroevolution to spatially evaluate the legacies of macroevolutionary processes to current diversity patterns of the genus Myrcia in the Atlantic Forest. We used biogeographical reconstruction and a partition of the species-level diversification rate metric (DR) between the part of DR that occurred in the same biogeographical region of the site of assemblage (in situ speciation), and the part of DR that occurred in another biogeographic region (lineage dispersal). In addition, we quantified the species richness, phylogenetic structure, and mean age of the assemblages.
We found a major distinction in the role of in situ speciation and lineage dispersal between tropical and subtropical sites, in which subtropical sites had a high in situ speciation while tropical sites had an even contribution of both processes. Our results suggest an effect of climatic dynamics on the spatial pattern of diversity. In the southern Atlantic Forest, the dynamics tend to select cold-adapted lineages; in the central Atlantic Forest, high environmental dynamics in this mountainous area seems to promote both speciation and extinction, leading to assemblage predominance of young lineages; in the northern Atlantic Forest, the old age of assemblages, high species richness, and phylogenetic diversity corroborate the existence of the Bahia refugium. Niche evolution and niche phylogenetic conservatism appear to play important role in the diversification of Myrcia and the current distribution of its lineages, and future studies are needed to investigate the niche and trait evolution in the genus.

Dispersal and Biodiversity: Using mechanistic models to stress macro-eco-evolutionary processes connectedness and feedbacks.

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Dispersal, along with speciation and extinction, are fundamental macro-eco-evolutionary processes that govern Earth's biodiversity. Dispersal thus shapes biodiversity while it can also be a consequence of biodiversity, given that spatial variation in species interactions might affect a population's fitness with possible consequences to dispersal processes. Species diversity and dispersal are therefore interconnected. While the link from dispersal-to-diversity is relatively well understood, the reverse, diversity-to-dispersal, is relatively understudied on macro-eco-evolutionary studies. Here we explore eco-evolutionary processes accounting for environmental filtering and ecological interactions dictated by evolving population traits inside deep-time dynamic landscapes. We apply traits trade-offs to focus on dispersal ecology and evolution intricate and complex relationship with biodiversity and historical biotic and abiotic contexts.

Global plant-frugivore trait matching is shaped by climate and biogeographic history

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Species interactions are influenced by the trait structure of local multi-trophic communities. However, it remains unclear whether mutualistic interactions in particular can drive trait patterns at the global scale, where climatic constraints and biogeographic processes gain importance. Here we evaluate global relationships between traits of frugivorous birds and palms (Arecaceae), and how these relationships are affected, directly or indirectly, by assemblage richness, climate and biogeographic history. We leverage a new and expanded gape size dataset for nearly all avian frugivores, and find a positive relationship between gape size and fruit size, that is, trait matching, which is influenced indirectly by palm richness and climate. We also uncover a latitudinal gradient in trait matching strength, which increases towards the tropics and varies among zoogeographic realms. Taken together, our results suggest trophic interactions have consistent influences on trait structure, but that abiotic, biogeographic and richness effects also play important, though sometimes indirect, roles in shaping the functional biogeography of mutualisms.

What drives seed dispersal effectiveness? A systematic review

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Seed dispersal is a critical phase in plant reproduction and forest regeneration. In many systems, the vast majority of woody species rely on seed dispersal by fruit-eating animals. Animals differ in their size, movement patterns, seed handling, gut physiology, and many other factors which affect the number of seeds they disperse and the quality of treatment each individual seed receives, and consequently their relative contribution to plant fitness. The Seed Dispersal Effectiveness framework (SDE) was developed to allow systematic and standardized quantification of these processes, offering a potential for understanding the large-scale dynamics of animal-plant interactions and the ecological and evolutionary consequences of animal behavior for plant reproductive success. Yet, despite its wide acceptance, the SDE framework has been primarily employed descriptively, and almost always in the context of local systems. As such, the drivers of variation in SDE across systems, and the relationship between drivers remains unknown. We conducted a systematic review of all studies that quantified endozoochorous SDE for multiple animal species dispersing one or more plant species in a given system, and offer an integrative examination of the factors driving variation in SDE. Specifically, we addressed three main questions: (a) is there a tradeoff between high dispersal quality and quantity?; (b) does animal body mass affect SDE or its main components? and (c) what drives more variation in SDE, seed dispersal quality or quantity? We found that (a) the relationship between quality and quantity is mediated by body size; (b) this is the result of differential relationships between body mass and the two components, while total SDE is unaffected by body mass; (c) and neither quality nor quantity explain more variance in SDE globally. Our results also highlight the need for more standardized data to assess large-scale patterns in seed dispersal effectiveness.

From energy to diversity: A mechanistic investigation into the energy availability-species diversity relationship

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The distribution of species richness across the globe, particularly the gradient from the tropics to the poles, has been a longstanding interest of ecologists, especially concerning the mechanisms behind this distribution. Four main hypotheses for this gradient have received attention: historical (relating to glaciation events), structural (relating to niche richness), dynamic (relating to predation and competition structure), and energetic (relating to energy availability). This project focuses on the fourth, the relationship between ecosystem energy availability and the corresponding diversity at various trophic levels. There is research, namely biodiversity-ecosystem function research, that makes connections between energy availability and species diversity; however, the intermediate relationships are often left to assumptions or not considered fully. We investigate the intermediate patterns and processes that contribute to the relationship between energy and species diversity. We find literature that defines a relationship between species diversity, often species richness, and ecosystem energy availability, often categorized to solar energy metrics or productive energy metrics. Using the literature this project determines how energy availability relates species abundance and diversity at multiple trophic levels, following a bottom-up approach. While there are many investigated mechanisms between available energy and species diversity, we more directly investigate those that consider species abundance. We expect to find there to be a general consensus that there is a positive relationship between energy and species diversity as well as the intermediate steps connecting them, with variation based on scale, organismal identity, and energy measurement.

SESSION 36:

Macroecology

From macroecology to policy options

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Macroecology is a field of science with a high potential to inform political and societal decision making. For example, negative long-term trends of insects or birds in agricultural landscapes suggest deteriorating agricultural systems and the needs for different management regimes. Global analysis of hotspots of species richness can identify regions with especially high biodiversity and hence conservation needs. However, how can we bridge fundamental macroecological research with decision making and politics? I give examples of Leopoldina working groups on the management of agricultural landscapes and on shaping international agricultural trade as well as on decision making processes for selecting protected areas. I use these examples to identify a number of requirements for macroecologists to provide sound policy advice. These include the necessity to work in interdisciplinary working groups, to consider multiple perspectives, including the social sciences and humanities, to listen to political and societal knowledge demands, to create awareness and attention, and to make use of windows of opportunities. One most important requirement for sound advice is to be policy relevant but not prescriptive. Science should provide multiple policy options, opening the door for societal and political debates. Macroecologists are well equipped to offer their knowledge to societal and political decision making, contributing to reaching the goals of the Kunming-Montreal global biodiversity framework.

Endozoochorous plant communities in Madagascar in response to defaunation

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It is unclear whether and how Malagasy endozoochorous plants respond to global changes, such as defaunation. In this study we applied structural equation modelling across 649 communities that comprise the endozoochorous flora of Madagascar to assess the drivers and consequences of dysfunctional seed dispersal. We hypothesize that absence of suitable seed dispersers has led to local extinction of plants with seed sizes that are too large to be swallowed by extant co-occurring frugivores. Alternatively, large-seeded plants have persisted in defaunated landscapes, but suffered from dispersal limitation and high extinction risk. We integrated occurrence records of endozoochorous plants and frugivores with data on dispersal traits, protected areas and threat status. We illustrated which communities in Madagascar are suffering from more mismatching between endozoochorous plants and co-occurring frugivores, and how the mismatching level is related to local protection measurements and the threatened level of these communities.

Non-Native Plant Species Lead to Taxonomic Homogenization Along Mountain Roads Across Multiple Spatial Scales

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Mountain ecosystems are currently experiencing an increase in introductions and spread of non-native plants along their elevational gradients, specifically along mountain roads. As established in lowlands, the addition of non-native species may increase, decrease, or not change the number of species within a community. In any case, these introductions affect the composition of the community and therefore the community's similarity or dissimilarity to neighboring communities. Biotic homogenization describes the loss of differences between communities and currently, we have little knowledge of how non-native species influence community composition along elevational gradients.

Utilizing standardized vegetation surveys collected in 19 regions along mountain roads, we analyze whether non-native species are homogenizing host communities at different spatial scales: within singular elevation gradients, across gradients within a mountain region, across regions within continents, and at the global scale. We found that at all scales, non-native species homogenize plant communities though there is variation between regions and continents. At the local scale, the majority of elevation gradients with a significant effect of non-native species exhibited homogenization across the communities. Analyses at the regional scale revealed similar results. However, not all the same regions display homogenization between the local and regional scale, indicating that the scale at which homogenization occurs can vary. Homogenization was also found at the continental scale in North America, South America, and Europe. Interestingly, while no singular gradients or regions showed significant homogenization in Europe, it was unveiled in the continental analysis. This study suggests that finding a significant result for plant community homogenization by non-native species along mountain gradients can depend on the scale at which analysis is done, supporting the need for multi-scale approaches.

Same, but different: Alternative states of forest structure across three temperate mountain regions of Europe

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The habitats and ecosystem services provided by mountain forests are critically linked to forest structure, which is shaped by interacting effects of topography, climate, natural disturbances, and human land use. Ongoing changes in land use and disturbance regimes are likely to affect forest structure, but their effects are not fully understood. We used Landsat-derived disturbance maps (1986-2020) and data on forest structure from spaceborne lidar (GEDI) to examine how differences in disturbance regimes, environmental conditions, and anthropogenic drivers affect patterns of forest structure across three European mountain ranges: the European Alps, the Carpathians, and the Caucasus mountains. We found similar disturbance regimes in the Alps and Carpathians but considerably lower disturbance activity in the Caucasus, which is partly explained by differences in current forest management and by legacies of past land use. Similarly, disturbance rates increased over the past 35 years in the Alps and Carpathians, but decreased since the 1990s in the Caucasus. Notwithstanding these differences, we found similar patterns of forest structure, with two alternative states emerging consistently across the three mountain ranges: a closed-canopy state (74-80% of forests with >70% canopy cover and 10-30 m in height), and an open-canopy state (<50% canopy cover, <10 m in height). Open-canopy forests consistently occurred close to the upper and lower treelines, while the effects of disturbance and local anthropogenic drivers differed between mountain ranges. Stand-replacing disturbances played an important role in the Carpathians, while forest structure in the Caucasus was closely linked to proximity to settlements, reflecting local forest use. Different disturbance regimes and land uses can thus lead to a remarkably similar forest structure, highlighting that structure is an emergent property of many interactive drivers.

Combining future projections of land-use and climate change impacts on biodiversity

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Biodiversity loss, land degradation, and climate change are acknowledged environmental challenges faced by humanity. Human activities including land-use changes are key stressors for biodiversity, thus, future projections of biodiversity impacts need to include both climate change and land-use change. While a lot of studies focused on mapping and projecting the vulnerability of multiple species based on different climate change scenarios or warming levels, land-use trajectories are often not included in these projections. Recent work made first steps to address these deficiencies. For example, Hof et al. (2018) evaluated potential future impacts of climate and land-use changes on global species richness of terrestrial vertebrates under a low and high emission scenario. However, the analyses of land use change impacts did not account explicitly for the habitat requirements of different species. In this study, we aim to combine future climate scenarios and a matrix of land-use projections derived from integrated assessment modeling (IAM) to quantify the impact of climate change and land-use change on biodiversity separately as well as the combined impact.

To this end, we use the global simulations with species distribution modelling results from the Hof et al. (2018) study forced by four GCMs and the RCP2.6 and RCP6.0 grennhouse gas concentration scenarios following the ISIMIP2b simulation protocol and apply a land-use filter on the species occurrence probabilities to determine the implications for the world's amphibians, mammals and reptiles at a 0.5° resolution.

The included future projections of land-use change are either based on the Land Use Harmonization dataset v2 (LUH2) which are matched with the IUCN Habitat and Classification schemes to refine the climate envelope and filter out regions where species cannot persist due to land use.

Demography-environment relationships improve mechanistic understanding of range dynamics under climate change

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A central question in biodiversity research is how key eco-evolutionary processes - such as physiology, demography, and dispersal - shape the geographic range and local abundances of a species' population. These eco-evolutionary processes usually act on different spatial and temporal scales. In an individual-based modelling approach, all relevant processes are simulated at the local scale and their combined effects are scaled up to the population level. Thus, the responses of distribution and abundance to environmental changes can be assessed. We model the range and population dynamics of several bird species in Switzerland over two decades of climate change within the individual-based modelling platform RangeShiftR, where we include the processes physiology, demography, and dispersal. From country-wide survey data we infer their demography-environment relationships, which relate climatic variables with basic demographic rates, within a Bayesian framework. This allows us to assess which biotic processes are most affected by climate change and compare these effects among the considered bird species. Our results can thus help to effectively target conservation strategies for particularly vulnerable populations.

Physiology meets biogeography: spatial variation of thermal tolerances of grasshoppers in central Europe and Pakistan

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To understand whether and how species will be able to cope with changing climatic conditions, the integration of thermal physiology and biogeography bears great potential. Specifically, knowledge about the variation of thermal tolerance ranges and limits across space will enhance our understanding of species' responses to climate change, and may improve biodiversity projections under future climate change scenarios.

Here, we present results from our studies on the variation of thermal tolerances of grasshoppers, crickets and locusts (order Orthoptera) along elevational and climatic gradients. We collected physiological data on thermal tolerance limits of several thousand individuals of about 70 species of orthopterans in the German state of Bavaria as well as in the mountain ranges of central and northern Pakistan. When exploring how and to which extent thermal tolerances vary within and among species, we found that while intraspecific variation was large, there were also clear patterns of interspecific differences that could only partly be explained by phylogenetic relatedness. Thermal limits such as critical temperature maxima decreased with elevation, as expected, but with subtle differences between different regions which were likely due to varying microclimate. Overall, we argue that the multi-disciplinary integration of data and methods from biogeography, physiology and ecology as well as across taxonomic and spatial scales is a promising, albeit challenging, avenue towards more realistic projections of potential distributions and diversity patterns under global change.

The Potential of Re-evaluating Biodiversity Patterns in Environmental Space

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Macroecological questions addressing diversity – environment relationships have been addressed almost entirely in geographic space, yet most hypotheses are formulated in terms of environmental conditions. The few recent examples that have evaluated patterns directly in environmental space indicate that such refocusing provides different perspectives on the mechanisms driving broad scale patterns of diversity. Yet we lack both conceptual frameworks and macroecological studies to fully evaluate the potential contribution of such a re-focusing on environmental space in macroecology. Here we introduce the concept of environmental space and briefly review how the concept has been used in four main endeavors: species distribution modeling, macroecological correlates of species diversity, macroecological rules and macroevolution. In doing so, we lay the groundwork for how the concept, methodology and common language could be extended and used in future cross-field research aimed at uncovering new knowledge about the generation and maintenance of diversity and protecting current biological diversity on our changing planet. A focus on environmental space will likely not only reinforce geographically based hypotheses but also reveal hidden effects of the environment on biological diversity that are missed when the focus is on geographic space alone. We encourage a re-evaluation of hypotheses and frameworks that have dominated ecological theory since the foundations of ecology with a very simple shift in the lens, that is from geographical to environmental space.

The geography of climate and the global patterns of species diversity

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Global climatic gradients are strongly associated with global biodiversity gradients. However, it remains unknown whether biodiversity is directly driven only by climatic conditions themselves (e.g., warm vs cold, humid vs dry) or if biodiversity is also affected by the geographic extent (e.g., total area) and isolation (e.g., contiguous or fragmented) of these climatic conditions. Here, we shift the lens from geographic space to a multidimensional space defined by climate conditions and explore diversity patterns in this climate space. We find that greater geographical extent and isolation of climatic conditions result in greater diversity and compositional turnover of terrestrial tetrapods (30,000+ species). A joint analysis of both climate itself and the geography of climate explains that nearly 90% of the variation in richness, however, 60% of this variation is simultaneously explained by both effects, suggesting a non-trivial answer to the effects of climate. Our findings extend and revise the classic hypothesis that larger regions host more species by showing that the effect of the geographical extent of climates is inherently intertwined with the effects of geographic isolation - climatic conditions occurring in the tropics have large geographical extents but are also more fragmented.

Tree functional diversity effects on woody vegetation productivity are climatically sensitive

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Aim: Plot-scale experiments show that functional diversity (FD) plays a pivotal role in maintaining ecosystem functions such as net primary productivity (NPP). However, how FD affects NPP across larger scales under varying climatic conditions is sparsely studied, yet is important for forest–atmosphere interactions and policy development. Hence, we assess the effects of functional dispersion (FDis) and community-weighted means (CWMs) of woody plant traits on NPP across China and if such effects are modulated by climatic conditions at large scale.

Location: China.

Time period: Contemporary.

Major taxa studied: Woody plants.

Methods: Using comprehensive datasets on distribution, functional traits and productivity for 9120 Chinese woody plant species, we evaluated the distribution pattern and the relationships of FDis and CWM (including three orthogonal trait indicators: plant size, photosynthetic capacity and flower duration) with NPP through multiple linear regression models. Structural equation models were used to test the effects of climatic conditions on FDis/CWM–NPP relationships.

Results: We found both general FD effects, but also that the magnitude of these could be modified by climate, with CWM and FDis of plant size especially promoting NPP in warm and wet regions, respectively. Climate indirectly increased NPP through positive effects on CWM or FDis, notably via mean photosynthetic capacity.

Main conclusions: This study provides the first comprehensive evidence for FD effects on NPP under varying climates at large scale. Importantly, our results suggest a general increase in the importance of plant traits for woody vegetation NPP with rising temperatures and wetter climates. Restoration and reforestation actions need to carefully consider not just CWMs and FDis, but, as an additional path, also their interactions with climate, to predict how FD may promote ecosystem functioning under future climatic conditions.

Environmental niche characterization of plant functional groups

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Ecosystem functioning is thought to be mediated by traits of organisms living within phylogenetic constraints. Plant groups of similar traits (functional groups) are likely to fit into a similar environmental niche. Characterizing functional groups' niche space along environmental gradients would allow us to better understand patterns of trait variation.

We aim at understanding the role of functional groups for global trait-environment relationships, i.e. their patterns of functional diversity at a given environment.

Here, we compare the environmental functional richness gradients of plant functional groups. These functional groups represent either major differences in size and economic traits, derived from global in situ trait data in the TRY database, or plant growth forms. We find their gradients - although deviating in absolute terms from the total subset - to be decreased in range. This may indicate global trait gradients to reflect functional group replacements. Further, we find diverging global richness patterns of size and economics traits along latitude. Consequently, different ecosystem functions are likely to diverge along latitude, as well.

This study's findings provide valuable insights into the functional diversity - environment relationship and indicate how global change may affect functional groups differently.

Tree diversity, not host specificity, drives global wood-decaying fungal diversity

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The diversity of most species groups increases from the poles towards the equator, known as the latitudinal diversity gradient. Despite the vast generality of this pattern, ecologists still debate the underlying mechanisms, which range from climatic to biotic interactions. Nevertheless, this knowledge is crucial to predict present and future impacts of global change on diversity and the connected ecosystem functions. Global diversity patterns of fungi are only known from soils; wood-decaying fungi have not been studied yet, despite their importance as primary decomposers for global carbon cycles.

Here we used a global experiment to study wood-decaying fungal diversity based on metabarcoding to identify whether increased specialization and niche packing or tree diversity and niche space drive their global diversity. On 52 plots, we exposed three standardized dead-wood objects of local common tree species. We analyzed gamma diversity per biome, alpha diversity on log and plot levels, and network specialization against absolute latitude and tree species diversity.

On the biome scale, fungal diversity was highest in the tropics and lowest in the boreal biome. However, alpha diversity per log did not significantly increase with latitude. Network specialization increased slightly but not significantly with latitude. However, local tree species diversity strongly influenced alpha diversity per plot.

Wood-inhabiting fungal diversity seems to follow the latitudinal diversity gradient on large grain size, i.e. biomes, but not on small, i.e. logs. The overall pattern seems driven by increased tree species diversity rather than increased specialization, as already found for other plant-dependent species groups. Due to their high specialization, the anthropogenic and climate change induced alternations in forest cover and woody plant species richness, especially in the tropics, threatens wood-decaying fungal diversity with an unpredictable impact on global carbon cycling.

A glimpse into the dark: systematic assessment and modeling of groundwater biodiversity in Switzerland

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Groundwater ecosystems harbor a unique and highly adapted biodiversity. However, this biodiversity is still poorly studied, mainly due to difficulties in groundwater accessibility. To be able to protect groundwater ecosystems, understanding the distribution and diversity of groundwater organisms is essential. We established a very broad citizen science approach and compiled highly resolved and large-scale data on groundwater amphipods across Switzerland. Water providers were systematically integrated to collect repeated detection–nondetection data on groundwater amphipods. In total, more than 900 sites were sampled and over 2,000 groundwater amphipods were found. We identified a high species diversity of groundwater amphipods, consisting of few common and many rare species. The distribution of frequently found groundwater amphipod species could be modeled using an occupancy modeling approach and a set of environmental covariates. However, a large part of the diversity consisted of species found at a very limited number of sites. Interestingly, these rare species were distributed evenly across the study region. Our results emphasize the contribution of rare and narrowly distributed species to overall groundwater biodiversity. Integrating these species in biodiversity assessments is essential, but simultaneously, data collection and distribution modeling is challenging. We highlight the need of systematic sampling approaches to cover both, common and rare species. Such approaches are important for a better understanding and conservation of groundwater biodiversity.

Equilibrium theory of biodiversity dynamics: Patterns, predictions, and parameters

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Recent evidence has come to light supporting the existence of biodiversity limits at multiple spatiotemporal scales, yet the mechanisms behind these limits remain poorly understood. The Equilibrium Theory of Biodiversity dynamics (ETBD) suggests that there is a carrying capacity for species richness (an equilibrium) which is driven by the relationship between energy availability, species richness, total abundance, and population size dependent extinction and/or origination rates. Many large-scale ecological theories such as this are limited in their development due to poorly defined or untestable predictions. To avoid this pitfall, we aim to fully explore the parameters and relationships within this theory to identify novel predictions and gain further understanding of the mechanisms behind biodiversity limits. To achieve this, we developed an R package to produce simulation models that generate patterns in species richness and evolution via the assumptions of ETBD. We explored parameter space and used AMOVA models to evaluate the relative importance of initial conditions and parameters on the variation of emergent patterns. We show that ETBD can function under ecologically realistic parameters. Furthermore, we show that population size dependent origination rate, and not extinction rate, drive evolutionary patterns. Additionaly, we predict that communities acting under ETBD and following a log-series SAD will maintain higher diversification rates and lower equilibria compared to communities following a log-normal SAD. Our results provide support and testable predictions for an emerging ecological theory and deepen our understanding of the possible mechanisms responsible for large scale patterns in biodiversity and evolution.

Floral traits predict hummingbird visitation rates better than conspecific and heterospecific flower abundance: a three-country comparison

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Flower visitation rates by pollinators are influenced by many factors, including flower abundance and flower traits, such as those related to attractiveness and nectar availability. In this study, we use a macroecological perspective to search for emerging patterns of the influence of flower abundance versus floral traits on hummingbird visitation frequency across three countries. We sampled 32 sites monthly for 2 years along broad elevation gradients (from 100 to 3,500 meters) in Ecuador, Costa Rica, and Brazil and collected interaction data using time-lapse cameras, counted floral abundance, and measured flower traits of all species along a 1.5 km transect. We used generalized additive mixed models to relate visitation frequency corrected for sampling effort to conspecific and heterospecific abundances and a series of floral traits. Heterospecific abundance was calculated separately for 25% plant species with greater trait similarity to the focal species and for the remaining 75% of species. Our results reveal that floral traits have a stronger influence on hummingbird foraging preferences than flower abundance. The relative importance of each trait varied among countries, with tube length and corolla opening being highly important in Ecuador and corolla curvature in Costa Rica. No flower trait explained the frequency of hummingbird visitation in Brazil. These findings suggest that the selective pressure imposed by hummingbirds on plant traits - which results in the hummingbird pollination syndrome – is likely to vary among regions. The lack of effect of flower abundance is contrary to local-scale evidence suggesting a strong role of competition or facilitation among neighboring plants in attracting hummingbirds. In conclusion, while flower abundance may provide a general indication of resource availability, our results suggest that floral traits play a more crucial role in determining hummingbird foraging preferences.

Biodiversity regulation and species richness equilibria at large scales

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There has been a hot debate on whether biodiversity is bounded by region-specific limits on species richness. I will provide empirical evidence of biodiversity regulation based on paleontological time-series, and will argue that biodiversity is regulated via a feedback between the number of species, population sizes of individual species and rates of origination and extinction. I will provide foundations of the Equilibrium Theory of Biodiversity Dynamics (ETBD) which addresses these links and, in contrast to other theories of diversity dynamics, explicitly deals with complex and bivariate relationships between species richness and community abundance. ETBD predicts that biodiversity equilibria are driven by the interplay between (1) total resource availability (area x energy) within given region, (2) factors modulating overall origination and extinction rates (e.g. topographic heterogeneity or environmental stability), and (3) the way how species richness affects community abundance. This illuminates the origin of macroecological biodiversity patterns including the latitudinal diversity gradient, as well as potential scenarios of current biodiversity changes. I will argue that although nature is often out of equilibrium, understanding biodiversity equilibria represents a baseline for understanding species diversity in space and time.

Do the species with large geographic range diversify faster?

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Range size is often assumed to influence species diversification rates, but the relationship between range size and past and future diversification remains elusive. On one hand, there are strong theoretical arguments that large-ranged species should have higher rates of diversification. On the other hand, the small-ranged species often exhibit low phylogenetic isolation in the empirical datasets, suggesting fast diversification of small-ranged species. This discrepancy between theory and the data may be caused by the fact that typical methods of data analysis do not account for range size changes during speciation, and that the phylogenetic aggregations of small-ranged species may reflect past rather than incipient radiations.

Here we use a state-dependent diversification model accounting for changes of range size both during and outside speciation, and apply them to range size data and phylogenies of birds and mammals. We show that range size changes during speciation are ubiquitous and small-ranged species indeed diversify generally slower, as theoretically expected. Although the diversification is driven by large-ranged species in most of our datasets, we also identified multiple clades where this general pattern is reverted, typically volant taxa inhabiting isolated insular landscapes.

Our results suggest that the phenomenological measures of diversification based on species isolation, such as diversification rate metric, may often identify species or areas that underwent fast diversification in the past, but their future potential is low. At the same time, the effect of range size on diversification in the real-world systems is strongly context-dependent. We argue that future efforts for estimating species evolutionary potential should integrate range size and phylogenetic data using more realistic assumptions about range-size evolution, account for local spatial and phylogenetic context, and possibly also integrate population-level genetic data.

Fossil leaves reveal drivers of herbivore functional diversity during the Cenozoic

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Herbivorous arthropods are the taxonomically and functionally most diverse group of multicellular organisms on Earth. The most discussed drivers of this inordinate diversity are high niche availability associated with the diversity of host plants and dense niche packing due to host partitioning among herbivores. However, the relative contributions of these two factors to dynamics in the functional diversity of herbivores throughout Earth history remain unresolved. Using fossil data on herbivore-induced leaf damage from across the Cenozoic, we infer quantitative bipartite interaction networks between plants and functional feeding types of herbivores. We fit a general model of diversity to these interaction networks and discover that host partitioning among functional groups of herbivores contributed twice as much to herbivore functional diversity as host diversity. These findings indicate that niche packing primarily shaped the dynamics in the functional diversity of herbivores during the past 66 million years. Our study highlights how the fossil record can be used to test fundamental theories of biodiversity and represents a benchmark for assessing the drivers of herbivore functional diversity in modern ecosystems.

The dynamics of the diversity-energy relationship during the last 21,000 years

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Spatial diversity patterns are linked to energy availability, but how the diversity-energy relationship changes in space and time is unclear. There are three possible scenarios: (1) equilibrium dynamics, where diversity is always positively related to energy availability in both time and space, (2) out-of-equilibrium dynamics, where diversity is determined by energy availability in equilibrium, but diversity variation lags behind changes in energy availability, leading to a mismatch between temporal and spatial diversity-energy relationship, and (3) disequilibrium dynamics where the equilibrium does not exist or is irrelevant. We attempt to distinguish these scenarios using spatiotemporal pollen data for woody and herbaceous species.

Applying spatiotemporal paleoecological data, we evaluated the correlation between pollen type diversity (for both woody and herbaceous plants) and energy availability, as indicated by temperature, precipitation, and CO2 fluctuations, across the world in 1000-year intervals.

Our findings reveal that for woody species, a positive temporal diversity-energy relationship emerges only amidst rapid energy level shifts, while a positive spatial relationship is significant when these levels stabilize, aligning with the out-of-equilibrium scenario. This suggests the existence of diversity equilibria acting as attractors, yet diversity often remains out of equilibrium. Conversely, for herbaceous species, the diversity-energy relationship is typically weaker and inverse to that of woody species, indicating their distinct strategies and unique environmental constraints.

Quantifying latitudinal dynamics of biomes in Europe by unifying fossil pollen records of the last 12,000 years

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Understanding how the spatial distribution and composition of biomes has developed from past to present is the basis for accurately predicting how plant communities will develop under ongoing anthropogenic climate change in the future. Studies of fossil pollen and genetic information showed that individual plant species dispersed northwards at different rates in Europe after the LGM in response to retreating glaciers and increasing global temperatures. The reconstruction of spatio-temporal distribution of biomes and successional states demonstrated a northward movement of wider ecological units during the Holocene. Yet, biome reconstructions based on present biomes cannot detect former biomes without modern analogues.

Using more than 550 taxonomically standardised fossil pollen time series in Europe encompassing over 230 fossil pollen taxa and the last 12,000 years, I employed unsupervised hierarchical clustering to group fossil pollen assemblages into ecological units conceptually comparable to biomes. Hierarchical clustering is a well-established method to identify biomes in modern macroecological studies but has not been employed on comparable time-scales. I quantified the latitudinal displacement of the identified biomes throughout the Holocene by fitting linear models to the latitude of the spatial centroids, leading and tailing edges of the biomes across 1000-year bins. The formerly demonstrated northward movement of biomes could not be reproduced using extensive pollen assemblage data suggesting that spatio-temporal vegetation patterns are less pronounced when more taxa are considered. The median latitudinal displacement of spatial centroids of biomes ranged form 0.0 to 0.5 latitudinal degrees per 1000 years. New biomes emerged mainly in South and Central Europe. The identified biomes appeared to represent temporally and spatially explicit vegetation communities which were reconfigured with changing abiotic conditions and thus not moving distinctly northward.

The evolution of local co-occurrence in birds in relation to latitude, degree of sympatry, and range symmetry

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Recent speciation rates and the transition of species into secondary, range-wide sympatry are usually faster farther from the equator. Does this include also faster transition to secondary syntopy (co-existence in local assemblages)? To answer this question, we studied the evolution of syntopy in songbirds (Aves: Passeriformes) using worldwide citizen science data (eBird project). We chose recently diverged species pairs according to various selection criteria (species pairs from subclades not older than 5 or 7 My, range-wide degree of sympatry not lower than 5% or 25%, three definitions of the breeding season). We related their syntopy to latitude, degree of sympatry (breeding range overlap), range symmetry, and age of split. Most species pairs showed a positive local association. Furthermore, there was a positive relationship between syntopy and latitude (although its strength varied across datasets). However, syntopy did not differ between the tropics and temperate areas but increased from the Southern to the Northern Hemisphere. Syntopy was also higher in species pairs with higher degree of sympatry and more symmetric ranges. In sum, the evolution of secondary syntopy does not seem to be a rate-limiting step in speciation. However, given speciation rates and syntopy are higher in the Northern Hemisphere, other factors must be responsible for lower local diversity there.

Global Plant Co-Occurrence Patterns Decode the Interplay of Macroecological Drivers

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Species display patterns of co-occurrence due to shared environmental needs or historical processes. These patterns, in turn, can be used to predict the drivers that influence species distribution. The lack of global-scale species distribution data prevents us from testing these relationships across the global continuum. GBIF data promises new possibilities to explore these associations on a global scale.

Here we assess the relative importance of different drivers in shaping plant species co-occurrence and how their prominence varies across the globe. The study focuses on two questions: (1) what is the contribution of different drivers in shaping plant co-occurrences on a global scale? (2) are the relationships between co-occurrence patterns and drivers homogeneous across the globe?

First, we utilize the Isometric Feature Mapping (Isomap) method to analyze global vascular plant co-occurrences. Isomap is a nonlinear extension of multi-dimensional scaling, which allows for an effective representation of high-dimensional datasets without any prior assumptions. Leading Isomap dimensions jointly explain up to 88% of the variation, encoding major species co-occurrence gradients.

Next, we will employ the eXtreme Gradient Boosting (XGBoost) algorithm to examine the relationships between the gradients obtained from our analysis and a range of environmental and historical drivers. Our hypothesis is that the contribution of these drivers to the plant co-occurrence patterns will not only vary across dimensions, reflecting their relative importance, but also exhibit spatial heterogeneity. In other words, we expect to identify different leading drivers across different regions. By testing this hypothesis, we aim to provide a nuanced and comprehensive understanding of the macroecological drivers shaping the global distribution of vascular plants.

Comparing different patterns of intraspecific variation for the integration in ecological niche models. Will they tell us the same story?

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Ecological niche models (ENMs) are vastly applied to predict species range shifts under climate change. However, classical ENMs assume species homogeneity, disregarding the effects of gene flow limitations and resulting intraspecific differentiation through local adaptation. Compared to classical species-level ENMs, incorporating intraspecific variation (e.g., by using genetic data) can improve model performance and provide more realistic predictions under climate change. This, however, requires pre-defined subunits within species reflecting adaptation to local/regional climatic conditions. As precise information on adaptive features (e.g., ideally genes/traits under selection) is rarely available, the use of proxies to identify patterns of intraspecific variation related to climatic adaptations may be a possibility to overcome this shortcoming to better inform ENMs.

We use publicly available observations of European beech (Fagus sylvatica L.) from forest inventory plots to create individual population-level ENMs for different patterns of intraspecific variation. As patterns of variation, we consider: 1) genetic clusters, 2) climatic clusters and 3) performance clusters (based on tree height) derived from provenance trial data. The obtained individual ENMs are combined into summed population-level models respective for each pattern of intraspecific variation. Finally, we compare the classical species-level ENM and the different summed population-level ENMs based on measures of discriminatory ability and the predicted suitable areas under current and future climatic conditions. In doing so, we aim to identify similar and/or complementary patterns of intraspecific variation across the range of beech that may be used for more accessible and realistic predictions. In addition, we hope to identify populations that are particularly at risk or resilient to future climatic conditions.

Cross-continental shifts of ecological strategy in a global plant invader

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Plant invasions are a global problem with large ecological and economic impacts. Understanding the ecological drivers of such invasions requires the comparison of plant performance and functional traits, and their environmental associations, across native and introduced ranges. However, so far large-scale cross-continental field studies of invasive plants are rare. Here, we present comprehensive data for one of the worst invaders of the temperate zone: Japanese knotweed. We surveyed 150 populations along three 2000 km latitudinal transects in the native range of East Asia as well in the invasive ranges of Europe and Eastern North America. We show that larger plants and denser populations in the invasive ranges are associated with shifts in leaf economy and chemical defenses in the field. In invasive populations, knotweed leaves are larger and more nitrogen-rich, but have reduced chlorophyll, lignin, and leaf toughness. With parallel shifts in leaf tannins, flavonoids and alkaloids, this resu lted in unique multivariate knotweed phenotypes in Europe and the US, which are distinct from that of the native range. Decreased herbivore and pathogen pressure in invasive populations and altered environmental associations indicate that a combination of enemy release and novel habitat conditions might have driven the emergence of these novel ecological strategies in a global plant invader.

Spatial missmatch betwee wild bee diversity hotspots and protected areas in Switzerlad

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Wild bees play a critical role in maintaining multiple ecosystem functions, yet their populations are currently facing significant threats. To effectively conserve these vital pollinators, it is crucial to understand the factors that determine the spatial distribution of wild bee diversity. In this talk, we present our research, which focuses on modeling the taxonomic and functional diversity of wild bees in Switzerland. By utilizing extensive monitoring data from over 3000 community plots, we aim to uncover nationwide diversity patterns, assess the drivers that shape wild bee diversity, identify hotspots of diversity, and explore their relationship with protected areas. Our findings provide valuable insights for future conservation efforts.

Applying spatial biodiversity models in cities

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Cities represent a system made of complex interaction between human and natural processes, resulting in a spatially heterogeneous mosaic of social and ecological conditions. While the expansion of cities often destroys habitats and living grounds for,many taxa, cities may also offer areas to preserve wildlife and support people's well-being. To achieve that, fine-scale spatial information describing changes in species-, biodiversity distribution and its contributions to people across urban areas is needed. Here we show that implementing spatial biodiversity models in urban areas is increasingly possible thanks to the exponential availability of georeferenced ecological data and environmental information, representing a promising tool to further understand urban biodiversity patterns. Biodiversity models output can be used to better understand the ecology of urban environments, but also to improve urban planning, wildlife management, and to promote social and environmental justice.

The effect of biotic interactions on modelling responses to climate change in an alpine ecosystem

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Species distribution models (SDMs) are widely used to project geographic distributions of species under future climate change. These correlative models are designed to capture realised ecological niches, but are often fitted with exclusively climatic data to capture a species' environment. Therefore, SDMs usually ignore biotic interactions, which are known to shape ecological niches of species and affect their geographic distribution. Here, we fitted climate-based SDMs with and without biotic interaction effects for an alpine study system with strong interdependencies of species, using a combination of very finely resolved spatial data across Switzerland and of less resolved data across the rest of Europe. We focussed on Swiss stone pine (*Pinus cembra*), which forms the tree line in the European Alps, and its primary seed disperser, spotted nutcracker (*Nucifraga caryocatactes*). We also developed SDMs for Norway spruce (*Picea abies*) as the main competitor of the focal tree, and for common hazel (*Corylus avellana*) as an additional important food source for the bird. Our model comparison showed different results for the two focal species regarding the inclusion of biotic interactions: for Swiss stone pine, including occurrence probabilities for spruce (competitor) and nutcracker (seed disperser) in the SDM did not improve model quality and fit, whereas quality and fit of the nutcracker SDM were significantly improved by inclusion of occurrence probabilities for the bird's food sources (Swiss stone pine and hazelnut). Under different climate-change scenarios, our model projected strong range losses for the pine across Switzerland by the end of the century, whereas projections for the nutcracker showed mostly increased occurrence probabilities. Our results imply that accounting for food plants is helpful to model herbivore distributions, but that the signature of biotic interactions such as competition and seed dispersal might be more challenging to capture.

Climate change drives accelerations in ectothermic rates of evolution

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Ectothermic animals rely on the external environment to regulate their body heat, and as a result, temperature can significantly impact their biology, including metabolic rate, body size, and generation time. Climate change is expected to cause an increase in global surface temperatures, which can shorten ectothermic development rates and thereby increase the number of generations per year in multivoltine species. To date, the relationship between temperature and development rate has not been investigated systematically across taxa. This relationship is crucial to understand because the frequency of successive generations drives the rates of mutation and recombination and therefore impacts evolutionary rates, which can enhance adaptive capacity and increase the likelihood of successful adaptation to global change.

Here we have developed a species-specific and spatially explicit method to predict the number of generations per year for ectothermic animals under a climate condition of interest. We utilized empirical data collated from the literature to model temperature-dependent development across 52 species of terrestrial invertebrates. These data are combined with species distribution models and a stage-structured population model to generate daily population structures for the projected range of a species under a selected temperature regime. Through the prediction of past, current, and future population structures, we have discovered an ongoing increase in the number of generations per year, which serves as a useful proxy of evolutionary rates and corresponds to the intensity of the climate change scenario. Thus, climate change has been continuously elevating ectothermic rates of evolution since the start of the industrial revolution, and this trend is expected to continue in the future. These results have significant socio-ecological consequences, which are relevant to ecosystem stability, conservation, agriculture, and health sciences.

Body colour drives optimal dragonfly phenology via thermoregulation

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Phenology, the seasonal timing of life events, is an essential component of biodiversity which partly results from species´ life cycle synchronisation to optimal seasonal moments. The mechanisms involved are, however, complex and understudied which limits our ability to predict biodiversity responses to global change drivers. Thermoregulation is crucial for shaping diversity patterns, particularly in ectotherms such as insects. Dark-bodied species are able to inhabit colder areas due to their higher absorbance of solar radiation – a pattern known as the Thermal Melanism Hypothesis. Thermal melanism is well supported to drive spatial variation of insect diversity, but whether it also may influence phenological patterns remains unexplored. Here we show, using a unique dataset of thousands of spatio-phenologically explicit dragonfly and damselfly assemblages, that dragonfly body colour lightness patterns respond to seasonal variation of solar radiation, with darker early- and late-season assemblages and lighter mid-season assemblages. This suggests that colour-based thermoregulation can determine insect phenology in relation to optimal seasonal conditions. We also show that the phenological pattern of dragonfly colour lightness advanced significantly over the last 30 years. Our results, together with the static nature of solar radiation, suggest that global warming may drive flight periods to sub-optimal seasonal conditions. Our findings open a new research avenue for a more mechanistic understanding of phenology and spatio-phenological impacts of climate warming on insects and other ectotherms.

Assessing conservation and restoration potential of biotopes in Bavaria

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Changing environmental conditions and land use are threatening biodiversity on a large scale, making successful conservation and restoration essential for maintaining biodiversity. Previous studies used distribution models to identify potential areas for conservation or restoration, however, a more holistic approach requires the identification of various species or biotopes that can be conserved or restored in an area. We used the distribution model Maxent to identify varying levels of conservation and restoration potential for 29 different biotopes in Bavaria, Germany, by comparing the environmentally suitable areas identified by the models with the current biotope distribution. Conservation potential was identified when biotopes occurred at suitable environmental conditions and restoration potential when suitable environmental conditions were present, but biotopes were not observed. We found that 69.57% of biotope observations occurred under suitable environmental conditions, 22 biotopes showed more restoration potential than their current distribution, and there was geographic similarity between conservation and restoration potential. The study's approach provides valuable insights for conservation and restoration decision-making by considering both conservation and restoration suggestions of multiple biotopes. Further, our approach can be extended to other regions globally, and incorporating future climate projections could identify resilient locations for biotope conservation or restoration.

The big four of plant taxonomy - a comparison of global checklists of vascular plant names

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Taxonomic checklists used to verify published plant names and identify synonyms are a cornerstone of biological research. Specifically in large-scale studies typical to macroecology and works related to global change and biodiversity loss, taxonomic information from many different sources needs to be harmonized before performing analyses. For the taxonomic group of vascular plants, four global authoritative taxonomic checklists exist: Leipzig Catalogue of Vascular Plants, World Checklist of Vascular Plants, World Flora Online (successor of The Plant List, TPL), and WorldPlants. We compared these four checklists in terms of size and differences across taxa.

We matched taxon names of these checklists and TPL against each other, identified differences across checklists, and evaluated the consistency of accepted names linked to individual taxon names. We assessed geographic and phylogenetic patterns of variance. Finally, we tested name-matching performance and taxonomic name resolution with two use cases.

All checklists differed strongly compared to TPL and provided identical information on about 60% of plant names. Geographically, differences in checklists increased from low to high latitudes. Phylogenetically, we detected strong variability across families. The two use cases, a comparison of name-matching on taxon names submitted to the functional trait database TRY, and a check of completeness of accepted names evaluated against an independent, expert-curated checklist of the family Meliaceae, showed a relatively similar performance across checklists.

This study raises awareness on the differences in data and approach across these checklists potentially impacting analyses. We propose ideas on the way forward exploring synergies and harmonizing the four global checklists.

From Pliocene to Present: An evolutionary analysis of the climatic niche in the genus *Fagus*.

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The climatic niche of a species describes its fundamental ecological requirements for growth, reproduction, and survival. Over evolutionary time, the climatic niche may change due to evolutionary processes, including diversifying selection, genetic isolation, and random processes. The genus *Fagus* (beech) is a well-known example of a group of deciduous trees with a wide distribution and ecological importance. Furthermore, the evolutionary history of this genus is exceptionally well studied and provides the possibility to compare fossil-driven insights with reconstructions based on the current realized niche properties of the extant species. Here, we present a macroecological analysis of the evolution of the climatic niche in the genus Fagus, which involved meticulous compilation and subsampling of distribution data and ancestral niche constructions.

We compiled occurrence data for all species of the genus *Fagus* from various sources, used a literature survey and vegetation plot data to remove data inaccurate in terms of altitude, and subsampled these cleaned data to reduce spatial autocorrelation. We then used the machuruku method to estimate the climatic niche of each species based on climatic variables and to reconstruct the potential distribution areas of the respective taxa starting from the Pliocene.

Our results show that the climatic niche of the genus *Fagus* is surprisingly conserved, despite the occurrence of Chinese beech species in subtropical zones. The climatic niche of the genus Fagus is characterized by a low annual temperature range and timely precipitation during the growing season. The ancestral climatic niche reconstruction suggests that the recent *Fagus* species have evolved in a predominantly vicariant speciation pattern.

Ecological Patterns and Drivers of Plant Diversity on Rock Outcrops in the Northern Western Ghats of India

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Rock outcrops are landscapes with most of their area as exposed bare rock. This habitat faces harsh environmental conditions as a consequence of seasonal water availability, high light and wind intensities, and heterogeneous soil cover. The plant life on rock outcrops is mainly herbaceous, seasonally, and edaphically controlled. In the Northern region of the Western Ghats of India (NWG), the rock outcrops are one of the predominant habitats. Geological literature classifies these outcrops based on altitude and lithotype. Various past studies on NWG outcrops have primarily documented the floristic diversity with a large number of novel species descriptions. However, ecological knowledge of these unique habitats is still deficient. We investigated the lithotype-vegetation and altitude-vegetation relationship on NWG rock outcrops. We recorded plant diversity from 30 sites and classified them into seven plant functional types. Along with the vegetation data, macro-environmental variables (temperature, precipitation, altitude, etc.) and soil nutrients (soil carbon and nitrogen) were recorded. Cluster analysis and NMDS grouped the sites into two distinct groups, which were primarily based on lithotype, altitude, mean diurnal range and distance from the sea. CCA investigating the relationship of vegetation and environment across lithotypes revealed that Geophyte abundance was associated with precipitation variables, while Carnivores and Succulents were associated with temperature variables. Graminoids seemed to utilize all the environmental factors optimally. Soil carbon, soil nitrogen and their interaction significantly influenced the abundance of Legumes and Geophytes, while soil carbon and its interaction with lithotype significantly influenced the Graminoid abundance following ANCOVA. We inferred that the distribution and dominance of different plant functional types in the NWG rock outcrops are influenced primarily by altitude and lithotype.

SESSION 37:

Computational Ecology

An Integral Projection Model for African elephant (Loxodonta africana) and its Application

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African elephant populations have been constantly exposed to illegal killing and climate extremes, and their conservation is a multifaceted problem. While the species has been extensively studied, the demographic mechanisms that lead to population stability and their sensitivities to disturbances are not well understood. We use published data to build, parameterise and analyse a mechanistic population model for the African savannah elephant that dynamically links density-dependent resource availability with demographic rates and phenotypic traits. Annual projections of population size and structure, reproductive output and mortality events from the literature-parameterised population model show high concordance with observed dynamics in the unexploited Kenyan Amboseli elephant population. Uncertainty analyses showed that primarily inter-calving intervals limited reproduction and slowed population growth during an increase phase, while mainly adult mortality is important for regulation once a population reached stability, suggesting non-universality of demographic sensitivities between transitory and stable-state dynamics. Finally, as an applied example for local tailoring, we fit the generic model to population data from Amboseli.

Re-using SE-IBMs for other regions - simple and rewarding? A case study for the European wolf (*Canis lupus*)

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After being hunted to extinction in historic times, in recent years a few large mammals absent in Germany for decades experienced an exceptional expansion of their range. The expansion of the German wolf population in particular presents not only an opportunity for ecological studies but also a large challenge to management, because husbandry practices need to be adapted quickly when (or even better: before) wolves appear in formerly unoccupied areas. Spatially explicit IBMs are a popular way to describe highly dynamic population expansions, but they tend to be difficult to develop, parametrize and validate. Therefore, it seems expedient to adapt existing models to the situation of interest.

Here, I present challenges and solutions to adapting a model written for the expanding wolf population in the Italian Alps to Germany. The largest hurdle in repurposing an existing model is to find suitable input data: To replace the Alpine habitat suitability map I chose a published habitat suitability map for Germany by Fechter et al. Publicly available data concerning the German wolf population served for the starting values as well as to calculate input parameters where easily applicable. I kept the original parameters where data specific to Germany was unavailable, which were calibrated to the Alpine model or even calculated from extensive field surveys in the Italian Alps.

Results show a qualitative accordance of model output with spatial and non-spatial population measures in reality, although quantitative comparisons reveal that further parameter calibration steps would be necessary to obtain a model suitable for predictive purposes.

Investigating the effect of pesticides on Daphnia clonal populations using a stochastic model

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Daphnia is a widely used model organism for environmental risk assessment of pesticides. Long-term lab experiments with Daphnia can be useful for the detection of sublethal effects on populations that are subject to chronic exposure to pesticides. However, demographic stochasticity can led to large fluctuations in time and among replicates of different clonal populations, which makes the interpretation of such data and the quantification of treatment effects difficult.

We use an age-structured discrete population model (Palamara et al.)[1] to analyse experimental data with clonal populations of Daphnia galeata that were exposed to sublethal concentrations of the insecticide Diazinon and the herbicide Diuron. We apply Bayesian inference to infer model-structure, states and parameters of the model. For each clone, we infer potential treatment effects on fertility and mortality by comparing the posterior parameter distributions of models that were calibrated separately to each treatment and clone.

The use of stochastic population models allowed us to quantify effects of Diazinon on Daphnia galeata in the presence of high stochasticity, and to compare such effects among clonal populations. With this study, we demonstrate how we can use stochastic models and a systematic model selection approach to infer mechanisms from population data, to help identifying sublethal pesticide effects. The model-based analysis can also support the optimization of the experimental design of future studies and help identify how different populations can develop resistance to toxicants in natural environments.

[1] Palamara, GM, Dennis, S.R, Haenggi, C., Schuwirth, N., Reichert, P. Investigating the effect of pesticides on Daphnia population dynamics by inferring structure and parameters of a stochastic model Ecological Modelling 472 (2022) 110076

SyrFitSources: An agent-based model for hoverflies and their resources on landscape scale

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In the last decades, insect populations have declined severely due to different aspects of global change. One important component of global change is land-use change. Especially for bees, there are dynamic population models considering the composition and configuration of resources in the landscape. For less popular insects with other ecological niches like hoverflies (Syrphidae) such models are lacking. Hoverflies are as well important pollinators but the larvae of many genera predate on aphids.

To understand the effects of the spatiotemporal distribution of resources on aphidophagous hoverflies, we developed SyrFitSources, an agent-based model which simulates the behavior of the hoverfly Episyrphus balteatus as larva and as imago. To enable faster computation in areas of a few square kilometers throughout a year, the landscape was discretized into patches represented by agents connected through a habitat network. Each so called patch agent has a habitat-specific set of plants. The plant populations of a patch are implemented as agents of their own and provide nectar and pollen dependent on their abundance and species identity. Further, the plants get infested with aphids whose population dynamics are simulated with difference equations based. The species-specific amount and phenology of pollen and nectar were taken from the FloRes data base, while the carrying capacity of aphids was estimated from literature. Furthermore, the daily mean temperature was incorporated into the model as it influences the aphids' growth rate, the voracity and development time of juvenile hoverflies and the activity probability of the imagines.

Finally, we validated SyrFitSources with observed activity patterns of E. balteatus from 13 landscapes in Bavaria, in each of which three malaise traps were set up in summer 2011. SyrFitSources can be used to investigate the effects of land-use change or of agricultural biodiversity measures in real or hypothetical scenarios.

Effects of nitrogen limitation on trait patterns of mosses and lichens

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Mosses and lichens carry out crucial ecosystem functions in various regions across the world, including biotic fixation of nitrogen by associated cyanobacteria. These functions will likely be affected by climate change, depending on the response of mosses and lichens to factors such as warming or elevated atmospheric CO2 concentration that may promote or reduce growth in a species-specific way, thus altering functional composition of moss and lichen communities. Thereby, it is largely unclear to what extent the potentially positive effects of elevated CO2 in the future can be utilized by the organisms for enhanced growth, since limitation by other factors, such as nitrogen, may prevent a strong response to CO2. Since nitrogen is key both for projecting future growth of mosses and lichens and their impacts on ecosystem nutrient cycling, we include nitrogen dynamics in a trait-based, eco-evolutionary model of mosses and lichens and examine how emerging distributions of functional traits are affected by potential nitrogen limitation and which consequences follow for ecosystem nutrient supply.

The effect of evolution of trait means and trait variances on minimum viable population sizes in a changing environment

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It is predicted that many populations will have to evolve rapidly to be able to persist in the face of human-induced rapid environmental change. For biodiversity conservation, it is thus critical to better understand the conditions under which populations can successfully adapt and persist in a changing environment and how large populations need to be to do this, i.e. to find out what is a minimum viable population size for adaptation in a changing environment. Classical models for trait evolution in a changing environment have found that there are critical rates of environmental change above which species can no longer adapt rapidly enough. These models have generally assumed that trait variance stays constant as the population is evolving, an assumption that is surely violated in small populations that can rapidly lose genetic variation due to drift. Because of this assumption, it was difficult to answer questions regarding minimum viable population sizes. Here we introduce a new modelling approach that keeps track of mean traits, trait variances, and population sizes. Unlike in classical models, also the trait variance can change due to selection, genetic drift, and mutation. In addition, our eco-evolutionary models account for non-linear relationships between fitness and trait variation. We develop simple and insightful analytical models and compare them to individual-based simulations. Based on the model dynamics, we then compute different minimum viable population sizes that either focus on short-term dynamics such as the successful (re)introduction of a population to a location or on long-term dynamics such as the long-term persistence of a population in a certain habitat.

A multi-species, multi-trophic level, animal community home range model

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Creating an individual based model that is able to simulate animal community dynamics while accounting for trophic interactions is key in gaining a mechanistic understanding of how landscape changes generate trophic cascades that affect the structure and stability of animal communities. Here, we present a dynamic, spatially-explicit, multi-trophic level, animal community model based on allometric relationships that simulates species home ranges location as a response to the distribution and richness of plant food resources and the presence of simple, reflective barriers.

We extend Buchmann et al's IBM home range formation model for herbivorous mammals and bird functional groups to included trophic interactions and time. We do this in three ways: firstly, functional traits will include diet preference allowing for trophic levels assignment; thus, extending the original primary consumer model to a multitrophic model, where the home range distribution of lower trophic levels acts as resource landscape for higher levels. Secondly, time is included by considering various time-driven aspects: i) mortality via defined mass-dependent life-span, mortality rate and elimination of animals from landscapes resource changes over time, i.e., resource-driven mortality; ii) new home range formation to exploit newly available resources that result from a changing resource landscape; iii) primary resource landscapes are able to change at each time step to represent time-varying processes that affect resource availability and distribution.

We present an example running of how our model may be used to aid in predicting the distribution of animal communities in urban planning on a landscape where food resources are fragmentated by large roads.

Estimating intrinsic growth rates and interaction strengths from time series data

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Cyanobacterial harmful algal blooms have been a persistent problem for human. Toxic blooms pollute water, which sometimes is the main source of drinking water for surrounding areas. Toxic blooms also have negative effects on the ecological communities, including both aquatic and terrestrial populations.

Most efforts have been focusing on predicting blooms, using statistical models and process-based models. Statistical models generally overlooks underlying ecological interactions, and only consider abiotic conditions, such as temperature, light intensity, nutrition concentration, and so on. Process-based models use mathematical expressions to describe explicit relationships among focal species and their surrounding environment, which is often highly complex with various parameters, many of which cannot be measured. Predictive models are useful in management decisions but do not help understand the origins of the blooms, which requires mechanistic models.

A few models study algal bloom by forcing changes in environmental conditions while others suggest that bloom is an intrinsic property of complex communities. These models, despite being mechanistic, are often highly conceptual, and only describe the successional dynamics of the system without providing explicit ecological reasons of why a bloom occurs.

Here, we explore the algal bloom phenomenon, combining both ecological mechanisms and data inference. A widespread property of a bloom is that it never contains one but often several cyanobacteria strains. Whether a bloom is toxic or not depends on the domination of the toxic or nontoxic strains, which can be investigated using niche overlap, fitness difference, and species robustness metrics of coexistence theory. Those metrics are derived from the intrinsic growth rates and the interactions strengths, which can be directly estimated from time series using a modified S-maps inference method. By following the evolution of coexistence metrics, we show how we can integrate biotic interactions to abiotic condition in studying the conditions leading to a bloom.

What causes invasion success? Connecting major hypotheses in causal networks

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To answer the question of what causes invasion success, a large number of hypotheses have been formulated. For example, the enemy release hypothesis suggests that in the non-native area, species are facing a reduced pressure by enemies, leading to an increased performance and thus invasion success. It has been suggested to combine several of such major invasion hypotheses in networks, based on e.g. co-citation or conceptual overlaps. These existing networks, however, do not represent causal relationships. A solution is to build causal networks, in which the connections (edges) between the variables (nodes) indicate hypothesized causal relationships.

With this presentation, we suggest building such causal networks based on ten major invasion hypotheses. In a first step, we modeled the individual hypotheses as hypothesized causal relationships. We then combined them in in two networks depicting hypothesized causes of (i) invasiveness and (ii) invasibility. This bottom-up approach for building a causal network from well-known and well-defined components has the advantage that the complexity of the network can be built up bit by bit. The nodes can be given as rather specific, well-defined variables, and the exact meaning of each edge is explicitly stated. We suggest linking the causal networks to an ontology providing precise definitions for the respective variables and relationships.

Causal networks can deliver the basis for advanced machine learning applications. Machine readable versions of causal networks connected to ontologies allow for the implementation of AI tools that can aid with causal reasoning and could in the future allow drawing causal inferences from complex data. In teaming up with data scientists and experts in formal logics, it can thus become possible to efficiently analyze data not only for detecting patterns, but also for inferring causes.

MitoGeneExtractor: Efficient extraction of mitochondrial genes from next-generation sequencing libraries.

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Mitochondrial DNA (mtDNA) sequences are often found as byproducts in next-generation sequencing (NGS) datasets that were originally created to capture genomic or transcriptomic information of an organism. These mtDNA sequences are often discarded, wasting this valuable sequencing information. We developed MitoGeneExtractor, an innovative tool which allows to extract mitochondrial protein coding genes (PCGs) of interest from NGS libraries through multiple sequence alignments of sequencing reads to amino acid references. In a case study, we applied MitoGeneExtractor to recently published genomic datasets of 1993 birds and were able to extract complete or nearly complete sequences for all 13 mitochondrial PCGs for a large proportion of libraries. Compared to an existing assembly guided sequence reconstruction algorithm, MitoGeneExtractor was faster and substantially more sensitive. We compared COI sequences mined with MitoGeneExtractor to COI databases. Mined sequences show a high sequence similarity and correct taxonomic assignment between the recovered sequence and the assigned morphospecies in most samples. In some cases of incongruent taxonomic assignments in this case study, we found evidence for contamination in NGS libraries, which can be identified with the MitoGeneExtractor output. Further, we successfully reconstructed organellar PCGs with MitoGeneExtractor from various NGS datasets (i.e., Illumina short-read data, PacBio and Oxford Nanopore long-read data) obtained from genomic and transcriptomic sources over a broad taxonomic range (i.e., vertebrates, invertebrates, plants). MitoGeneExtractor allows a fast extraction of mitochondrial and plastome PCGs, if the gene contributed to the read population. An important use case of MitoGeneExtractor can be the extraction of organelle marker gene sequences in order to confirm species assignment or identify library contamination.

Species distribution models based on ML and DL - can we reliably infer ecological effects?

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Species distribution models (SDMs) increasingly use Machine learning (ML) and deep learning (DL) algorithms to describe the response of species to environmental predictors. The main reason to prefer these models over statistical models such as logistic regression is their superior predictive performance. A concern, however, is that this comes at the cost of explanatory power, in particular because i) ML and DL are more likely to exploit spurious correlations in the data and ii) because explainable AI (xAI) tools that extract effects or response curves from fitted models are often sensitive to feature collinearity. Here, we show that all of these concerns are justified, but can be alleviated by appropriate methodological choices. First, similar to statistical models, a prerequisite for ML to learn correct causal effects is that feature selection must be based on causal principles, such as conditioning on confounders following Pearl's backdoor adjustment. We also show that this can increase the generalizability of the models, for example when predicting under climate change. Second, appropriate explainable AI (xAI) tools must be used: We propose to use Average Conditional Effects (ACE), which are robust to feature collinearity, to extract effects from ML models. Finally, the choice of ML algorithm is crucial. We show that if the other two conditions are met, neural networks and boosted regression trees are better suited than random forest to reliably separate collinear effects. We conclude that under the right conditions and with the right tools, predictive ML models can provide more reliable effect estimates (e.g. about the environmental niche). Moreover, as a byproduct, causally constrained ML models often exhibit lower generalization errors, which is relevant when trying to build models for extrapolation, as is done in climate change predictions.

Spatial randomization approach to spatially autocorrelated ecological data

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Both environmental and ecological data are frequently heavily spatially autocorrelated. Ignoring spatial autocorrelation both in response and predictor variables can lead to completely misleading conclusions about their apparent relationship. Variety of approaches has been proposed to address this problem, most of them being parametric and/or requiring some arbitrary choices to avoid overfitting or to properly model the spatial autocorrelation present in the data. Here I present a novel, completely nonparametric approach for assessing the effect of spatial autocorrelation on the results of different kinds of statistical models, ranging from generalized linear models to random forests. The method is based on spatial randomization, a technique routinely used in spatial point pattern analysis. The approach, which was already proposed for assessing correlation of two autocorrelated variables, has been adapted for the general case of response-predictor modeling, and is currently being implemented in a new R package. The method will be described, it's performance assessed, and its application demonstrated on a real-data example.

hydrographr: an R package for scalable hydrographic data processing

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Freshwater biodiversity is declining, yet there are still large knowledge gaps regarding the spatial distribution of species. A major factor that challenges the accurate mapping of aquatic biodiversity is the need for complex geo-spatial processing of hydrographic data, such as stream network, basin and sub-catchment data, that are able to capture the longitudinal connectivity between water bodies. Scalable tools that allow working with such data across large spatial extents and at high spatial resolution often involve advanced command-line GIS skills and programming language integration, making biodiversity analysis workflows computationally inaccessible to many freshwater researchers. Aiming to bridge this gap, we developed the R package hydrographr, available at https://github.com/glowabio/hydrographr. The package covers a broad range of geo-spatial processing functions to process hydrographic data for e.g. spatial analyses, species distribution modelling, or connectivity analyses. The package includes functions for downloading spatial layers of the high-resolution Hydrography90m dataset, and wrapper functions for the open-source GIS software GDAL/OGR and GRASS GIS to efficiently process, read and extract information from spatial layers and assess network distances and stream connectivity. The functions allow developing scalable workflows at large spatial extents yet at very high resolution, because they process data directly on disc, opposed to loading it in the R-environment. While they are tailored towards the Hydrography90m dataset, they can be equally used to process other types of hydrographic or even terrestrial layers. In this talk, we will showcase the functionality of the package using a workflow for freshwater species distribution modelling.

Information-based framework for presence-absence pairwise indices of diversity

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Many indices comparing species assemblages have been developed. However, despite attempts to establish consistent and clear framework for these indices, the interpretation of the indices varies among different sources and there is no consensus about their proper meaning. Previous efforts primarily focused on the mathematical aspects of the indices, their relationship to alpha diversity, and the partitioning of indices to capture net components of spatial biodiversity phenomena such as turnover and nestedness.

We contend that the independence of indices in terms of their informational content is crucial for drawing accurate inferences about the diversity patterns they quantify. We demonstrate how to examine the informational content of indices, explain why partitioning distorts the information conveyed by the indices, and highlight how any attempt to eliminate dependencies between indices, including alpha diversity, leads to the measurement of different phenomena than intended. In addition, we present several case studies where our framework yields divergent results compared to published findings. We introduce a method for converting any index to Jaccard similarity and Simpson beta, enabling meta-analyses across different sources of literature.

We need to talk about the topology of interaction networks

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This presentation describes a novel cognitive model that provides an integrative solution to two classical dilemmas about interactions between organisms of different species. Our research team, in collaboration with other experts, embarked on an extensive investigation to uncover the underlying principles that could lead to this solution. Through a comprehensive analysis, first, we demonstrated the commonalities between the dilemmas, and employed a graphical model to better understand the theoretical connection between them. We then developed an algorithmic model that predicts the four most commonly observed network topologies in nature. Our cognitive model, initially designed for antagonisms in monolayer networks, was subjected to a series of empirical tests and logical deductions. The results show that the model can be extended to mutualisms and multilayer networks, highlighting its broad applicability. Currently, we are working to refine the model and develop it into a new syntactic theory, which may have significant implications for basic and applied ecology. We invite the audience to join us as we share the journey of discovery, unveiling the exciting possibilities that this new cognitive model presents.

Exploring the development of the ecological niche concept using text mining methods

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The ecological niche is one of the key concepts in ecology. At the same time, there is much debate surrounding its definition and estimation. In this paper we present a systematic and quantitative overview of over 30,000 studies on the ecological niche. Using an evidence synthesis framework, Research Weaving, we provide an overview of scientific trends over the last 100 years. We explored the study species, the locations of field studies, type of studies, as well as scientific patterns of keywords, citations and author collaborations. Furthermore, we used topic modelling to discover hidden semantic topics in the paper abstracts.

The most common organisms studied in the ecological niche literature were animals, arthropods, plants and bacteria, while the most common study areas were located in China, Brazil, USA and Australia. Some new topics have emerged recently (e.g., the stable isotopes analysis), whereas other topics have fainted (e.g. habitat selection studies). Overall, the ecological niche is clearly a dynamic, alas declining, concept, which encompasses plenty of sub-concepts, as more scientific communities are adopting this term and adjusting it to different research contexts.

SESSION 38:

Making Use of Unstructured Data Streams in Ecology

A text and image analysis workflow using citizen science data to extract relevant social media records: combining red kite observations from Flickr, eBird and iNaturalist

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Big data, often in the form of user-generated content or social media have emerged as potential complementary approaches to more traditional data sources for conservation practices such as species distribution mapping. However, despite evidence that combining different data sources improves the representativeness of the dataset, many current studies focus on single sources. Data integration is one route to overcoming common biases such as participation inequality in user-generated content. We conceptualise and implement an automated workflow which extracts red kite (Milvus milvus) posts from Flickr data to integrate them with existing data from two Citizen Science platforms eBird and iNaturalist. Two data modalities – text and images - are analysed and used as sequential filters. Generic keyword matching of red kite relevant terms is applied to the text whereas two object detection models are applied to the images one of which was trained on labelled photographs from Citizen Science experts. Our workflow downsampled 600’000 initial posts to just 3065 candidate posts; making manual verification feasible. We reached a precision of 0.658 if text or image classifiers were used separately and a near perfect precision of 0.992 if they were combined. We found that 14% of the data could only be correctly classified based on the images. Our modular setup comprised of a series of modality checks allows for a generalisable workflow, adaptable to different needs (precision vs. recall) and target species. Besides the workflow implementation we were interested in analysing the previously claimed benefit of merging different sources. Besides an expected data volume increase we observed new spatio-temporal patterns and also the number of users contributing data increased.

The Krefeld study and its Impact on Public Perception of the Insect Crisis: Insights from Google Trends Data

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The insect crisis, as conservation topic, has historically received little attention among the general public. Yet the study “More than 75 percent decline over 27 years in total flying insect biomass in protected areas” by Hallmann et al. gained vast media coverage upon its publication. Given the media’s known influence on public perception, we investigated i) whether coverage of this publication increased awareness among the German public for insect die-off, and ii) whether it contributed to people’s intentions to undertake insect protecting actions. We used Google Trends to examine people’s internet activity in Germany in relation to relevant keywords.

A high peak in Google searches for insect die-off (“Insektensterben”) was indeed visible immediately after the study publication, and search volume remained significantly higher for the following six months, confirming that the topic gained attention. Further, searches for the three keywords insect hotel, bee-friendly and bee meadow (“Insektenhotel”, “bienenfreundlich”, “Bienenweide”) increased significantly over the summers of the years 2017 to 2019. It appears that increased media attention around insect die-off spurned by the publication of Hallmann et al. not only addressed the crisis, but also encouraged implementation of simple insect protection measures by the public.

These findings suggest that cooperation between the media, conservation organizations and scientists to disseminate evidence-based information alongside practical conservation measures may have lasting benefits.

Opportunistic plant occurrence data enable bio-indication of environmental factors for Europe

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Environmental conditions can be indirectly inferred from the occurrence of plant species by knowing their ecological niches. Using this principle of bio - indication to map environmental conditions over large areas and high resolution so far has been hampered by the limited availability of species occurrence data.

Due to the increasing popularity of species identification apps such as Flora Incognita, PlantNet or iNaturlist, opportunistic plant occurrences data are rapidly accumulating which facilitates assessments of vegetation composition over large areas and with increasing observation density.

This raises the question of whether this data can be used for European high resolution mapping of environmental conditions such as abiotic factors (e.g. soil, climate), pollution (e.g. salt), and disturbances (e.g. soil disturbance, mowing, grazing). To this end we generate maps of respective factors for Europe by combining opportunistic plant occurrence data with recently available Ellenberg-type indicator values on respective niche dimensions (Denger et al. 2023, Tichy et al. 2023, Midolo et al. 2023). We evaluate our approach based on cross-consistency checks with results using expert-based vegetation mappings and with independent data sources for environmental conditions.

Our results show that with the help of opportunistic plant observations it is now possible to generate high resolution maps of environmental conditions on continental as well as regional scales.

Mapping environment using opportunistic data has several advantages compared to direct physical environmental measurements: measurements are less cost and labor intensive and are possible also in remote regions, resolution potentially can be increased by several orders of magnitude, mappings rely on real measurements and are not only up-scaled from satellite data (as e.g. many soil maps are), estimates relate to the specific growing environment of plants and therefore comprise information, bio-indication allows also mapping variation not only mean values. With increasing density of opportunistic plant occurrence data the approach will allow for mapping environmental change and detection of pollution and disturbances in time. Possible applications are agriculture, environmental planning, pollution detection, or the improvement of plant identification apps by using mean indicator values as prior information.

Macrophenology dynamics from crowd-sourced mobile application data

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Monitoring changes in phenology is key to understanding the impact of climate change on ecosystems. Crowd-sourced data from smartphone applications are gaining in popularity in many ecological applications and are especially relevant for automated species recognition. However, the potential of crowd-sourced data for studying phenology at macroecological scales has not been deeply explored. We aim to quantify the collective phenological cycle of plant co-ocurrences based on citizen science data.

We analyse crowd-sourced German plant observation data collected with the smartphone application Flora Incognita, which identifies plant species native to Central Europe from images in real time using deep learning. We propose that the dynamics of collective flora behaviour is embedded in the temporal co-occurrence observations. To extract this collective phenological dynamics we propose the nonlinear dimension reduction method isometric feature mapping. Further, we introduce a measure to characterise the dynamics across large spatial scales introducing macrophenology.

Our results demonstrate that the macrophenological patterns can be effectively detected from crowd-sourced plant observation data. The strong collective flowering in spring and summer allows us to clearly characterise phenological transitions, specifically the faster changes in spring compared to autumn. The emerging complexity measure of collective behaviour is an indicator for linear and nonlinear temporal changes in macroecological patterns in the summer and the rest of the year, respectively.

Despite biases and uncertainties associated with opportunistically collected crowd-sourced data it is possible to derive meaningful indicators for monitoring plant phenology. In the near future multi-year records of such data will be available to explore phenological shifts and how they are impacted by climate change in near real time.

Hotspots of geographic range change for eight charismatic carnivores in the Neotropics

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In this study, we aim to assess the changes in the geographic range distribution of eight charismatic Neotropical carnivores using Integrated Species Distribution Models (ISDM). To do this, we combined presence-absence and presence-only data and modelled the species' distributions at two time periods (2000-2013 and 2014-2021) using a Bayesian model based on a Poisson point process in JAGS. The model integrates the different data sources and accounts for sampling effort and spatial autocorrelation. Our results reveal that the modelled geographic ranges differ from the current distribution range maps from IUCN. We show the geographic range differences for the species between the two periods and map the hotspots of range change, highlighting areas where contractions and expansions are accumulating. Our study demonstrates that ISDMs can be used to model the dynamics of the geographic range of species in Latin America over the last two decades, despite the data deficiencies. Our modelling framework can be applied to assess other species and regions that also lack high-quality data, providing a promising solution to overcome the issue of high-quality data scarcity in the study of range dynamics.

Advancing Phenology Research: Deep Learning and Metadata for Identifying Phenological Stages in Community Science Images

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Phenology, the study of seasonal timing in biological events, is a crucial aspect of understanding and monitoring ecosystem dynamics. Traditional approaches of in-situ phenology data collection often rely on labor-intensive and time-consuming methods. However, the increasing availability of opportunistic occurrence data in combination with images of the specific record as well as advances in deep learning techniques open up new possibilities in phenology research. This poster presents a novel approach to classify phenological stages in community science images. Here, we train a convolutional neural network (CNN) to classify images of plant species into distinct phenophases. In addition to images, metadata e.g. geolocation, elevation and recording date are included in the training process. By considering such contextual information, the model can account for the influence of environmental factors on phenological patterns. This approach leads to an improvement of the image based classification of various events, such as budding, flowering, and fruiting, across different plant species and ecosystems. In the future, this method can be applied to different plant species and thus analyze images from different sources (e.g. identification apps, Flickr, Twitter, etc.) with respect to their phenological stages. This opens up a new data stream for future phenological research to provide valuable insights into phenological shifts and their ecological implications.

Opportunistic plant observations reveal spatial and temporal gradients in phenology

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The timing of phenological events plays a crucial role in ecosystem processes. Ongoing global warming strongly affects plant species` phenologies and monitoring those changes on different scales is essential to understand their consequences. Opportunistic plant observations collected e.g. via species reporting platforms or identification apps provide a growing source of spatiotemporal plant observation data. Here, we used such data to address the question whether such opportunistic plant observations can be used to monitor changes in species phenologies and are suitable to derive large-scale relationships such as “Hopkins’ bioclimatic law” which quantifies the phenological delay with increasing latitude, longitude and elevation.

Observing two subsequent years we found significant shifts in the timing of mean flowering date from 2020 to 2021 for almost all of the observed 20 wild flowering, herbaceous species. This shift was much more pronounced for the spring-flowering species (6-17 days) than for the summer flowering species (1-6 days).

Moreover, depending on the species, we observe an elevational shift between -5 and 50 days per 1000m and a latitudinal shift between -1 and 4 days per degree northwards.

Our results indicate that the growing amount of opportunistic plant observation data provides reliable phenological information that already allows to quantify large-scale bioclimatic relationships. In combination with data collected within traditional phenological observation networks, opportunistic data can be used to parameterize climate- and vegetation models and are expected to allow for more timely and fine-grained predictions.

SESSION 40:

Remote Sensing of Biodiversity

Transfer learning from citizen science photos enables plant species identification in UAV imagery

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Accurate information on the spatial distribution of plant species and communities is in high demand for various fields of application, such as nature conservation, forestry, and agriculture. A series of studies has shown that CNNs accurately predict plant species and communities in high-resolution remote sensing data, particularly with data from Unoccupied Aerial Vehicles (UAV). However, such methods require ample training data to generate transferable CNN models. Reference data are commonly generated via geocoded in-situ observations or labeling of remote sensing data through visual interpretation. Both approaches are often laborious and present a critical bottleneck for CNN applications. An alternative is to use plant photographs from citizen science projects such as iNaturalist. Despite the heterogeneity of crowd-sourced plant photos, it still could be a valuable source to overcome the challenge of limited training data. Here, we explore the potential of transfer learning from such a crowd-sourced data treasure to the remote sensing context. Therefore, we investigate firstly, if we can use crowd-sourced plant photos for CNN training and subsequent mapping of plant species in the UAV imagery. Secondly, we test if the predictive performance can be increased by a priori selecting photos that share a more similar perspective to the remote sensing data. Therefore, we used three case studies to test our proposed approach:

- Mapping Portulacaria Afra in the context of shrub monitoring and desertification counter measurements (South Africa).

- Mapping Fallopia japonica invasions in a fluvial system (Germany).

- Mapping the distribution of 10 tree species (Germany).

For each case study, we used multiple UAV-based RGB orthoimages and queried the iNaturalist database for photos of the target species. Using these photos, we trained CNN models to classify the target species. Our results demonstrate that CNN models trained with heterogeneous, crowd-sourced plant photos can indeed predict the target species in UAV orthoimages with surprising accuracy. Filtering the training photos by acquisition properties improved predictive performance. This study demonstrates the potential of citizen science data in overcoming vegetation assessment challenges and harnessing crowd-sourced and big data for remote sensing applications.

Integrating GRASSMIND and PROSAIL models for simulating remote sensing indicators of diversely managed grasslands

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It's crucial to expand our knowledge of grassland biodiversity using cost-effective, thorough data-gathering techniques to propel ecological research forward. A new method combining two models, the individual-based grassland model (GRASSMIND) and the 2-D radiative transfer model PROSAIL is proposed. This combination captures changes in grassland traits across various management regimes andcould detect particular regimes in remote sensing observations.

The GRASSMIND model provides a tool to adjust key influences on grassland dynamics of species-rich plant communities, such as the frequency and timing of cutting events and fertilization, daily weather data, and soil qualities. PROSAIL predicts grassland canopy reflectance based on leaf biochemical properties and community structure, or optical traits.

This integrated approach is a robust instrument for gathering large-scale, continuous data on significant grassland biophysical attributes. This will deepen our understanding of the correlations among biodiversity, grassland management, the remote sensing signal, and both abiotic and biotic factors.

An extensive optical plant trait sampling was conducted and coupled with remote sensing measurements in variously managed grassland communities for model parameterization. Data on plant height, leaf area index, fresh/dry weight, pigment concentrations, and hyperspectral observations were collected. Grasslands with a significant gradient in land-use intensity (from extensive to intensive) were studied at three distinct field sites.

By merging terrestrial and satellite data, we can better comprehend the ecological processes and management techniques' effect on biodiversity. The results of the field campaign, including lab-derived plant traits like chlorophyll and carotenoid concentrations, are provided. The procedure for integrating GRASSMIND and PROSAIL is detailed, along with their parameterization and validation.

Remote Sensing Indices for Environmental Grassland Monitoring in Europe

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Grasslands are of great value for biodiversity. However, European grasslands are facing severe pressure. Depending on the area, abandonment followed by succession or intensification are major threats. In addition, low rainfall in the vegetation season has been recorded in recent years, causing degradation.

Environmental indicators can simplify the description of complex environmental conditions. They are important for understanding and managing human-environment systems. Biodiversity is one environmental indicator, highly relevant for grassland monitoring. Remote sensing approaches are an economical way to monitor grassland indicators. But there is a lack in a systematic review of different remote sensing indices for nature conservation and biodiversity monitoring of grassland habitats. Remote sensing indices are derived from remote sensing signals by building ratios of bands or by aggregating temporal or spatial information. They not only simplify the complexity and dimensionality of data by utilizing various bands, but they also aid in filtering out crucial information or incorporating new information.

Through a comprehensive literature review, we provide an overview of remote sensing indices used in biodiversity monitoring of European grasslands. We relate the indices acquired on different scales from drones to satellites to biodiversity. We expect to present a novel scheme for classifying remote sensing indices, which facilitates the comparison and overview of commonly used indices and refers to the underlying biophysical, biochemical, physiological abstraction mechanisms. We will give recommendations for remote sensing indices depending on natural conditions and grassland types and clarify peculiarities and pitfalls of remote sensing monitoring of grassland indicators. The results will assist researchers and nature conservation managers in identifying the most useful indices for biodiversity monitoring supporting monitoring and management of grassland ecosystems.

Multi-scale analysis of bird diversity using spectral heterogeneity and classified remote sensing data in diverse landscapes

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To protect bird biodiversity effectively, it is crucial to understand the drivers of species richness patterns and their scale dependence. Remote sensing images that have been classified into land cover classes are commonly used to explain bird species richness. However, recent studies have shown that unclassified images can provide equally good or even better results. In our study, we aimed to investigate whether unclassified multispectral data from Landsat 8 can replace image classification for bird diversity modelling.

We analyzed (using generalized linear models) species richness from the Breeding Birds Monitoring program in the Czech Republic between 2014 and 2017 at two spatial resolutions of approx. 131 km^2 (basic squares) and 8 km^2 (small squares). As predictors of the richness, we employed classified land cover data from Corine Land Cover 2018 database, spectral heterogeneity from unclassified remote-sensed reflectance (computed in three ways: coefficient of variance, standard deviation, and Rao's Q index), and median values from unclassified remote-sensed reflectance.

We found that spectral heterogeneity was the strongest predictor of bird species richness, explaining up to 64% of the variability of richness in basic squares and up to 52% in small squares. To achieve such high performance, it was necessary to incorporate information about type of environment in the models, suggesting that the environment plays an important role in explaining bird species richness. Furthermore, the results for basic and small squares differed. These findings highlight the importance of the chosen spatial scale.

We conclude that unclassified remote-sensed data can explain similar or even greater amount of variability in bird species richness than predictors derived from classified land cover data. To accurately explain bird species richness, however, it is necessary to take the type of environment and the applied scale into account.

Exploring the overlap of spectral and biological species diversity in the Amazon rainforest

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The conservation of biodiversity in the face of environmental stress caused by natural and anthropogenic factors remains a formidable challenge. However, in-situ methods for monitoring and resulting are not always practical. To address this issue, high-resolution satellite data and advanced machine learning techniques can provide spatio-temporal biodiversity information with high precision. The Amazon rainforest, which is home to numerous ecological processes and services, is a prime focus for conservation efforts. However, a suitable biodiversity indicator for rapid assessment and monitoring of biodiversity in the Amazon rainforest is still missing. Thus, this study aims to compare different biodiversity indicators to identify the suitable indicator that represents the agreement between spectral and biological diversity. Our study area encompasses the Amazon tall tower observatory (ATTO) and its surrounding region. Multitemporal PlanetScope data at 3 m spatial resolution are subjected to dimensionality reduction and clustering techniques to estimate diversity indices needed to test the concept of spectral species composition and diversity. Our work seeks to establish statistical evidence for an agreement between spectral and biological species in the Amazonian rainforest. This approach could provide critical information on species composition and ecological status, enabling effective biodiversity conservation and management.

Applicability of high-resolution global canopy height maps to biodiversity modelling

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It is well recognized that the vertical and horizontal structure of forests, including their height, is an important predictor of biodiversity. However, until recently, we lacked comprehensive global data on the spatial patterns of forest structure. This has changed with Global Ecosystem Dynamics Investigation (GEDI) mission launched in 2018 and specifically designed for vegetation mapping. We investigated the accuracy of the two recent global canopy height maps developed from GEDI data (the global forest canopy height map (GFCH); https://glad.umd.edu/dataset/gedi/ and the high-resolution canopy height model of the Earth (HRCH); https://langnico.github.io/globalcanopyheight/) in various types of forests in the temperate biome using airborne laser scanning data as a reference and assessed their usability for biodiversity modelling using a virtual species approach. Our results show considerable differences between the evaluated maps. The accuracy of estimated canopy height was highly dependent on the canopy height itself. GFCH consistently underestimates the height of all canopies regardless of their height, while HRCH tends to overestimate the height of low canopies and underestimate tall canopies. In the temperate biome, HRCH provides better estimates of height of tall canopies, while GFCH better represents the canopy heterogeneity. Biodiversity models using global canopy height maps are sufficient for estimating simple relationships between species occurrence and canopy height, but their use leads to a considerable decrease in discrimination ability of the models and to mischaracterization of species niches when derived indices (e.g. canopy height heterogeneity) are of concern. We show that global canopy height maps are useful for biodiversity modeling, but there is still space for their improvement. They can not replace more accurate ALS data and their use should be limited to areas where more accurate data are not available.

Mapping global distribution and extent of potentially groundwater-dependent vegetation: A novel multicriteria framework

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Groundwater-dependent vegetation (GDV) is essential for providing habitat for highly adapted and vulnerable species, and sustaining human livelihoods. However, climate and land use change threaten GDV and highlight the need for global mapping of the distribution and extent of GDV.

A novel multicriteria framework is presented to identify areas that provide suitable environmental conditions to hold potentially groundwater-dependent vegetation (pGDV), where vegetation behaviour (vitality, evapotranspiration) also indicates groundwater use. Global and openly available datasets focussing on 1) groundwater vegetation interaction; 2) soil water holding capacity; 3) topographical landscape wetness potential; 4) land use land cover and 5) hydraulic conductivity of rocks are combined in an easy-to-use index tested in the Mediterranean biome. Regions where pGDV is present indicate precipitation-independent high vitality and evapotranspiration of natural vegetation occurring in low permeable valleys or at low slope areas where water likely accumulates and the groundwater table is shallow, while soil properties allow infiltration. The final pGDV map can support prioritisation of those areas for further high-resolution identification and analysis of GDV.

A novel high-resolution GDV-mapping concept implements different criteria aiming at: 1) high vitality and wetness during dry periods, 2) low seasonal changes in vitality, 3) low interannual changes in vitality, 4) high topographic potential of water accumulation and low water table depth and 5) topography (elevation, slope). Vegetation plots from a study area in Campania were assigned ecohydrological indicators (phreatophyte coverage, indicator values) to ground-truth derived GDV-likelihoods and train machine learning algorithm for classification. Detailed GDV-maps ensure sustainable groundwater management and in turn protect threatened GDV as local biodiversity hotspots.

Combining remote sensing and in situ probe measurements for lake monitoring

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Worldwide, freshwater ecosystems are impacted by anthropogenic forcing including global warming-induced alteration of hydrological regimes and land use changes. For river systems, these changes might have far-reaching consequences as nutrients received from the terrestrial surrounding upstream may unfold both short and long-term effects downstream through system-wide changes of water residence time. River-connected lakes may modulate the spatial spread of eutrophication events throughout an aquatic network. However, studies on river-connected lake systems are scarce and limited by low temporal and spatial resolution. We investigated how local nutrient loading affects phytoplankton development along river-connected lake chains on a regional-scale by linking theoretical models with experimental and observational field studies. We specifically studied how local nutrient inputs drive phytoplankton growth and how nutrients and phytoplankton propagate along the aquatic network modulated by flow regime and lake size, both influencing water residence time. Our field study encompassed 19 lakes in NE-Germany, contrasting strongly river-connected lakes along the Upper Havel with weakly connected lakes. High temporal and spatial resolution was achieved by combining water constituent measurements and automated in-situ probes with ground-based, space- and airborne reflectance measurements. Our results suggest that - depending on flow regime, lake characteristics and residence time - similar point sources lead to profoundly different maximum intensity, spatial range and regional-scale magnitude of eutrophication events in lake chains. We also highlight the potential of combining in-situ measurements with remote sensing to improve lake meta-ecosystem monitoring.

UAV-based thermography reveals spatial and temporal variability of evapotranspiration from a tropical rainforest

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Tropical forests are diverse ecosystems, encompass heterogeneous site conditions and experience seasonal fluctuations of rainfall. Evapotranspiration (ET) from tropical rainforests plays a significant role in regulating the climate system. Our objectives were to quantify ET from a tropical rainforest and to assess its spatial and temporal variability across sites and seasons. In an undulating terrain in lowland Sumatra (Indonesia), thermal infrared images were taken from an unoccupied aerial vehicle (UAV) of upland and riparian sites during dry and wet seasons. ET was predicted from land surface temperature data retrieved from the thermal infrared images and applying an energy balance model. Average ET across sites and seasons was 0.48 mm h^{-1}, and is comparable to ET from a nearby commercial oil palm plantation where the method was calibrated with eddy covariance measurements. In the rainforest, for given trees, a positive correlation was found between UAV-based ET and tree transpiration from ground-based sap flux measurements corroborating observed spatial patterns in the forest. ET at rainforest upland sites was 11% higher than at riparian sites across all seasons. The plot-level variability of ET was lower at upland sites than at riparian sites, and was largely increased from the dry season to the wet season. This seasonally enhanced variability can be an effect of local site conditions including partial flooding and diverse responses of tree species to moisture conditions. Thus, UAV-based thermography revealed considerable spatial and temporal variability of ET from a tropical rainforest across sites and seasons.

ECOSTRESS reveals the importance of topography and forest structure for evapotranspiration from a tropical forest region of the Andes

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Tropical forests are a main source of evapotranspiration (ET), but such heterogeneous landscapes pose a challenge for continuous estimations, thus few ET studies occur and gaps of information persist. New spaceborne products such as ECOsystem Spaceborne Thermal Radiometer Experiment on Space Station (ECOSTRESS) are promising tools to close such gaps. We predicted ET for different days, using ECOSTRESS data across a large, protected tropical forest (2,250 km^2) situated at the western Andes. ET was modelled with a set of topographic, meteorological and forest structure variables. Data was retrieved from open-source products such as GEDI, PROBA-V and ERA5 avoiding variables included in the ECOSTRESS L3 algorithm. We applied a random forest approach and to reduce the risk of spatial overfitting caused by spatial autocorrelation we followed the best strategies available for spatial predictions such as forward feature selection and target cross validation. The models indicated high accuracy in spatially explicit prediction of ET across different locations, r^2 of 0.61 to 0.74 and fair errors (nRMSE%: ‹14%). No single variable was dominant, and five variables explained 60% of the model's results, thus highlighting the complex relationships among predictor variables and their influence over ET spatial predictions. Among all forest structure variables, leaf area index played a key role for spatial prediction of ET in all models, along with the topographic variables of elevation and aspect. We hypothesize that finer resolution leaf area index products may contribute to improving ET predictions, especially when considering a seasonal tropical forest or degraded land covers. We conclude that ET can be well predicted with a random forest approach, which could contribute to close observation gaps at the western slope of the Andes and could potentially be applied across another tropical underrepresented regions.

Using different drone image resolutions and ground truthing for identifying plant rings in arid Namibia

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The formation of rings made by different plant species occurs in many arid regions over the world. However, the spatial information on the distribution of plant rings has not yet been sufficiently studied. One way to monitor the ring patterns is to use high-resolution drone imagery. This is relatively easy during the rainy season when sprouting plants appear green and have distinct ring shapes. Nevertheless, the same plant rings are difficult to identify during drought periods when the color of the dead grass merges with its background. In this case the rings are difficult to identify on the ground even with the eye. Within work on a bachelor's thesis the potential of remote sensing for the identification of plant rings was examined in arid south-west Namibia in 2023.

In this survey we mapped the distribution of old grass rings made by the species *Stipagrostis namaquensis* within a study plot of 100 m × 100 m. We used high-resolution drone RGB-images with a ground sampling distance of 1 cm and compared the detectability of plant rings to the same orthoimages with a resolution of 2 cm and 5 cm, respectively. These lower resolutions would be equivalent to 200 m × 200 m and much larger study plots flown at higher altitudes. Furthermore, we photographed and mapped numerous plant rings on the ground and assessed their visibility in drone images.

Using our data, we classified the identified objects in drone imagery as "clearly visible" rings and "unclear" rings. This poster contribution gives an insight on the decline in detectability of rings in images with lower resolution and discusses the advantages and disadvantages of covering increasingly large study plots with drones. Given that we mapped these plant rings during an unfavorable drought period, we adjust our data interpretation and discuss the differences in ring identification relative to more favorable wet years with predominant green plant rings.

Aboveground forest biomass in the Himalayas derived from spaceborne (GEDI) and ground-based laser scanning

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Mountain forests encompass highly heterogenous environmental conditions. The monitoring of forest characteristics such as aboveground biomass in these environments is particularly challenging. Recent approaches emphasize the use of spaceborne laser scanning such as GEDI (Global Ecosystem Dynamics Investigation) for which ground-referencing is recommended. In the high mountains of Nepal, we assessed tree species composition and conducted ground-based mobile laser scanning across wide ranges of altitude (1200 m to 3800 m a.s.l.) and rainfall (990 mm yr^1 to 3700 mm yr^1). Our 55 plots were composed of broadleaf or needleleaf trees, and mixtures of them. Needleleaf trees predominantly occurred at high elevation and low rainfall. The assignment of plant functional types used for GEDI biomass computation did not match ground-based observations in almost half of the study plots. Using the same GEDI biomass allometries across all our plots yielded only a low R^2 between spaceborne and ground-based predicted aboveground biomass. However, for actual GEDI footprints (n = 33 plots) and ground-based assignment of plant functional types, the R^2 of a linear regression was 0.49. The residuals of this regression model increased with steepness of the slope. The predicted aboveground forest biomass from ground-based observation varied five-fold and tended to be higher in GEDI-based predictions. Thus, further attention should be paid to the assignment of plant functional types, the process of gridding, and the consideration of slopes. Overall, we regard spaceborne (GEDI) observation of forest aboveground biomass in mountain regions such as the Himalayas very promising.

SESSION 42:

Ecological Forecasting for Decision Making

The Dependence of Forecasts on Sampling Frequency as a Guide to Designing Experiments and Field Observations in Community Ecology

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It is critical that forecasts of ecological dynamics are skillful. One source of information for making forecasts is observed time series of population abundances. An unresolved question is at what frequency samples should be taken when recording such time series. This is important because the ecological processes that drive ecological dynamics occur on different time scales. Using a simple simulated dataset as a baseline and a more complex high-frequency plankton dataset, we tested how different sampling frequencies impacted our abundance forecasts of different plankton classes and the estimation of their interactions. We then investigated whether plankton growth rates and body sizes could be used to select the most appropriate sampling frequency. We found that a reduction in sampling frequency worsened our forecasts and led us to both over- and underestimate plankton interactions. Plankton growth rates and body sizes proved to be indicators of the optimal sampling frequency only in the simulated dynamics, while the complexity of the field data prevented this. We conclude that while forecasting is itself an objective in ecology, its dependency on sampling design means it can also be used to determine how frequently and how often a process needs to be sampled to be accurately captured and forecasted. We hypothesize that this extends to the design of scientific studies and monitoring programs which are not necessarily aimed at forecasting, as the inference of processes (such as the plankton interactions in this study) is likely to be most accurate at the sampling frequency that also yields the best forecasts. Ultimately, better study designs will improve the inference of processes and forecasting of dynamics, which is fundamental for a better theoretical understanding of ecology and for the implementation of better performing policies and measures that deal with current global challenges.

Constraining nonlinear time series modeling with the metabolic theory of ecology

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Forecasting the response of ecological systems to environmental change is a critical challenge for sustainable management. The metabolic theory of ecology (MTE) posits scaling of biological rates with temperature, but it has had limited application to population dynamic forecasting. Here we use the temperature dependence of the MTE to constrain empirical dynamic modeling (EDM), an equation-free nonlinear machine learning approach for forecasting. By rescaling time with temperature and modeling dynamics on a 'metabolic timestep,' our method (MTE-EDM) improved forecast accuracy in 18 of 19 empirical ectotherm time series (by 19% on average), with the largest gains in more seasonal environments. MTE-EDM assumes that temperature affects only the rate, rather than the form, of population dynamics, and that interacting species have approximately similar temperature dependence. A review of laboratory studies suggests these assumptions are reasonable, at least approximately, though not for all ecological systems. Our approach highlights how to combine modern data-driven forecasting techniques with ecological theory and mechanistic understanding to predict the response of complex ecosystems to temperature variability and trends.

From forecast to its forecast skill horizon with the continuous ranked probabiliy score

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Ecological forecasts are model-based statements about currently unknown system states in time, space or phylogeny. For a model forecast useful to inform decision-makers, model validation and verification determine adequateness. Both require a measure of forecast goodness that can be translated into a limit up to which a forecast is acceptable, known as the 'forecast horizon'. While verification of meteorological models follows strict criteria with established metrics and forecast horizons, assessments of ecological forecasting models still remain an experiment-specific choice and forecast horizons are rarely reported. In this study, we characterize a temporal forecast horizon in such a way that it serves as a standardized verification tool. We transfer methods from ensemble forecast verification to a population dynamic model as case study. We suggest the continuous ranked probability score as metric, highlight the use of a reference model for predictive skill assessment and finally show how a forecast horizon can be determined even in the absence of observations. Doing so, we aim to contribute to the discussion on advancing the workflow for ecological forecasting.

How the choice of model performance metric affects the outputs of species distribution models

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Species distribution models (SDMs) are routinely used to assess the impacts of environmental changes on biodiversity. To evaluate the predictive performance of these models and to binarize their continuous outputs into species' presence and absence, the true skill statistic (TSS) is commonly used. Recently, this metric has been criticized for its dependence on prevalence, i.e. the proportion of recorded sites where the species is present. For species with a lower prevalence, TSS values are more prone to overpredicting the distribution range and assign higher TSS values then to species with a higher prevalence. However, implications of this shortcoming for the outputs of SDMs have not yet been evaluated.

The aim of our study is to compare how the choice of model performance metric affects range sizes and range shifts predicted by SDMs. To that end, we first fitted an SDM for each of 1,680 European vascular plant species, using a selection of relevant climate and soil variables as predictors. We evaluated the performance of these models and binarized their outputs with multiple performance metrics, including TSS, F-measure, overprediction, underprediction, sensitivity and specificity. Then, for each species and performance metric, we calculated the species range shift under two climate change scenarios (mild and extreme climate change). In this presentation, we will show how the SDM outputs (range size and range change) relate to the choice of performance metric, the species' prevalence, and the climate change scenario.

Forecast-based action for conservation

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The growth of research in ecological forecasting demonstrates the great potential to anticipate ecological and conservation outcomes. However, a lack of operational ecological forecasts and limited examples of forecasts being used in decision making suggests that a new approach is needed to translate forecasts into action. Advances in meteorological forecasting and innovation in the humanitarian sector provide a possible solution – forecast-based action (FbA). FbA provides a framework by which ecological forecasts could be routinely translated into anticipatory action, ensuring that ecosystems and biodiversity are prepared for, and thus resilient to, environmental change. Based on lessons learned in the humanitarian sector, I will suggest how FbA could work in conservation, demonstrating key concepts using a theoretical example of heatwave impacts on sea turtle embryo mortality. I will address likely challenges in realising FbA in conservation, including establishing a financing mechanism, allocating funds to actions, and decision making under uncertainty. FbA will demand changes in research, practice and governance, but has the potential to improve the resilience of ecosystem function and biodiversity to environmental change.

Conserving biodiversity under global change: towards a universal biodiversity projection platform

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Biodiversity and ecosystems are degrading worldwide at an alarming rate. Addressing this crisis and preventing further losses requires accurate predictions about which species and ecosystems are most at risk to ensure efficient use of limited conservation and management resources. Yet, our understanding and predictive capacity of ongoing biodiversity dynamics remains limited, mostly due to technical and data challenges. We reviewed existing biodiversity modelling frameworks and their applications for decision support and found problematic gaps. Current applications are heavily biased towards correlative models and towards the population and species level. Existing mechanistic models cannot easily be reconfigured for other species or systems, omit key biological processes, and cannot accommodate feedbacks with Earth system dynamics.

To fill these gaps, we envision an adaptable, accessible, and universal biodiversity modelling platform that is able to forecast essential biodiversity variables, from the gene to the ecosystem level. Wider usage of mechanistic biodiversity models should be further facilitated by a toolbox with easier-to-use methods for data integration and model validation, and best practice guidelines. To address these needs and coordinate efforts, a new working group on biodiversity modelling and knowledge-to-action hub are being launched within the Group on Earth Observations Biodiversity Observation Network (GEO BON). Here, we provide a brief summary of current biodiversity modelling approaches and prevailing challenges, and outline our vision for more integrated modelling.

Demographic synthesis to inform global tree species conservation

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Conserving the world's tree species requires better information on which types of tree species are most vulnerable to different threats. Here, we explore the potential for the identification and use of species' life history strategies to predict tree species' susceptibility to different pressing threats, namely climate change, pests and pathogens, and selective logging. We provide an overview on the different sources of demographic data and modelling approaches for trees, including their strengths and weaknesses for the assessment of species vulnerability. Next, we synthesize the evidence on which tree species' life history strategies will be most vulnerable to the aforementioned threats. Finally, we highlight promising avenues of research to improve quantitative vulnerability assessments for conservation prioritizations of trees worldwide.

SESSION 43:

Scales, SARs and SADs

Using GBIF to understand global species abundance distributions

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That some species are rare and others are common is one of the oldest observations in ecology. But the exact shape of the distribution of species abundances on Earth has remained elusive. Some have argued that nature shows a bias towards rare species, while others have proposed that most species have intermediate abundances. We use more than 1 billion observations from the Global Biodiversity Information Facility (GBIF) to assess the global species abundance distributions (gSADs) of 39 taxonomic classes of organisms, stratifying our analysis temporally from 1900 to 2019. Our analysis shows that as sampling effort increases through time, the shape of the gSAD is unveiled, i.e., the shape of the sampled gSAD changes, revealing the underlying gSAD. The best statistical fit for almost all classes was the Poisson log-normal distribution, with negative binomial and log-series distributions having poor-fit to the data. The fraction of species unveiled for each class decreases with the total number of species in that class and increases with the number of individuals sampled, with some groups such as birds being fully unveiled. We also found that the percent of the gSAD that is unveiled is strongly dependent on observed species richness, where more speciose classes are less well-sampled, as well as sampling effort where increased number of occurrences allows for a higher likelihood of the class being fully sampled. The results presented here illustrate the importance of considering SADs in a global context, but also highlight the importance of future work to better understand the shape of global species abundance distributions. This evidence for a universal pattern of gSADs across classes suggests that there are general ecological or evolutionary mechanisms governing the commonness and rarity of life on Earth.

A unified approach to the species-area relationship using statistics of extremes

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The species-area relationship (SAR) is one of the most fundamental patterns in ecology. Assuming a sampling scheme of nested areas starting from an arbitrary (focal) point, what matters to determine the number of species as area size increases (the SAR) is to find, for each species, the individual closest to the focal point, i.e. the one with the minimum distance. This observation is important because it reveals the SAR can be analysed using methods from statistics of extremes, specifically, those dealing with the minima. Typically, a SAR exhibits three phases: one for small areas characterized by a fast increase in the number of species, one for intermediate areas characterized by a power law with an exponent smaller than 1, and another for large areas, also characterized by fast growth. We use statistics of extremes to elucidate the quantitative and qualitative properties of each phase. We illustrate our results using computer simulations and real data on amphibians, birds, mammals, and reptiles from the GBIF, the largest biodiversity aggregator of global biodiversity records.

A fractal perspective of community distributions: from a Cantor dust to the Canonical Lognormal

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Fractals are known to be an important approach in describing species distributions. While most of this has focused on single-species distributions, there are also indications that fractal or scale-symmetric processes play an important role in communities. What do species communities produced by fractal-based constructions look like? In order to answer questions like this, we study communities with species ranges constructed by algorithms similar to that for the Cantor Set. The SAD and SAR produced are examined in terms of their connection with fractal parameters such as dimension. We finally turn this question around to ask how known community patterns, such as the Geometric or Canonical Lognormal, could be related to geometric constructions.

Patterns of plant biodiversity in multiple nested-plots in Mediterranean grassland, Turkey

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Plant biodiversity in Mediterranean semi-natural grasslands may vary depending on the spatial scale. Species-area relationships (SARs) describes diversity patterns across spatial scales and mostly well fit by power law function. Scale-dependent patterns of species richness has been investigated in local scales in various studies across Europe. However, information in the Mediterranean Basin is still limited. In this study, we aimed to find out species richness patterns in a Mediterranean semi-natural grassland system in West Anatolia using multiple nested-plots (seven grain sizes from 0.0001 m^2 to 100 m^2 plots). The study area is Spil mountain, where is located in between İzmir and Manisa cities in Turkey. Elevational range of the mountain is 240 - 1419 m a.s.l. The Mediterranean climate is rainy winters and hot summers. The mean annual temperature is 17.8 °C and the mean annual precipitation is 697 mm in İzmir. We collected 27 nested-plots and 60 normal plots (without nestedness) alongside an elevational gradient in the mountain. In this study, we will present general patterns of species richness across grain sizes as well as beta diversity patterns. In addition, we will present a general overview of underlying mechanisms of environmental characteristics.

Upscaling plant community dynamics from the individual to the community scale

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Transporting critical information across scales is one of the major issues in ecology. For example, a considerable challenge is to include essential information on spatial patterns and demographic stochasticity emerging from the collective behavior and interactions of individuals at the "microscopic" neighborhood scale into dynamic models operating at the "macroscopic" population or community scale.

Here I propose an upscaling approach that incorporates the essence of neighborhood crowding competition among trees and translate it by means of spatial transfer functions into macroscopic models of community dynamics. The transfer functions express model parameter as function of individual-level parameters and indices of the emerging spatial patterns. As point of departure I use deterministic Lotka-Volterra style models of forest dynamics, but extend them to include demographic stochasticity by translation into master-equation models of the birth-death type. The corresponding birth-death models describe the dynamics of the probability that a species with initially N0 individuals has at timestep t abundance n.

The birth-death models captured the full range of stochasticity incorporated into a symmetric individual-based implementation of a deterministic community model and were able to correctly predict the emerging species abundance distributions, given the same initial condition and the same number of simulation years are used. A scale collapse of the results of the birth-death model reveals the conditions under which a species can recover from low abundances, and it provides a direct and quantitative connection between the extinction risk and both, individual-level parameters and measures of spatial patterns, as incorporated through the transfer function into the macroscopic model. The proposed framework allows for studying the role of demographic stochasticity in a more efficient way than conducting individual-based simulations and allows for analytical predictions of the species extinction risk.

Beyond geographic scales: How trait-based movement can help understand species-specific scales in ecology

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“Given that scale is relative to organisms - forces acting at a scale of 1 m are unlikely to be the same for bacteria and elephants - how can we rescale depending on the organism?” (McGill 2010 Science)

The scale-dependance of biological patterns and relationships is gaining increasing attention across a broad range of research areas in ecology and evolution. So far, spatial scale has usually been defined from an anthropocentric perspective as the local scale is typically similar to the scale at which data is collected. However, natural communities consist of different species with different traits and therefore these geographic scales (i.e., micro, meso, and macroscale) do not necessarily match the scale at which different species live and interact, which inherently implies that research for any given geographic area mixes processes operating at different species-specific scales. We, therefore, face the challenge of how to “rescale depending on the organism”.

Here, we present a concept that employs animal movement to create evident and species-specific boundaries between scales. Movement is the core process driving species interactions and distribution patterns, thereby shaping biodiversity and connecting it across scales. By using trait-based movement, we aim to move beyond geographic scales in order to improve our understanding of ecological patterns and processes from species’ perspectives.

Animal and plant space-use drive plant diversity-productivity relationships

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Positive plant diversity-productivity relationships are a widely recognized pattern and often attributed to niche complementarity, which reduces competition between plant species. However, competition within a plant community is a combination of small-scale competition for resources (i.e. exploitative competition) and larger-scale competition from shared herbivores (i.e. apparent competition). To understand how niche complementarity drives plant diversity-productivity relationships therefore requires an understanding of the spatial scaling of competitive processes within a plant community. Thus, we investigate how the spatial overlap in plants' resource access and home range sizes of animals affect plant community composition and functioning in food web simulations. We found that spatial overlap of plant' resource access is a prerequisite for positive diversity-productivity relationships, but causes exploitative competition that can lead to competitive exclusion. Mobile herbivores can cause apparent competition between plants, resulting in negative relationships. However, top predators with larger home ranges integrate sub-food-webs composed of smaller species, offsetting the negative effects of exploitative and apparent competition and leading to strongly positive diversity-productivity relationships. Overall, our results show that differences in plant and animal space-use can greatly alter the composition and functioning of plant communities. Correctly scaling animal space-use additionally opens new perspectives for linking local and landscape processes.

Scale mismatches between predictor and response variables in species distribution modelling: good practices for appropriate grain selection

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There is a lack of guidance on the choice of the spatial grain of predictor and response variables in species distribution models. This poster summarizes the current state of the art with regard to the following points: (i) the effects of changing the resolution of predictor and response variables on model performance; (ii) the effect of conducting multi-grain versus single-grain analysis on model performance; and (iii) the role of land cover type and spatial autocorrelation in selecting the appropriate grain size. In the reviewed literature, we found that coarsening the resolution of the response variable typically leads to declining model performance. Therefore, we recommend aiming for finer resolutions unless there is a reason to do otherwise (e.g. expert knowledge of the ecological scale). We also found that so far, the improvements in model performance reported for multi-grain models have been relatively low and that useful predictions can be generated even from single-scale models. In addition, the use of high-resolution predictors improves model performance; however, there is only limited evidence on whether this applies to models with coarser resolution response variables (e.g. 100 km^2 and coarser). Low-resolution predictors are usually sufficient for species associated with fairly common environmental conditions but not for species associated with less common ones. This is because coarsening the resolution reduces variability within heterogeneous predictors and leads to underrepresentation of rare environments, which can lead to a decrease in model performance. Thus, assessing the spatial autocorrelation of the predictors at multiple grains can provide insights into the impacts of coarsening their resolution on model performance. Overall, we observed a lack of studies examining the simultaneous manipulation of the resolution of predictor and response variables.

SESSION 47:

Biodiversity Monitoring

Shaping together the future of biodiversity monitoring in Germany

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The need for high-resolution biodiversity data has increased in recent days in order to analyse consequences of environmental changes, survey conservation measures and inform policy. For this reason, the federal government has launched the National Monitoring Centre for Biodiversity (NMBZ) in 2021.

The NMBZ brings together stakeholders from research and practice in order to advance and establish a nationwide biodiversity monitoring in the long term. By connecting the monitoring community, it aims to establish a network of comprehensive, nationwide biodiversity monitoring systems, thus fostering standardization in sampling methods for long-term biodiversity observation. The centre consolidates existing monitoring programs, identifies gaps in the monitoring landscape and triggers the development of new programs to ensure the availability of representative biodiversity data for Germany. Involving government ministries, research institutions and other stakeholders, such as the highly valuable volunteer community, it coordinates and expands monitoring practices, facilitates collaboration among stakeholders and supports knowledge and data transfer.

The centre prioritizes the development of monitoring methods, data management, and technological integration to improve data availability and efficiency. With the establishment of an information and networking platform, it aggregates monitoring data, tools, and resources for research and citizen science projects.

The structure of the centre includes a central office, a cross-departmental steering committee, a principle expert committee, and specialized expert committees.

At the long term, the centre focuses on creating a robust national data basis for analysing biodiversity changes, identifying causes, and proposing conservation actions.

National Biodiversity Monitoring in Forests (NaBioWald) - a federal-state initiative

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The conservation of biodiversity is of great societal interest. The status and future development of biodiversity in German forests cannot be sufficiently determined by the national monitoring programs already existing. NaBioWald aims to close this gap by providing comprehensive and representative information on the development of biodiversity and on the effects of influencing variables. NaBioWald is intended to provide an important basis for biodiversity-oriented forest management, to support the forest and nature conservation policies of the federal and state governments, and to contribute to the fulfilment of national and international reporting obligations.

A working group consisting of representatives of federal and state institutions in forestry and nature conservation including further experts from scientific institutions is currently working on a monitoring concept. One focus is on the possible influences of forest management, climate change, air pollution and air borne pesticides on biodiversity.

To implement the necessary monitoring work, existing German-wide (forest) surveys are to be supplemented with additional surveys and interfaces to ongoing and developing biodiversity monitoring programs are to be created. This approach will be integrated into the activities of the National Biodiversity Monitoring Center. Due to the manifold anthropogenic influences, as well as the complexity of the topic and the effort of monitoring, a shared workload among the many different actors from science, administration, forestry and nature conservation on federal and state level is required. A draft concept is to be discussed in an extended circle of experts and presented as a final draft to politicians for a decision on implementation.

We present the current state of work and the further process of NaBioWald.

How advanced metadata standards for biodiversity survey and monitoring data help you creating FAIR data

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In an ever-changing world, field surveys, inventories and monitoring data are essential for predicting biodiversity responses to global drivers such as land use and climate changes. This understanding provides the basis for appropriate conservation management. However, field biodiversity data collected across terrestrial, freshwater and marine realms are highly complex and heterogeneous, and the successful integration and reuse of such data depends on how they follow the FAIR principles (Findable, Accessible, Interoperable, Reusable). Focusing on biodiversity field surveys and monitoring data, we aim at supporting comprehensive metadata generation with interoperable metadata standards using semantic artefacts that facilitate data access, integration and reuse across terrestrial, freshwater and marine realms. To this end, we revised, adapted and expanded existing metadata standards, vocabularies and thesauri to build a FAIR metadata form (i.e., a form which is both machine-actionable and follow domain-relevant community standards), and a vocabulary of biodiversity monitoring terms. Using available biodiversity data, we will refine and illustrate the strength of the concept in cases of real use. We will evaluate differences and similarities of metadata characteristics across marine, freshwater and terrestrial realms, and assess the completeness of the metadata associated to datasets deposited in different repositories for data reusability, thus promoting the FAIR-handling of biodiversity metadata and data reusability.

Diversity of Insects in Nature protected Areas (DINA) – results from four years of transdisciplinary research on insect decline

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The loss of insect diversity and thus of an important part of overall biodiversity is widely known and accepted. The transdisciplinary research project DINA (Diversity of Insects in Nature protected Areas), funded by the Federal Ministry of Education and Research (BMBF) recorded not only the diversity of flying insects but investigated also environmental influences on the animals Eight different institutions led by NABU (The Nature And Biodiversity Conservation Union) partnered the project.

In 21 selected nature reserves across Germany extensive procedures for sample preparation and analysis were established:

(1) recording the insects with Malaise traps

(2) sample division with new developed design for manually species identification in parallel with genetic identification (DNA metabarcoding)

(3) vegetation surveys in combination with DNA metabarcoding of plant tissue in insect samples

(4) pesticide residue analysis and a range of landscape indicators

The framework conditions for the acceptance of measures for insect protection were investigated in social science surveys. Dialogue series at three of the DINA sites with local stakeholders from nature conservation, authorities and agriculture contributed to a better understanding of areas of conflict and developed locally adapted and jointly supported solutions for integrated insect protection.

Based on our results, with 10 scientific publications so far, we formulated political recommendations for better insect protection in Germany. Top-line advices are: 1. Prioritise biodiversity in target setting and planning for nature protected areas; 2. Enable nationwide monitoring and location-based risk analyses; 3. Supporting the willingness of central stakeholders as farmers to cooperate.

Biodiversity monitoring plant-insect interactions via metabarcoding Malaise trap plant traces.

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The declines in insect abundance and diversity over the past decades has captured the attention of international audiences and is beginning to move policy decisions to protect pollinators and beneficial insects. Declining diversity has also been observed in plants, and as insects and plant are intrinsically intertwined, the protection and biomonitoring of plants is crucial to reduce insect declines. Economical, rapid, and standardized methods to assess the biodiversity of insects and plants is in critical need of development, in order to provide sound recommendations for policy decisions. Malaise traps are a common method of collecting flying insects, and when insects are captured in Malaise traps, they carry traces of plants they have visited, either on the body surface or in the gut contents. DNA metabarcoding offers a promising method for identifying these plant traces, however, this method is not without its shortcomings and is in the initial stages of development. To examine the soundness of this method we used the ITS2 barcode and analysed samples from 21 sites across Germany that intersect with agriculture and protected land. Here we report on the feasibility of sequencing these sample types, analysis of the resulting taxa, the usage of cultivated plants by insects near nature conservancy areas, and the detection of rare and neophyte species. DNA metabarcoding has advantages for rapid largescale biomonitoring in efficiency and resolution over microscopic identification of pollen, as well as identification of plant traces not identifiable without molecular methods. We expect with further development it could aid in providing reliable recommendations for the protection of plant and insect biodiversity.

"nützLINK" – a monitoring approach for beneficial arthropods in agricultural landscapes in Germany.

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The global loss of biodiversity and the decline of insects has severe consequences for many ecosystems worldwide. In agriculture, important ecosystem services such as crop pollination and natural pest control are at risk. The continuous monitoring of beneficial arthropods providing these ecosystem services is necessary to detect changes in their populations, while also helping to record positive effects of agroecological measures on biodiversity in general. Adult hoverflies are important pollinators, while the larvae of many species are effective predators of various field crop pests. Many hoverfly species roam through diverse habitats due to their life cycle and high mobility and are affected by resource availability and potential disturbance factors over a wide spatial range. As part of the collaborative project MonViA (https://www.agrarmonitoring-monvia.de/en/), the long-term monitoring of hoverfly populations ("nützLINK") will serve as an indicator for the condition of agricultural management on a wider spatial scale. Orchard meadows embedded in the agricultural landscape act as the spatial matrix for this approach. These extensively managed agroforestry systems provide temporary refugia and resources for many insect groups. Furthermore, citizens, communities and associations maintain many of these orchard meadows. This network of stakeholders is involved in the data acquisition within the Citizen Science approach of "nützLINK". Currently, the population trends of the target taxa are recorded with a combination of conventional (yellow pan traps, Malaise traps) and new methods where Citizen Scientists can be involved. These methods include the less invasive use of eDNA analyses, the development of artificial flowers as well as a camera trap for the automated monitoring of flower-visiting insects. The concept of this monitoring program and results from the 4-year pilot phase (2020-2023) are presented in this paper.

Emergence traps as a standardized method to monitor ground-nesting bees

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Ground-nesting bees constitute the vast majority of all wild bee species. Although they are the most abundant functional group of wild bees, ground-nesting bees are less studied than cavity nesting bees. The importance of floral resource availability on bees has been studied extensively, whereas findings about their nesting requirements are lacking. For this, a standardized method to monitor ground-nesting bees is needed. Transect walks or pan traps often only record transitory foragers ("food tourists"), but not bees actually nesting. Emergence traps, collecting recently emerged individuals from the ground, could be used as a standardized method to monitor populations, which is missing so far (Antoine & Forrest, 2020). The bees collected with this method can be clearly assigned to a specific nesting site and it can be controlled that collected bees have not immigrated from other nesting sites. Thus, conclusions can be drawn e.g. regarding the quality of the nesting site. Therefore, these traps help gaining a better understanding of the biology and ecology of ground-nesting bee.

In our study, the Grey-Backed Mining-Bee Andrena vaga is used as a model species as it is quite common, easily identifiable and forms large nest aggregations. This allows locating as many nesting sites as possible with the help of Citizen Science. 27 nest aggregations within the city of Braunschweig were selected for this study.

With the help of the emergence traps, the health status of the bees was analysed and compared between the different aggregations. The parasitism rate and the sex ratio were calculated and the body size of the sampled individuals were measured by their intertegular distance. The variables were analysed for correlations with landscape characteristics, aggregation size and nesting site characteristics.

Suitability of eDNA metabarcoding for dragonfly monitoring in quarrying sites

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In the intensively used Central European landscape, quarrying sites are exceptional locations due to their nutrient poverty and extreme environmental conditions. Because of the strong eutrophication and degradation of the (surrounding) landscape these sites are becoming increasingly important as replacement habitats for a wide range of species. Despite the existing knowledge of the considerable potential of quarrying sites for biodiversity, few data are available for the insect diversity of these areas. DNA metabarcoding could provide a low-threshold way to establish cost- and time-efficient monitoring and to assess reliable data for management decisions. This is especially important as existing valuable habitats do not underlie any protection status and their development is largely dependent on the company's willingness to protect and improve them. In the framework of our project GiBBS, which is part of the German Research Initiative for the Conservation of Biodiversity, we therefore aim to identify practicable methods to improve knowledge of biodiversity patterns in quarrying sites and to initiate adapted management based on this knowledge.

The data presented comprise the results from the first year of sampling in which we assessed biodiversity at six quarrying sites of limestone, sand and gravel in northwestern Germany. We investigated dragonfly diversity from small ponds to large scale gravel quarry lakes via the assessment of exuviae in combination with eDNA-metabarcoding of water samples. Based on the large dataset of 100 samples we are able to compare the (dis)advantages of both methods and their suitability to derive reliable data, also with regard to the implementation of an efficient long-term biodiversity monitoring in quarrying sites of the building materials industry.

The potential of multispectral imaging flow cytometry to advance automated environmental monitoring

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Identification and quantification of microscopic cells and particles such as algae, plant cells, pollen or fungal spores are important for environmental monitoring. Traditional methods using conventional microscopy require expert knowledge and are time consuming, which limits the sample throughput and thereby spatial and temporal data resolution. Multispectral imaging flow cytometry (MIFC) enables the measurement of up to 5000 particles per second from a liquid suspension and can simultaneously acquire up to 12 images of each particle for brightfield and different spectral regions at up to 600x magnification. The high throughput of MIFC has great potential for increasing the scope and accuracy of environmental monitoring, such as plant-pollinator interactions, fossil samples, air, water, or food quality, which currently rely on manual microscopic methods. Automatic detection of particles and cells is also possible when MIFC is combined with deep-learning computational techniques. The presentation provides insights to the great potential of MIFC in environmental research for a variety of research areas and focal organisms.

Machine learning to merge images and barcodes for assessing freshwater bioindicators

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The Water Framework Directive (WFD) requires the implementation of monitoring programs to assess the ecological status of aquatic ecosystems. Phytoplankton is an essential bioindicator group for this purpose, but accurate species identification is time consuming and requires expert taxonomic knowledge. We investigate a novel approach to automate phytoplankton species identification using machine learning techniques applied to image and genetic data. Our pipeline combines convolutional neural networks (CNNs) for species identification based on microscopic images with DNA barcodes as an alternative source of information. We hypothesize that the complementary use of genetic data can improve the accuracy of species identification, especially for character-poor taxa. In addition, we will evaluate the largest sources of image and barcode data for phytoplankton indicators by analyzing databases such as GBIF and GenBank. The integration of computer vision and genetic information within an artificial intelligence framework can not only help to explore the current status of phytoplankton bioindicators, but also improve their monitoring under the WFD.

Environmental DNA time series analysis of a temperate stream reveals distinct seasonal community and functional shifts but no influence of within-stream sampling position

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Environmental DNA (eDNA) extracted from water is routinely used in river biodiversity research, and via metabarcoding eDNA can provide comprehensive taxa lists with little effort and cost. However, eDNA-based species detection in streams and rivers may be influenced by sampling season, location, and other key factors such as water temperature and discharge. Research linking these factors and also informing on the potential of eDNA metabarcoding to detect shifts in ecological signatures, such as species phenology and functional feeding groups across seasons, is missing. Therefore, before eDNA metabarcoding can be applied routinely and standardized for biodiversity monitoring of macroinvertebrates, more data is needed. To address this gap, we collected 102 water samples every two weeks for 15 months at a long-term ecological research (LTER) site and at three different positions in the river's cross section, specifically the water surface, riverbed, and riverbank. We analyzed macroinvertebrate species and molecular Operational Taxonomic Unit (OTU) richness and temporal community turnover across seasons and sampling positions based on COI metabarcoding data. Using Generalized Additive Models, we found a significant influence of sampling season but not sampling position on community composition. Community turnover followed a cyclic pattern, reflecting the continuous change of the macroinvertebrate community throughout the year ('seasonal clock'). Although water temperature had no influence on the inferred community composition, higher discharge reduced the number of Annelida and Ephemeroptera species detectable with eDNA. Most macroinvertebrate taxa showed the highest detection rates in spring, in particular merolimnic species with univoltine life cycles. Further, we detected an increase in proportion of shredders in winter and of parasites in summer. Our results show the usefulness of highly resolved eDNA metabarcoding time series data for ecological research in streams and rivers. These findings could aid future research in disentangling variations in community composition due to recent and extreme changes from gradual changes and help deriving guidelines for future eDNA based biodiversity monitoring.

It's raining species: Rainwash eDNA metabarcoding as a minimally invasive method to assess tree canopy invertebrate diversity

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Forest canopies are highly diverse ecosystems, but despite decades of intense research, substantial knowledge gaps of their biodiversity remain. The limited accessibility of these ecosystems is a fundamental challenge. Here, time- and cost-efficient, ideally minimally invasive yet comprehensive applications are required to help close this knowledge gap. A solution could be provided by metabarcoding of environmental DNA (eDNA). This minimally invasive method has been proven as efficient monitoring tool in various ecosystems, yet its potential for canopy monitoring remains unexplored. Thus, we conducted metabarcoding on eDNA collected from rainwater that fell through tree canopies to explore its monitoring potential. We placed four 1 m^2 rain samplers beneath the canopies of four different tree taxa prior to a major rain event, filtered eDNA from the collected rainwater, and performed eDNA metabarcoding to profile the invertebrate community. We detected 50 invertebrate species by eDNA metabarcoding, of which 43 were representing true canopy biodiversity signals. Furthermore, we observed clear species occurrence patterns corresponding to the four tree taxa, suggesting that ecological patterns can be assessed using the method. In conclusion, our study provides a proof of concept that rainwash eDNA metabarcoding offers a minimally invasive and comprehensive method for tree canopy diversity monitoring.

Eight challenges when mapping species diversity for spatial planning and conservation

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This presentation summarizes efforts to develop a national framework for mapping species occurrences and distributions in Norway. It focuses specifically on mapping as part of spatial planning processes and applied conservation efforts. Eight key challenges are identified:

(1) Defining a clear scope for the survey is essential for subsequent decision e.g. on methodology.

(2) Developing a flexible but also robust methodological framework. Applied projects on species mapping often rely heavily on field biologists who use their ecological intuition to search for specific species and habitats. This approach can be hard to fit into a formalized and reproducible framework.

(3) Meta-populations and other spatio-temporal dynamics are difficult to map in short-term project but can still be very important in some species and ecosystems.

(4) Creating transparent and well-documented data. Species mapping for spatial planning and applied conservation can potentially have impact on decisions with large economic and societal consequences. This lends importance to transparency in data management.

(5) Integrating new technology. New technologies such as camera traps, audio sensors, e-DNA, and remote sensing represent a huge potential for efficient mapping and monitoring of species.

(6) Improve the quality of meta-data. To have well-structured, high-quality meta-data is essential when species diversity data are used in spatial planning, decision making and policy design.

(7) Data standardisation is important for findability and reusability of data but can be challenging given the diversity in scope and methods in species mapping project.

(8) Communicate data to users. The emergence of citizen science together and large-scale data infrastructure have had huge impact on the quantity of species occurrence data available. An important challenge is to make the information these data represent available to people involved in spatial planning, conservation and policy design.

Monitoring the distributions and niches of wildlife in a rapidly changing world

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Anthropogenic activities are causing rapid changes to ecosystems worldwide. These altered conditions have the potential to erode the distribution and environmental niches of species in space and time. New sensor and tracking technologies now enable an improved capture and monitoring, and novel data integration approaches support a generalization from fine to large scale assessment and prediction. I will illustrate these opportunities with examples from visual sensors (Wildlife Insights), movement tracking (Biologging Initiative, Animal Lives), and model-supported niche and distribution change assessment (Map of Life), with a particular focus on mobile organisms. I will assess how these approaches individually and in combination can quantify and disentangle aspects of organismal, spatial, and temporal scale.

Biodiversity change across space, time and the tree of life

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Biodiversity and ecosystem function face unprecedented threats from climate change and the 6th Mass Extinction may be underway. Some of the most important signals of this collapse come from time series that document declining biodiversity. Time series describing abundances for suites of species over large geographic and temporal scales are typically used to evidence this decline in biodiversity. Here we show that the precision of these estimates is undermined by widespread failure to accommodate phylogenetic, spatial, and temporal structure in such data. We remedy this with a novel statistical framework, applied to 10 high-profile datasets containing thousands of species, that simultaneously accounts for all three of these features of data. We demonstrate that the simplicity of existing methodologies hides the correct trend: our analysis leads to a reversal of conclusions about declines (or increases) in 7/10 datasets. We also show that existing methods massively underestimate the uncertainty in trends for each subset of biodiversity represented in these datasets. Finally, despite this re-estimation of high uncertainty, our method provides a way to acquire more robust estimates of future biodiversity trends which is critical for developing policy to protect our biosphere.

A concept for monitoring of arable weed diversity in Germany

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Weeds are an important part of the biodiversity in agricultural landscapes. Beside their inert value, weeds maintain and serve as a habitat and food source for higher trophic levels, they support essential ecosystem services such as pollination. For many decades, the weed diversity in European agricultural landscapes is rapidly declining. Still, no consistent data on the status and trend of arable wed diversity in Germany is currently available. Here, we present a national concept for an arable weed monitoring scheme designed to fill this gap. We estimated the necessary number and distribution of fields that need to be sampled (sample size), evaluated and selected the most efficient on-field weed survey method and conceptualized two options for obtaining the required survey fields. To extract the most information from the data obtained through the monitoring scheme, data on the weed presence and abundance in the different crops and regions in Germany should be presented as diversity profiles, which combine different diversity indices and make the results easily comparable to each other. The presented monitoring scheme was developed as part of the MonViA-project ("National Monitoring of Biodiversity in Agricultural Landscapes") and complements other existing plant diversity monitoring programs such as the High Nature Value Farmland (HNV)-monitoring. Once implemented, the monitoring scheme could generate a valuable dataset that allows analyzing the trend of weed diversity in Germany differentiated by crop, region, and cropping system.

Soundscapes and artificial intelligence provide powerful tools to track biodiversity recovery in tropical forests

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Tropical forest recovery is fundamental to addressing the intertwined climate and biodiversity loss crises. While regenerating trees sequester carbon relatively quickly, the pace of biodiversity recovery remains contentious. Here, we use bioacoustics and meta-barcoding to measure forest recovery post-agriculture in a global biodiversity hotspot in Ecuador. We show that the community composition, and not species richness, of vocalizing vertebrates identified by experts reflects the restoration gradient. Two automated measures - a soundscape index model and a bird community derived from a Convolutional Neural Network - correlated well with restoration (adj-R^2 = 0.62 and 0.69, respectively). Both measures also reflected composition of non-vocalizing nocturnal insects identified via meta-barcoding. We show that such automated monitoring tools, combining new technologies, can effectively monitor the success of forest recovery, using robust and reproducible data. Crucially, this will help ensure that forest restoration efforts result in resilient, biodiverse tropical forests and not simply ‘carbon farms’.

Effective population size of chamois (*Rupicapra rupicapra*) populations in two regions of the Bavarian Alps

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Being a fundamental metric in population and conservation genetics, the effective population size (Ne) is widely used for monitoring genetic diversity of various species. However, estimation of Ne is non-trivial in long-lived species with overlapping generations and may be influenced by sampling, e.g., if multiple non-distinguishable cohorts are sampled simultaneously. Here we derived Ne for two intensively studied populations of the iconic mountain dwelling chamois (Rupicapra rupicapra) in the Bavarian Alps. The availability of both fecal samples and tissue samples offered the unique opportunity to compare estimations of effective population size based on different sampling approaches. Fecal samples were collected between 2017 and 2019 as part of a study designed to estimate chamois population size (N) with spatial capture-recapture (SECR) based on genotyping. Simultaneously, tissue samples were collected from legally hunted individuals. Hunted chamois were aged by counting horn annuli allowing the assignment of individuals to cohorts by birth year. This enabled us to also test how the inclusion of samples from different time spans affected the estimation of the genetic effective population size. Furthermore, population size estimation from the spatial capture-recapture study were used to verify Ne estimates and to calculate Ne/N ratios for both study populations. Ne and the Ne/N ratio differed between the two study populations. The differences in the Ne/N ratio hint to differences in demographic parameters. Within each study area, estimates of Ne based on either feces or tissue samples were largely consistent. We thus conclude that estimation of Ne can be a valuable and versatile tool for monitoring genetic diversity in chamois.

Effects of roost temperature on metabolic rate: A field experiment in free ranging Bechstein's bats (*Myotis bechsteinii*)

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Temperature is one of the most important parameters associated with life on earth. Man-made global warming is therefore likely to have far-reaching effects on the physiology of many organisms. A widely observed pattern in endothermic animals is the decrease in body size with increasing temperature, mostly explained by a more efficient dissipation of body heat due to the larger surface area to volume ratio of smaller bodies. Interestingly, in some species the opposite effect, an increase in body size with higher ambient temperatures, has been observed. While such effect usually is linked to a higher food availability in warmer environments, it might also result from metabolic savings during the reproductive and developmental phases. In Bechstein's bats (Myotis bechsteinii), a long-lived mammal of high conservation concern, body size increases with warmer summer temperatures, which in turn has a negative effect on the individual life expectancy and eventually on the population dynamics. In Bechstein's bats it has been shown that the increase in body size is directly affected by temperature rather than indirectly mediated by food availability. While the underlying mechanisms remained unclear, we hypothesise energetic benefits during the rearing period: 1) warm conditions minimise energy costs to remain homoiothermic so that savings can be invested in body growth; 2) warm temperatures reduce the need for torpor, a strategy to save energy in cold weather, but known to impair the physical development of the juveniles. To test these hypotheses, we compare field metabolic rates between control and artificially heated day roosts of a wild maternity colony. By revealing the underlying mechanisms of the temperature-body size relationship, our results will help to understand how Bechstein's bats respond to climate change and eventually to assess if and how populations can persist in a warming world.

Drones as a novel technique to monitor the endangered Galapagos Marine Iguana

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The marine iguana (Amblyrhynchus cristatus) is an endemic species of the Galápagos Archipelago. The IUCN Red List of Threatened Species classifies it as vulnerable to extinction due to increasing threats, principally: invasive species, pollution, climate change, and urbanization. The marine iguana is an iconic well-studied species; however, a reliable complete population size estimate is not available, mainly because monitoring it with traditional methods (ground-based surveys) is logistically difficult, dangerous, and impossible for some colonies. Technological advances in recent years have allowed drones to emerge as an efficient and safe alternative to monitoring wild populations, especially for threatened species that occur in inaccessible habitats. We tested the use of drones for marine iguana monitoring by undertaking aerial surveys and compared the outcome to traditional ground-based surveys, performed in parallel. We studied four colonies, representing four subspecies, on three main islands. Aerial surveys involved drones flown mainly from boats, and ground-based methods were capture mark-resight (CMR) and visual simple counts. As expected, the highest abundances were obtained with CMR, as this is a two-day survey that accounts for imperfect detection probability. However, drones registered higher abundance (17-35%) on all sites when compared to visual simple counts (similar surveying methods, the second being the most commonly used by wildlife managers), evidencing better outcomes with less effort and lower risk to surveyors and the environment. To reduce the workload of data analysis, we are currently testing citizen science as a potential approach to crowd-source counting of marine iguanas in aerial photographs. In addition, we are working together with local wildlife managers in the Galapagos to develop and implement the new method for future standardized monitoring efforts to improve conservation management of marine iguanas.

Monitoring of cheetah (*Acinonyx jubatus*) using scat detection dogs in northern Kenya

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The cheetah (Acinonyx jubatus) is one of Africa's wide-ranging carnivores whose current global population is declining, mainly due to habitat loss and degradation. Kenya holds one of the largest cheetah populations in Eastern Africa. However, there is limited information on the cheetah populations in most of their resident distributions. Ecological monitoring of cheetah using conventional methods, such as direct observations is difficult because of their elusive behaviour and occurrence in low population densities both inside and outside of protected areas. Scat detection dogs are increasingly used in conservation to monitor transient and rare species due to the dogs' superior olfactory system. This study gives an insight on the use of scat detection dogs as non-invasive method of monitoring cheetahs in the Samburu and Isiolo ecosystem in northern Kenya. This area lies in the greater Laikipia-Samburu-Isiolo ecosystem and forms one of the four important cheetah populations in the larger Eastern Africa region. Little is known about the cheetah population in this ecosystem. Our study highlights how locally trained wildlife detection dogs were used to locate wild cheetah biological samples (faeces and hair) required for subsequent population genetic studies as well as in modeling species distribution. It illustrates how we optimized detection dog surveys using three different search strategies. As the study area is located in a characteristically hot and dry region in the northern Kenyan rangelands, our study elaborates the best weather conditions which improve the performance of the dogs in locating wild cheetah scat and explains how the body condition of scat dogs working in hot environments are affected on a on a short- (within hours) and long-term basis (12-24 h).

Use of conservation dog teams in railway infrastructure: 1 year of operation in DB Netz AG construction projects

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Construction projects often require the survey of strictly protected species. By default, animal surveys are conducted using visual and acoustic methods supported by technical tools. However, visual observations are limited in terms of season, time of day, weather conditions and ecology of target species. By deploying conservation detection dogs in teams with qualified mappers, the survey and species spectrum can be meaningfully complemented or expanded. In October 2020, the German railway infrastructure company DB Netz AG established a conservation detection dog unit to support species surveys being deployed since July 2022. The mappers qualification in ecology of target species, survey methods, canidology, detection dog training and operational skills are examined and evaluated by internal and external experts to provide reliable results. The target species for the detection dogs are sand lizards (Lacerta agilis), common wall lizards (Podarcis muralis), and smooth snakes (Coronella austriaca) in the reptile class, yellow-bellied toads (Bombina variegata) in the amphibian species group, all native bat species of the suborder Microchiroptera and the hazel dormouse (Muscardinus avellanarius) in the mammal class. Main objective is the validation of presence or absence of target species by the detection dog team on site. Currently, the results of the first year of detection dog team deployments are being evaluated. All data including environmental conditions are digitally processed and consolidated in the newly established "Kompetenzzentrum Artenkartierung" of DB Netz AG. First analyses show promising results for detection dog teams applied on surveying strictly protected and elusive species within constructional procedures.

Multiple taxa call for multiple measures: Multi-trophic biodiversity monitoring in Berchtesgaden National Park

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Global warming is changing natural dynamics – and with them, ecosystems and species communities. This may impair conservation and management targets with cascading effects throughout the trophic network. However, distinguishing climate-induced ecosystem changes from those caused by natural ecosystem dynamics remains a challenge and requires consistent, informative long-term data.

Berchtesgaden National Park established a biodiversity survey and monitoring scheme in 2021, pairing a space-for-time based biodiversity inventory with standardized long-term monitoring. We focus on the park's major habitats and elevation zones (600-2,250 m a.s.l.) to study the effects of climate, land cover, and natural succession on biodiversity. We compile biotic and abiotic data at the local to landscape level using field survey methods and remote sensing. Species identification combines classic morphological, metabarcoding, and AI-based approaches. Our data cover all trophic levels to reveal diverging responses between groups of taxa, which may result in novel species interactions.

In the first two survey years, we recorded 629 vascular plant, 117 vertebrate (Reptilia, Amphibia, Mammalia, Aves), and >1,400 invertebrate (Myriapoda, Heteroptera, Lepidoptera, Formicidae, and Coleoptera) species as well as >11,040 BINs of flying insects, >14,000 OTUs of soil bacteria, and >2,800 OTUs of soil fungi. To date, studies have used the data to look into biodiversity patterns over the course of forest succession, temperature buffering in different forest habitats, and projected plant thermophilization.

While modelling and space-for-time based approaches dominate current data analyses, yearly surveys will allow us to study temporal trends in community composition and ecosystem dynamics. The comprehensive baseline dataset and transition from space-for-time to time-series data will enhance our understanding of ecosystem responses to climate change and support biodiversity conservation efforts.

Achieving a real-time online monitoring system for conservation culturomics

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Environmental monitoring is increasingly shifting towards a set of systems that describe changes in real-time. In ecology specifically, a series of challenges have prevented the roll-out of real-time monitoring for features such as biodiversity change or ecosystem service provision. Conservation culturomics, a field concerned with interactions between people and nature, is well-placed to demonstrate how monitoring might move towards a network of real-time platforms, given its existence exclusively in the digital realm. Here we describe a set of considerations associated with the development of real-time monitoring platforms for conservation culturomics. We then introduce a near real-time platform for the Species Awareness Index, a global index of changing biodiversity awareness derived from the rate of change in page views for species on Wikipedia. This platform will update automatically each month, operating in near real-time (hosted here: https://joemillard.shinyapps.io/Real_time_SAI/), with plans to make the underlying data queryable via an API independent of the platform. The real-time Species Awareness Index will represent the first real-time and entirely automated conservation culturomic platform, and one of the first real-time platforms within the discipline of ecology. We conclude by envisioning a future for real-time monitoring, presenting a general framework for real-time monitoring in ecology, and calling for an online real-time observatory that can evolve with the structure of the web.

Successional development of vegetation on glacier forefields of the Northern Limestone Alps

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Glacier have retreated since the maximum of the "little ice age" around c. 1850. The resulting barren forefields provide the opportunity to observe the development of an emerging ecosystem from its beginning to better understand successional mechanisms and community assembly. While previous studies focused on the Central Alps, little is known about the vegetation dynamics of the forefields in the Northern Limestone Alps.

Using a chronosequence approach (i.e. age classes corresponding to time since glaciation), forefield vegetation are sampled at four glacier forefields in the Dachstein range and Berchtesgaden Alps. Across 52 permanent 1m²-plots frequency, total cover and the abundance of each species are recorded. Community-weighted means will be calculated using trait database entries and field trait records. Abiotic surveys and soil sampling will be conducted, and additional remote sensing data will be used to derive important environmental parameters.

First results show species number differed among the glacier forefields, with the lowest species richness in the Watzmann cirque, followed by Blaueis and the highest in the forefields of Great Gosau and Hallstätter Glacier. With an increase in age species number and cover per plot increase across all study areas. Most frequent species were *Hornungia alpina* and *Poa alpina*. Ordination and indicator analysis showed changes of composition along the chronosequence, with pioneer species such as *Cerastium uniflorum* in the younger plots, *Papaver alpinum* ssp. *sendtneri* in middle-aged plots, and *Carex firma* in the oldest plots.

Further analyses will identify plant traits associated with successional stages to gain a better understanding of the colonization and succession process, and the underlying filtering processes.

Optimized metabarcoding for automated monitoring within AMMOD stations

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With the continuous decline in biodiversity, it is important to develop high-quality techniques to monitor plant and plant-insect interaction networks over space and time using effective high-throughput methods. In this respect, the use of metabarcoding in some aspects outperforms conventional methods for detecting and quantifying plant-insect interactions by being rapid, relatively inexpensive, its potential for automation, and its ability for continual monitoring. Here we present the optimization of plant trace monitoring within the AMMOD stations via metabarcoding. The focus is on the identification of plant traces from the air (wind pollen trap) and in the ethanol of malaise traps entered by insects. A new wind pollen trap was developed that allows autonomous operations in the field over a longer period of time with different sampling intervals. Furthermore a malaise trap metabarcoding plant detection pipeline was developed. Recommendations for high quality laboratory processing of pollen caught in airborne flight as well as malaise trap plant debris are made and an optimized data analysis workflow is described. With the methodology developed here, plant-insect interactions and airborne pollen can be monitored in high-throughput methods with unprecedented accuracy. However, these methods need to be further developed as they still depend on the laboratory environment. Technical developments that offer new perspectives are addressed and discussed.

Monitoring Rewilding with eDNA metabarcoding

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Rewilding is an innovative approach to enhancing biodiversity by (re)establishing ecological processes. Monitoring changes in mammal communities is a key indicator for measuring the effectiveness of rewilding. However, traditional monitoring methods, such as camera trapping, can be time-consuming and expensive. Environmental DNA (eDNA) metabarcoding is a novel molecular technique that offers in several occasions a faster and more cost-effective approach to biodiversity monitoring. In this study, I assessed the efficacy of using eDNA metabarcoding for biodiversity monitoring in the Oder Delta, the only rewilding site in Germany. I collected water and soil samples from the same locations where we installed camera traps and compared the species lists obtained by both methods. To optimize the pipeline for eDNA metabarcoding, I have also collected samples from the enclosures of different mammals at the Leipzig Zoo and Wildpark. In the laboratory, I checked the effectiveness of the pipeline and controlled for possible contaminations. Our findings provide valuable insights into the potential of eDNA metabarcoding for biodiversity monitoring in rewilding sites.

Wild-bee trend monitoring in agricultural landscapes: Spatial design from the national to the local scale

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Monitoring data on wild bees are still lacking in Germany, despite their ecological and economic importance. Decision-makers have realised the need of large-scale monitoring programmes for wild bees to better understand how populations respond to land-use change and other pressures in the long term, and to enhance land management with regard to pollination services. Our aims are (i) to achieve a representative sample for a wild bee trend monitoring across the agricultural landscapes of Germany, and (ii) to develop algorithms for spatially designing the sampling sites.

The wild-bee trend monitoring in agricultural landscapes of Germany currently includes two survey modules for cavity-nesting wild bees and bumblebees realised in citizen-science approach. Based on the requirements of these population-friendly survey methods and envisaged statistical analyses including landscape effects on wild bee species abundances and diversity, 3x3 km² landscape quadrats for cavity-nesting wild bees and 1x1 km² quadrats for bumblebees are defined as spatial sampling units oriented towards the European LUCAS grid. The target sample size for a nationwide trend monitoring is estimated based on power analyses. In a systematic random sampling approach, 950 landscape quadrats throughout the agricultural landscape of Germany are established as potential monitoring areas, where both monitoring modules are run simultaneously. The local spatial design of monitoring surveys is realised in a semi-automated procedure, using algorithms based on landscape data and the feedback of volunteers from the field sites.

Wild bee monitoring in agricultural landscapes – An integrative approach for genetic diversity monitoring

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Wild bees are essential for functioning agro-ecosystems. Yet, they face dramatic population declines caused by factors such as land-use change amongst others. The increased awareness for the importance of wild bees among policy-makers and the general public, together with a lack of robust data on wild bee populations has led to the development and partial implementation of a nation-wide wild bee monitoring in agricultural landscapes in Germany. This monitoring scheme is designed in a modular fashion with some of which focus on cavity-nesting bees and bumble bees. It combines citizen science approaches with non-lethal and innovative detection methods, such as eDNA-based species detections, as well as educational opportunities and expert-based species detections. Species occurrence data, along with various other indicators, are co-analysed with landscape diversity indicators to assess pattern and drivers of changes in wild bee communities.

In order to include the third level of biodiversity, methods and indicators covering genetic diversity are being tested to be included in the monitoring scheme in the long term. These include phylogenetic diversity (Faith's PD) based on eDNA analysis of cavity-nesting bee communities. This may be expanded to include intra-specific diversity based on amplicon sequence variants (ASVs) determined from the metabarcoding approach. For bumble bees, single nucleotide polymorphisms (SNPs) are being analysed from non-lethally collected samples to assess genetic diversity (Π, He, Ho, Ne) on a population scale. This approach can be expanded to other wild bee species.

Our proposed novel approach incorporates genetic diversity assessments into the overall monitoring scheme and thereby covers the remaining, least considered, aspect of biodiversity. Thus, it will hopefully serve as inspiration for researchers and policy-makers to incorporate long-term monitoring of genetic diversity in other programmes as well.

InsectMobil: Impacts of landscape on insect diversity and composition through the use of citizen science and DNA metabarcoding

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Urbanization and agricultural practices account for some of the most drastic modifications to natural habitats as a result of anthropogenic land cover change. The relative importance of different land covers for shaping insect communities, however, remains unclear.

In this study, we combine large spatial scale sampling by using citizen scientists car net data collection (nets installed on vehicle roofs) and DNA metabarcoding to investigate the effect of landscape patterns of insect community composition and richness along with land cover heterogeneity. During June and July in 2018 & 2019 volunteers collected 334 car net samples on 67 roads in 7 federal states of Germany. To estimate taxonomic composition of insect bulk samples, DNA metabarcoding protocols were used, and the results compared to known data on flying insect richness and occurrence. The richness and diversity of flying insects were examined across main land cover types.

Our results indicate a strong negative association of urban cover on insect populations, implying that urbanization may contribute as a main driver to insect decreases. As a consequence, conserving and extending protected natural and semi-natural habitats should be the primary priority for temperate insect diversity conservation.

By conducting a simple, standardized citizen science initiative, we managed to sample flying insects at a broad geographical scale within one month, with a response rate of more than 86% of samples returned. Therefore, car net sampling with citizen scientists can serve as a promising approach for tracking flying insects at a landscape scale.

Spatial arrangement of flower strips has little impact on population genomic parameters of three wild bee species

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The number of insect pollinators, such as wild bees, is declining worldwide. One of the main reasons is the intensification of land use. To reverse the negative trend, agri-environmental measures such as flower strips have been implemented in the EU's Common Agricultural Policy. Beyond providing food and nest resources, it is assumed that flower strips also function as biological corridors to foster gene flow among isolated (sub)populations. Here, we investigated whether i) single legs from individual wild bees provide sufficient amount of DNA for genomic analyses and ii) spatial arrangement of flower strips effects population structure in wild bees.

We collected single legs from two eusocial bumble bee species (*Bombus lapidarius* and *B. pascuorum*) and one solitary ground-nesting bee species (*Dasypoda hirtipes*) that differ in sociality, foraging distance and food plants. In total, we sampled from twenty-two sites (14 perennial flower strips and 8 control sites) dominated by agricultural landscapes and scattered across Saxony Anhalt, Germany. Isolated DNA was processed in a RAD-seq approach and single nucleotide polymorphisms (SNPs) were detected. From the SNP analysis, we derived measures of genetic variation (Π, Hexp, FIS, FST), population structure and landscape genomics (IBD, IBR).

We found that single legs provided sufficient quantity and quality of DNA for genomic species validation using COI sequencing and fine-scale genomic population analysis using RAD-seq. Beyond that, spatial flower strip arrangement showed no consistent effect on population genetic parameters. However, the described approach is suited for measuring and monitoring genetic diversity in key pollinators and can in contrast to species diversity and abundances indicate timely changes at population level.

Soil biodiversity in protected, near-natural forests – a Biodiversa+ pilot study to pave the way for a European monitoring scheme

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Soil biodiversity is immense and includes a large (taxonomic) diversity of organisms, many of which are still unknown. The main limitation in the study of soil organisms is their physical inaccessibility, combined with a lack of taxonomic knowledge, due in part to the complex spatial structure of the soil matrix. Thus, soil biodiversity is poorly understood despite its central role in many essential soil processes such as nutrient cycling and carbon sequestration. There is an immense need for more data on soil biodiversity, particularly covering all taxa from microbes to invertebrates, which is currently largely lacking. Equally important is the establishment of standardised methods in Europe and beyond. In this respect, this pilot study of the Biodiversa+ network represents an important step towards a unified European (or even global) soil monitoring system. With partners across Europe, covering many different biogeographical regions, we are collecting samples for traditional morphological identification of macro-invertebrates and for eDNA analysis. In this talk we will present the opportunities, challenges and drawbacks of such large-scale monitoring.

APSCALE and TaxonTableTools: A comprehensive, platform-independent workflow with graphical user interfaces for processing, analyzing, and visualizing DNA metabarcoding data

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DNA metabarcoding is an emerging method to assess and monitor biodiversity worldwide and consequently the number and size of data sets increases exponentially. However, the conversion of sequence read data into meaningful biological information and the subsequent downstream analyses can be challenging for users with limited bioinformatics expertise. To address this issue, we introduce two platform-independent programs, APSCALE and TaxonTableTools, which together offer a comprehensive DNA metabarcoding workflow, encompassing raw data processing, ecological data analysis, and visualization. Currently, there is a lack of published DNA metabarcoding data processing pipelines that meet four essential criteria: (i) platform independence, (ii) user-friendliness including a graphical user interface (GUI), (iii) scalability to handle large datasets efficiently, and (iv) compliance with data protection regulations, particularly relevant for environmental agencies. APSCALE addresses these requirements and facilitates taxonomic assignment of sequences against diverse local databases. It is available in both command-line and GUI versions, ensuring flexibility and ease of use. Complementing APSCALE, TaxonTableTools (TTT) offers a GUI-based software solution for downstream analysis and visualization of DNA metabarcoding data. TTT incorporates various modules that support reproducible analyses, including preprocessing steps such as negative controls and replicate consistency filtering. Initially, TTT enables the user to further process and curate their data. Moreover, TTT provides specialized modules for exploring DNA metabarcoding-specific parameters (e.g., sequencing depth) and offers a wide range of analyses commonly employed in traditional ecological studies, such as alpha diversity and ordination analyses.

Landscape and habitat heterogeneity: key drivers of mountain bird communities in the Alps

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The Alpine landscape has undergone significant transformation over millions of years due to both abiotic and biotic processes, as well as human activities in recent millennia. This European Mountain region is a vital habitat for numerous endemic species adapted to extreme environments, making it an important biodiversity hotspot. However, human activities have led to significant biodiversity loss, especially in mountainous areas, necessitating research into the main drivers of this loss.

Birds are an essential component of most ecosystems, and their sensitivity to environmental changes makes them a valuable bioindicator for ecological studies. Understanding the effects of environmental changes on bird communities is crucial to identify distributional factors and potential impacts of global changes, which can inform the development of effective conservation strategies.

The Biodiversity Monitoring South Tyrol project has conducted research on bird communities in South Tyrol, examining the effects of landscape and habitat heterogeneity on bird populations. Using topographic and climatic variables, landscape composition, configuration, and heterogeneity metrics, both in the field and remotely, we investigated the main patterns driving the taxonomic and functional diversity of mountain bird communities. The results of this research indicate that habitat heterogeneity plays a crucial role in shaping rich and diverse bird communities.

To mitigate the impacts of land-use change on birds in the Alps, promoting a complex landscape structure with near-natural elements and a mosaic of different land-use/land-cover types is crucial. This approach can preserve heterogeneity in cultivated areas and the continuity of forests while promoting the conservation of extensive grasslands and wetlands. These habitats are fundamental for bird conservation and should be prioritized in conservation efforts.

Investigating Limiting Habitat Factors of Natterjack Toads in Lignite Mining Areas

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Large-scaled open cast mines function as important refuges for pioneer species that lost primary habitats such as flood plains. The strongly declining Natterjack toad (*Epidalea calamita*) is a prime example of this guild, as it is restricted to (post) mining sites in large parts of its central European range. We study habitat functions that are linked to demographic key factors for Natterjack toad population stability to inform and optimize habitat management in recultivated mines. These factors include (i) the desiccation risk of temporal spawning ponds, (ii) the survival of juvenile and subadult toads as well as (iii) functional connectivity.

The ongoing project is based in two active coal mines in the Central German Mining District south of Leipzig. Here, we survey pond occupancy along with desiccation events and limiting biotic and abiotic habitat characteristics. Further, we record the abundance of juvenile toads and the microclimate in different terrestrial microhabitats with repeated and standardized surveys. Lastly, we study the individual space use using mark-recapture (local scale) and the functional connectivity between different breeding sites (landscape scale) using microsatellites.

Effect of small scaled habitat characteristics were obscured by strong differences in precipitation in the first two out of three project years (2021 - 2023). Still, we found pond size and depth to be linked to early desiccation risk non-regard yearly precipitation. Spawn mortality due to high water acidity was another limiting factor in ponds. Juvenile and subadult toads avoided densely vegetated microhabitats, indicating that stepping stone habitat management must seek for low vegetation cover to direct dispersal. Marked toads showed a high site fidelity, as only 14 out of 166 recaptured toads dislocated between captures and recaptures. Nevertheless, genetic cluster analysis indicated high functional connectivity between different breeding areas within the mines.

Climate influences the spatio-temporal variation of bird functional diversity in a global biodiversity hotspot

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The Wadden Sea is considered one of the most important hotspots for bird biodiversity along the East Atlantic Flyway. Its migrating and breeding populations have been the subject of ornithological research for decades and are, among other factors, the basis for determining the status of the Wadden Sea National Parks and the World Heritage Site. So far, studies on the spatial variation and temporal fluctuations of bird populations in the Wadden Sea have mainly focused on organismal and abundance-based analyses. However, the use of trait-based functional diversity (FD) could provide a stronger link between the ecological functions of species and the environmental factors that influence an ecosystem, thus providing important information for conservation.

In our study, we use abundance data of breeding and migrating birds of the East Frisian Islands from 1996 to 2021 and link them to a matrix of species-specific functional traits to derive different aspects of FD. Using null models based on the observed changing structure of species abundance, we calculate the potential range of FD measures to estimate the impact of environmental changes such as climate change on FD.

Our results show that FD varies between breeding and migrating birds and between islands over time. We found that abundance-based diversity measures such as the Shannon index are increasing through time, which affects FD. Measured values are in the lower range of potential FD and are significantly linked to trends in climate variables (air temperature, precipitation and wind speed). For example, increasing air temperature influences an increase in Functional Dispersion. Given the observed links between the strong differences in temporal dynamics of FD across the East Frisian Islands and their different degrees of environmental change, we conclude that investigations of FD can provide new information on the climatic drivers of assemblage-level changes in species abundances.

SESSION 49:

Automated Monitoring Methods and Challenges

From specimens to conservation: Predicting species Red List status based on publicly available occurrence records

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The IUCN Red List of threatened species (RL) is the most comprehensive global quantification of extinction risk, and widely used in ecological research and applied conservation. Yet, due to the time-consuming assessment process, the RL is taxonomically and geographically biased, in particular towards the global North and vertebrate taxa, seriously tilting conservation efforts towards these regions and taxa. One promising approach to overcome biases in the global RL and to speed up RL assessments is the AI-based prediction of extinction risk, based on the combination of information from digitized collection specimens and citizen science data with remote sensing information on the environment. Here, I present IUCNN, an approach using deep learning models to predict species RL status from publicly available geographic occurrence records (and other trait data if available) and environmental information. I show that IUCNN and comparable AI methods can reach accuracies up to 95% in identifying threatened species. Furthermore, I use the results from two recently published case studies-on the orchid family and the biota of Madagascar-to illustrate the advantages and caveats on using AI and collection specimen to predict species extinction risk, including: reduced assessment time (seconds v. day per species), quantification of uncertainty, and unclear predictor importance.

The potential of AI and camera trapping for predicting spatiotemporal patterns of humans and wildlife

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As human activities in natural areas increase, understanding human-wildlife interactions is crucial. Big data approaches, like large-scale camera trapping studies, are becoming more relevant for studying these interactions. In addition, open-source object detection models are rapidly improving and have great potential to enhance the image processing of camera trap data of human and wildlife activities. This large-scale and long-term database further enables to model and predict spatiotemporal patterns of human activities in natural areas. Hence, we evaluate the performance of an open-source object detection model in a cross-regional visitor and wildlife monitoring using camera traps. Since the accuracy of the detection model was very high with 96.0% accuracy for animals, 93.8% for persons and 99.3% for vehicles and similarly the detection model can be readily used to count objects on images, this approach is suitable for ecological analysis of spatiotemporal patterns of humans and wildlife. Besides the great acceleration in processing speed, the model is also suitable for long-term monitoring and allows reproducibility in scientific studies while complying with privacy regulations. Therefore, we used the data of a long-term visitor monitoring with camera traps and visitor counters and multiple spatiotemporal predictors to model and predict visitor flows along a trail network in space and time. The most parsimonious model was able to identify spatial and temporal hotspots of human recreational activities and predict numbers of visitors in space and time. With this, the assessment of human-nature interactions in natural systems is substantially enhanced and enables the adaptation of management measures to reduce social and ecological conflicts.

Combined Extraction of Plant Species Abundances and Plant Phenology from Images using Convolutional Neural Networks

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Plant community composition and phenology are strong indicators of environmental conditions and are frequently used to capture environmental change. Typically, community composition regarding plant cover and the plants' phenology are estimated manually in the field, which is laborious, subjective, and prone to human error. Especially due to the large amount of work necessary for many investigated plots, manual data collection can only be done in rather large intervals, making it difficult to extract detailed information on changes in phenology and enabling only a temporally coarse data analysis.

Nowadays, it is possible to collect images of vegetation plots in high frequencies with automated camera systems that require little human intervention over long periods. We present an automatic system based on Convolutional Neural Networks (CNNs) that can extract information about the plant communities in terms of plant cover, as well as phenological stages such as flowering and senescence of detected species from automatically collected images. Here, we focus on grassland plots containing herbaceous species. This system enables the extraction of high-quality research data in a high temporal resolution, with which temporally fine-grained environmental studies are possible.

The final system will be made available to plant ecologists as an open-access application where users can upload images. The system will return the requested plant abundance and phenology data. The system is developed in interdisciplinary cooperation between biologists and computer scientists.

Exploring the potential of UAV for plant biodiversity monitoring in farmland

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Intensification of agriculture with high fertilization rates is causing the decline of wild arable herbs, which in turn has cascading negative ecological impacts. One way to promote the conservation of arable wild herbs can be result-based payment schemes that reward farmers based on observed biodiversity outcomes in their fields. One of the biggest challenges for these schemes are the costs and time needed for monitoring biodiversity, which is usually realized by evaluators in the field. This is one of the main reasons why such schemes are currently rarely implemented in the EU Common Agricultural Policy. Satellite and UAV remote sensing have already shown promising results for biodiversity monitoring in different ecosystems. In farmland, biodiversity monitoring is particularly challenging due to the small size of the plants and their partly overlapping spectral signatures. However, the combination of multiple UAV sensors started to show opportunities in this research area. Using the latest advances in deep learning, in this study we investigate the potential of UAVs for plant biodiversity monitoring on agricultural land. We focus on a farmland area in the UNESCO biosphere reserve "Upper Lusatian Heath and Pond Landscape" in Saxony, Germany, and evaluate the usage of different UAV sensors to disentangle the plant species of interest. The presentation will focus on opportunities and challenges in monitoring farmland biodiversity via UAV with particular emphasis on the following points: i) wild arable herbs for which training data can easily be developed from RGB images, ii) sensor and flight height maximizing the classification accuracy, iii) difficult to map wild arable herbs, and iv) potential for result-based payment schemes for other plant species that were not observed in the study area, but are of interest for the implementation of such schemes in Germany.

Using passive acoustic monitoring to investigate the effects of landscape structure and land-use intensity on bird and bat activity in agricultural landscapes of central Germany

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Agricultural intensification and habitat fragmentation have had detrimental effects on a wide range of taxa of agricultural landscapes in Germany and central Europe, among them bats and birds. The presence of semi-natural habitats (e.g. linear elements and isolated trees) in agricultural landscapes is known to positively affect bird and bat species, but so far, very few landscape-scale comparative analyses investigate their effect depending on the agricultural land-use intensity of the surrounding landscape. With novel monitoring techniques and artificial intelligence (AI) assisted species classification, landscape ecological research has unlocked new directions in the monitoring of biodiversity at larger scales, over longer periods of time and at multiple locations at once.

Against this backdrop, we conducted passive acoustic monitoring (PAM) field surveys in agricultural landscapes of differing land-use intensity in central Germany. Autonomous recording units (AudioMoths) were placed at isolated and linear semi-natural elements recording birdsong and bat calls. Subsequently, we identified the present species with the help of the AI-based classifiers BirdNET Analyzer and BatDetect2. Here, we present our methodological approach as well as preliminary results focusing on the effects of landscape structure (i.e. type and density of semi-natural elements) and agricultural land-use intensity (i.e. proportion of arable land) on presence, vocal activity, abundance and taxonomic diversity of bats and birds. We discuss if and how the influence of semi-natural elements on these endpoints is moderated by the agricultural land use of the surrounding landscape. By exploring the usefulness of PAM and AI-assisted species identification tools for landscape ecological studies, we highlight the benefits and drawbacks of these approaches.

A long-term passive ecoacoustic network for monitoring Hessian birds

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Passive ecoacoustic monitoring is a modern and non-invasive method to detect audible species that has gained popularity in recent years due to advancements in recording technology and AI tools for automatic sound recognition. However, implementing this technique into monitoring schemes has been challenging due to various factors, such as limited runtime, storage capacity, and a lack of remote servicing capabilities. These limitations can hinder long-term biodiversity monitoring, which requires continuous data collection over extended periods. To overcome these challenges, we have equipped 15 stations from the Hessian air monitoring network with custom-made audio recorders to monitor the vocal activity of birds in urban, open, and forested habitats. Our recorders are set to record the first ten minutes of an hour, ensuring a continuous data record across a nine-month trial period. We use mobile data plans to send recorded audio and device status data to cloud servers for automated downstream analysis, while also enabling remote access to the devices for service and potential intervention measures. We will present the current state of our project, including the functionality of our recorders and the outcomes of our automated bird identification efforts. We will also discuss the challenges and potential pitfalls of building reliable automated long-term ecoacoustic monitoring networks, including issues related to data storage and processing, hardware maintenance, and the personal labor needed to set up and operate the network.

Enhancing bird surveys: Evaluating acoustic monitoring and BirdNET for assessing urban bird diversity

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As cities continue to grow and further contribute to biodiversity decline, it has become more important than ever to rethink the way we approach green infrastructure in urban areas. To design effective, multifunctional urban green spaces that support biodiversity, we first need to understand how local features contribute to biodiversity through surveying local biodiversity. We then need to implement monitoring schemes to ensure newly designed green infrastructure is meeting the intended goals. However, traditional methods for surveying biodiversity can be time-consuming, expensive, and prone to bias. To overcome some of these limitations, ecologists have been ever increasingly implementing technical solutions like passive acoustic monitoring and automated species identification. Recent advances in machine learning have made species classification algorithms more accessible. However, questions remain about the quality of the results these algorithms produce under different conditions. Here we test BirdNET (Cornell Labs), a publicly available deep neural network for classifying bird calls in acoustic recordings. We compare BirdNET to expert identification in an urban acoustic dataset and present results from two case studies using data from different environments. Finally, we show how passive acoustic monitoring and BirdNET and can be used to understand the relationship between local greenness (NDVI) and bird species richness at a city scale.

Identification of digital herbarium sheets containing specimens with intact leaves and a measurable scale

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The massive amount of freely accessible, high-quality digital herbarium specimen images provides a wealth of data, but manual processing, extracting and analysis of these images to gain the information needed to answer research questions is prohibitively expensive. Here, artificial intelligence (AI) offers a promising opportunity to take advantage of the wealth of these digital images. However, many of the sheets that were digitized contain specimens in less than ideal conditions, e.g. sporting damaged or overlapping leaves or lacking a measurable scale. In order to avoid cluttering machine-learning approaches with unsuitable input data, images should be prefiltered. In the work presented here, we have developed an AI approach to automatically identify images suited as input for machine-learning methods.

We have used the labelled data of 11,604 images from Kommineni et al. 2021 to develop a deep-learning model to classify the images into 1) 'images with intact leaves and measurable scale' and 2) all remaining images. The percentages of 'images with intact leaves and measurable scale' and 'all remaining images' are 66 and 34, respectively. Here we present the model, which achieved an accuracy score of 0.89. However, the false positive rate of 7% is problematic, as these low-quality images will enter into the segmentation process, causing potentially erroneous results. Still, overall, we conclude that this model enables efficient exclusion of images that do not contain intact leaves and measurable scale for usage in segmentation and data extraction tasks. On the other hand, this exclusion will 1) reduces the input that the downstream deep learning pipeline processes and 2) provide high-quality input to the downstream deep learning pipeline which also generates high-quality outcome.

Using AI-enabled camera traps to study responses of insect communities to land use at high resolution

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Insects and grasslands are intensively studied ecological models because of their high diversity, sensitivity to environmental forcing, and importance for multiple ecosystem functions and services. Substantial insect abundance and diversity decreases have been documented, and land-use intensification has been identified as one of the most critical drivers of global species loss. Intensification of grassland management reduces the abundance and diversity of arthropods, but effects vary depending on the land-use component and group of arthropods studied. A mechanistic understanding of this variability is hindered by the coarse spatial and temporal resolution of insect monitoring imposed by resource constraints because of the labour intensity of established monitoring methods. To further our understanding of land-use effects on insect communities, we propose to develop and use digital monitoring systems based on photographs collected by insect camera traps and AI-enabled image recognition to collect data at very high temporal resolution in the grassland plots of the three regions of the Biodiversity Exploratories before, during, and after different land-management activities. Using this data, we will be able to investigate how land-use activities affect the dynamics and stability of the insect communities by quantifying the reference state, disturbance effects, and recovery phases directly. We will differentiate between demographic and (re)colonization processes in response to disturbances by land use, exploiting that demographic and behavioural processes operate at different time scales, for example, recolonization being much faster than reproduction. Ultimately, this project will advance the technology available for insect monitoring and the mechanistic understanding of the effects of land use on insect communities. Here we present the current state of the insect camera trap and the development of the AI algorithm for species identification.

Video-based monitoring of flower visitors on weed vegetation in organic farming

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The challenge of implementing biodiversity conservation in agriculture is becoming increasingly relevant as it is recognised as basis for functionality and resilience of agricultural systems. Current research seeks to address this challenge through the development of highly precise and AI supported technologies such as weeding robots. However, these technologies may fail to meet their ecological potential without coordinated focus on the interactions between different weed species and their associated biodiversity. In this study, different weed species were investigated in terms of their associated biodiversity in form of flower visitation rates. As visual insect observations in the field are labour intensive, we tested a camera supported method that a) enables a single person to take multiple observation videos at the same time and b) generates suitable video material for later analysis. The tested method succeeded in generating data that allowed manual post-hoc analysis and determination of flower visitation rates, while an automated video analysis is still pending. In total, 105 hours of video material were generated at four different organically farmed sites in North Rhine-Westphalia, Germany. 182 flower visitors were recorded. With 0.99 visitations per 15 minutes, the weed species *Matricaria chamomilla* showed the highest visitation rate. However, a higher sample size would have been required to detect significant differences in visitation rates between weed species. Further research is needed to address the lack of knowledge regarding associated biodiversity of weeds to exploit species-specific differences in decision-making of weeding robots to either remove or retain certain weeds in the field.

An automated pipeline for assessing leaf-associated interactions and leaf traits

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Phytophagous insects are closely associated with morphological and metabolic traits of tree species. For the pedunculate oak (*Quercus robur*) alone, at least 700 species of phytophages are known to affect the health and development of the leaves and, in some cases, can lead to severe leaf loss and tree death.

However, due to the lack of standardized methods for detecting components of tree fitness, the complex spatial and temporal patterns in leaf characteristics and phytophage interactions remain largely unknown.

To address this knowledge gap, we propose a novel approach utilizing imaging techniques and AI-based object detection to automate the assessment of herbivory, leaf-herbivore interactions, and leaf health. Our automated pipeline aims to overcome current limitations in assessing leaf damage, particularly in leaves with non-entire margins. By applying AI-based object detection techniques, we can accurately identify characteristic damages and quantify herbivore and pathogen damage in a standardized manner. Through comparisons with manipulated test data and human assessed estimates, we will evaluate the accuracy of our methods. The proposed approach will offer a wide range of applications and facilitate a spatially and temporally fine scaled monitoring of plants and associated biota.

Method comparison of microscopy, metabarcoding and multispectral imaging flow cytometry for identification and quantitative analyses of insect-dispersed pollen

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The identification and quantification of insect-dispersed pollen is important to understand pollen transfer and its effects on plant reproduction as well as to reconstruct past communities and climates using paleo-pollen. However, the principle method for pollen identification, microscopy, is time-intensive and requires strong taxonomic knowledge of pollen grains; it has thereby hampered the ability to answer large-scale research questions involving pollen. In addition to morphological identification, many recent advances have been made to automatize the identification of pollen, including DNA and image-based methods that promise accuracy, efficiency, and the potential to process large amounts of data. As these methods are relatively new, it is unknown how the output of these methods compares to the gold standard of microscopy or to each other. Therefore, we compared three methods for pollen identification, comprising metabarcoding, imaging flow cytometry coupled with machine learning, and microscopy. Firstly, we compared the methods on known artificial pollen mixtures and secondly, on the pollen loads taken from thirty pollinators collected in the field. Here, we present the results from our study, comparing species and abundance differences of pollen detection at different taxonomic scales (genus and family). We found that metabarcoding provided the most accurate species list of pollen in a mixture, while microscopy-based identification methods were able to more accurate assess the relative abundance of pollen species. The choice of method(s) depends on the goal of the study and the resources available.

KIWA: Artificial Intelligence for Early Detection of Forest Fire Events

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European forests are becoming increasingly vulnerable to emerging fire regimes. The consequences for biodiversity, habitat degradation, and carbon budgets are unclear. Novel ways of dealing with forest fire events are needed, to safeguard not only future biodiversity, but also to prepare affected countries for such events. Modelling approaches based on artificial intelligence (AI) are a promising tool for early fire detection. However, the reliability of the use of AI in fire risk assessment requires further investigation. To address this question, the KIWA project seeks to apply AI algorithms to large amounts of data collected from satellites, UAVs and fire image repositories, as well as make use of other climate and weather data. In doing so, KIWA aims to identify patterns in fire occurrence both in natural and managed forests. This would deepen our understanding of ecosystem resilience and risk to fire events to determine ways of incorporating new knowledge in measures related to forest fire risk and management. The findings of KIWA will enable institutions, such as fire departments and disaster management teams, to better cope with the increasing fire risk in Germany and beyond. After being successfully tested, AI could also be deployed in other forest ecosystems, particularly those that are ecologically prone to wildfires or are projected to be at higher fire risk in the future due to the ongoing climatic changes of our time.

Automated mapping and detection of fitness of shrubs in South Africa's Fynbos biome using drone imagery and deep learning

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Understanding population and community dynamics requires data on spatial distribution of plant individuals and their fitness. Requiring these data is a time and labour-intensive process. We present a workflow to automatically determine the species of shrubs of the Proteaceae family in the Fynbos biome in South Africa from drone-based photogrammetric data. We applied deep learning to segment five species of shrub individuals from the background based on spectral and height information. The spectral-height model achieved an average prediction accuracy of 74.4%, compared to 61.6% when using spectral information alone. A digital surface model and spectral information moreover yielded accurate predictions of inflorescence number per individual and of the total number of closed cones. Despite the challenge in distinguishing sprawling shrubs from the background, which may be overcome with additional training data, the presented workflow holds promise for the efficient mapping of shrub communities including relevant fitness proxies.

Avian nest attendance and incubation rhythms – reconciling movement ecology with acoustic ecology to collect life history data

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Allocating resources between survival, growth and reproduction is a basic principle for every organism. Understanding decision processes and inevitable trade-offs that lead to resource budgeting is among the basics of behavioural ecology. In this context, parental care in bird species plays an important role for their reproductive success, thus determining a large part of their fitness.

However, traditionally, collecting such data is labour-intensive, by observing incubation rhythms via hourly or day-long watches at nests. With the advent of high-resolution GPS telemetry, it is possible track parents and their parental investment directly, but that involves catching the bird at least once, is expensive, and requires identifying the individual nest. Detecting e.g., nest attendance or incubation periods automatically directly at the nest bears the potential of a labour-effective and low-disturbance method. To that end a data stream, well-known in avian science comes into play: Audio.

We tested its effectiveness of both methods to catch life-history traits in European Starlings (*Sturnus vulgaris*) in the Uckermark, North-Eastern Germany. We equipped 15 nests with autonomous recording units (ARU) collecting audio data. To extract how often the parent bird entered the nest or fledglings were begging from the acoustic data, we tested lightweight approaches like amplitude analysis and as well trained a neural network with manually annotated training data. At the same time, the bird's movements were tracked with a high resolution regional scale tracking system (ATLAS) every 8 seconds, and the returns of individual birds to the nest boxes as well as duration at the next boxes extracted. As a control, one exemplary nest was monitored manually for an exemplary period. We used the tracking and observance data to validate the acoustic event detection.

The effectiveness, as well as the perks and pitfalls of the proposed methods, will be presented. This work will provide a validation of the accuracy of acoustic data to collect life history data with relatively low effort. By developing methods, applicable on large scales we hope to foster the ecological understanding of organismal behaviour.

Plants response to estuarine constraints: a study of controlled salinity and inundation

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Estuarine wetlands span a wide array of environmental constraints. As ecosystems at the interface between marine and terrestrial environments, salinity and inundation are among the most important factors impacting growth performances and plant community composition. Vegetation is under high stress in areas where both gradients meet at their high point (close to the river and/or low altitude, resulting in frequent inundations from the tide, and close to the sea, where water salinity is at its highest due to the mixing of fresh water and salt water) and plant communities are shaped by the harsh environmental conditions.

In the current context of climate change, a rise in sea water levels will displace salinity and inundation gradients in estuaries and their associated wetlands. This will significantly change the physical and chemical parameters of the soil types and impact the plant communities within estuarine ecosystems.

We therefore set out to determine the effect of the modification of water salinity and submergence frequency on plant productivity in a pot experiment in controlled conditions. Five individuals of three species (*Alopecurus geniculatus*, *Festuca arundinacea* and *Holcus lanatus*) of estuarine wetlands were exposed to three saltwater concentrations and three inundation frequencies. Growth and biomass production of each individual were assessed non-destructively through photography weekly for 3 months. Leaf traits (SLA, LDMC and chlorophyll content) were also measured during the experiment. We will present the design of this experimental setup, the photography tool developed especially for this study, as well as the results.

SESSION 50:

Wildlife in Human-Dominated Landscapes

Mapping human- and bear-centered perspectives on coexistence using a participatory Bayesian framework

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Coexistence with wildlife is becoming a key challenge in Europe as populations of large carnivores recover in human-dominated landscapes. Modeling the spatial distribution of conditions for human-bear coexistence can help support conservation by identifying priority areas and measures to support coexistence, but existing models often only address risks either to humans or to large carnivores.

We present a participatory modeling process that incorporates both human-centered and large carnivore-centered perspectives on coexistence, which we applied to a case study of coexistence between humans and the endangered Apennine brown bears (Ursus arctos marsicanus) in Italy. Local and expert knowledge, as well as available data on bear habitats and land use, were integrated into a spatially explicit Bayesian network. This model is used to predict and map the tolerance to bears from the human perspective and the risk of fitness loss from the bear perspective. We found that conditions for human-bear coexistence vary between human communities and are spatially heterogeneous at the local scale, depending on ecological factors, social factors influencing the level of tolerance in community, such as people's emotions and knowledge, economic factors, such as livelihoods, and policies such as damage compensation. The participatory modeling approach allowed us to integrate perceptions of local people, expert assessments, and spatial data, and can help bridge the gap between science and conservation practice. The resulting coexistence maps can inform conservation decisions, and can be updated as new information becomes available. Our modeling approach could help to efficiently target measures for improving human-large carnivore coexistence in different settings in a site-specific manner.

Protecting grazing livestock against wolves: What drives farmers' intention to implement measures?

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Grazing farm animals on grasslands can support biodiversity conservation, sustainable food production and animal welfare. With the wolf (Canis lupus) repopulating Germany, pastoral farmers are confronted with new challenges and depredation of livestock has become a salient issue in the public debate. Non-lethal protection measures, such as wolf-deterring fences, are considered indispensable for preventing carnivore attacks on livestock, but are costly and require pro-active initiative by farmers. However, the drivers of farmers' intention to adopt non-lethal interventions are not well understood. Drawing on Ajzen's (1991) Theory of Planned Behavior, we assumed that attitudes, subjective norms, and perceived behavioral control can explain farmers' intention to implement livestock protection measures.
We conducted an online survey among Bavarian livestock farmers in late 2022 and received 353 completed questionnaires from owners of different grazing animals across the state. We used structural equation models to explain farmers' intention to implement i) livestock protection measures in general and ii) wolf-deterring fences in particular. The results show that subjective norms are an important factor, i.e., farmers care about the views of their peers regarding livestock protection measures. At the same time, perceived behavioral control, i.e., farmers' perception to have resources and skills to implement measures, moderates the effect of attitude on intention.
In addition, intention to implement measures increased with the level of concern about wolf attacks. Our findings contribute to understanding farmers' perceptions of interventions to protect their livestock from carnivores. To be successful, targeted policy measures need to enhance feasibility and financial viability of herd protection measures and should support a disseminator role of successful farms.

Dodging humans – how wolves acclimatize to the anthropogenic landscapes of Poland

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Wolves can adapt to various climatic conditions, habitats, and prey but are able to live in human-dominated landscapes. Over the last 40 years, wolf population recovered in Poland and now occupies over 60 000 km^2, i.e. 20% of the country. We used telemetry and snow tracking to study wolves in four areas with various levels of human impact. In general, wolves avoided humans and infrastructure spatiotemporally, i.e. they used areas of high human activity when humans were absent or less active. For example, wolves chose midnight hours to cross busy roads. When crossing fenced highways, wolves accepted wildlife bridges but also used viaducts constructed for local traffic and railway crossings. Wolves avoided forest roads used by loggers and foresters during business hours but used them as principal travel routes within their territory at night. They took advantage of roads by setting territory boundaries on the framework of public road grid. For den and rendezvous sites, wolves selected areas relatively difficult to access for people, far from infrastructure and settlements. In addition, the selection of resting sites by wolves depended on the time of day – during daylight, wolves rested at sites more concealed and further from forest roads. Wolves took advantage of forestry enclosures protecting young forest plantations to hunt roe deer. Although wolves opportunistically prey on livestock if available, even packs with easy access to livestock predominantly prey on wild ungulates. We conclude that wolves can acclimatize to variation in human presence. The temporal dynamics in human activity and wolf behavioral responses are crucial to understand wolf behavior. Behavioral plasticity allows wolves not only to survive in anthropogenic habitats by minimizing the risk associated with humans and infrastructure but also to take advantage of some aspects of human activity.

Hikers in sheeps clothing - Co-Occurence of wolves and ungulates in a human dominated landscape

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Ecological research often focuses on environmental factors that influence species distributions and aims to quantify the spatiotemporal interactions among co-occurring species. Interactions between species, whether between predator and prey or competitive relationships within the same guild, manifest in both spatial and temporal patterns. In multi-use landscapes such interactions are further affected by human influences, such as recreation or hunting.

In this study, we investigated space use of red deer (Cervus elaphus), roe deer (Capreolus capreolus) and wild boar (Sus scrofa) using camera traps in an area heavily used by humans, the Veldensteiner Forst in Central Franconia. In addition to the presence of wolves (Canis lupus), we predicted that both human influences (e.g., hunting, recreation) and habitat factors affect the spatio-temporal behavior of ungulates. First, we investigated temporal patterns of the interactions between ungulates, humans and wolves at the diurnal and seasonal scale. Next, we applied occupancy models to identify environmental factors and species interactions that influence space use.

Temporal activity analysis suggested that ungulates responded negatively to the presence of wolves and humans. All ungulates showed seasonal avoidance of wolves during vulnerable times (i.e., during breeding season). At the diurnal scale, ungulates showed stronger avoidance of humans than of wolves. Red deer showed the highest diurnal temporal overlap with wolves. The highest plasticity in reacting to human and wolf activity was found for wild boar. No significant spatial interactions were detected between predator and prey species or between roe deer and red deer in multi-species occupancy modeling.

Our results suggest that wolf-ungulate interactions in Veldenstein are masked by the strong presence of humans and ungulates seem to tradeoff between both threats. Avoidance was found to rather occur in time than in space. Future research should focus on integrative spatio-temporal modeling. Exploring such spatio-temporal relationships is particularly important to consider in wildlife management decisions and recreational management.

Behavioural responses of red deer to drive hunts in a military training area

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Hunting is the primary method for controlling wildlife population sizes. Similar to non-human predators, human hunters affect prey not only through direct lethal effects but also by influencing their behaviour. To balance harvest with other wildlife management goals, it is crucial to evaluate the behavioural consequences of hunting. We investigated how red deer Cervus elaphus modified their spatial behaviour in response to drive hunts in a military training area in Germany, where the species contributes to preserving open habitats used for military activities.

We analysed the movement of 51 GPS-collared red deer (39 females and 12 males) at two sites that vary in the degree of forest cover. We included 63 drive hunts in 2015—2022, accounting for 286 deer-hunt events. The red deer increased their movement rates on the day of the hunt, and females increased movement rates more than males. Red deer left their home ranges in 62% of the hunting events. We recorded two main types of flight responses: (1) immediate flight at the start of the hunt and return to the area on the evening of the same day, (2) progressive moving away until the next day, followed by a return around 3 days after the hunt. The maximum displacement and the probability of leaving home ranges were related primarily to the red deer's distance from the hunted area. Red deer at the site with higher forest cover moved on average further away than deer at the less-forested site. Our findings contribute to understanding the behavioural consequences of hunting. We discuss the plausible implications of the results for red deer management.

Understanding the risk-reward trade-off: Do fine-scale behavioural responses of red deer to large carnivore cues vary with distance to forest edge and forage quality?

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In light of the ongoing recolonization of large carnivores in Europe, wild ungulates increasingly have to trade-off between food acquisition and predation risk avoidance, which often results in suboptimal habitat and resource use. In an ongoing study, we examine the effects of perceived predation risk imposed by lynx (Lynx lynx) and wolf (Canis lupus) on red deer (Cervus elaphus) vigilance behaviour, visitation frequency and duration on foraging sites with respect to distance to forest edge and diet quality. Predation risk effects were measured on a total of 76 experimental plots equipped with camera traps recording 30s videos within the Grafenwöhr military area in Germany. Experimental plots were placed at different distances to the forest edge both within the forest (n = 36) and in open meadows that are partly mowed in summer (n = 20 mown / 20 unmown), resulting in differences in diet quality. On each experimental plot, wolf and lynx presence was simulated by applying both scat and urine, respectively, and horse urine/dung to control for unknown, unhazardous smells. Each experimental plot received one of the scent-treatments for one consecutive week. This was repeated three times, with a 1-week break, at which each plot received each of the treatments. In addition, diet quality, vegetation height, canopy- and habitat openness were measured. At the end of the experiment, a total of 5429 red deer videos had been recorded. For these videos, red deer visitation frequency, visitation duration and the time spent vigilant are analysed. Here, we first expect red deer to increase their vigilance but reduce the frequency and duration of visits under perceived predation risk. Second, in open areas, we expect this response to be stronger with increasing distance from the forest edge. Last, we expect prey responses to be less pronounced in mown than in unmown areas because of higher forage quality in mown areas. The results of this study will be presented at the conference.

Contrasting density gradients of two ungulate species – a study using spatial capture-recapture modelling

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Interspecific interactions of species are important drivers of space use shaping densities and spatial distribution of wildlife communities. In mountainous landscapes, the availability of resources like forage and cover varies in space and time influencing the extent of spatial segregation among herbivores that occupy similar ecological niches. For example, recent studies have suggested a competitive role of European red deer (Cervus elaphus) in relation to Alpine chamois (Rupicapra rupicapra). However, the factors influencing their spatial overlap have not been investigated using distribution data.

We compare spatial predictions of local densities for both species in two distinct areas in the Bavarian Alps which differed in habitat composition and level of human land use. We estimated density distributions applying a Bayesian spatial capture-recapture (SCR) analysis based on a systematic collection of faeces and genotyping while accounting for sampling effort as well as sex-specific differences in detectability and space use.

Chamois densities were primarily influenced by terrain ruggedness and varied between the two study areas. Red deer densities exhibited less variability and increased in regions with more forest cover. In the study area with fewer alpine habitats, we found a positive correlation in density distributions implying that local chamois densities followed patterns that were similar to those of red deer. In the second study area with a higher amount of alpine habitats, chamois density was negatively correlated with red deer density, indicating segregation between the two species.

In summary, the observed patterns of density distributions suggested that the extent of spatial segregation between these two ungulate species is largely determined by the availability of alpine habitats. Applying genetic sampling and SCR can provide insight on the relationship between habitat and ungulate densities which is crucial for sustainable management of these species.

Spatial capture-recapture models suggest sex-specific density patters of wildcats along a forest-open habitat gradient

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The genetic analysis of hair samples obtained with lure traps has become an established method to monitor populations of European wildcats (Felis silvestris). If the spatio-temporal sampling resolution is sufficient, genotyped hair samples provide information to estimate local densities and model habitat selection simultaneously. In this study, we used non-invasive genetic data to fit a spatial capture-recapture model and estimate sex-specific wildcat densities in a heterogenous landscape comprised of both, open habitats and forests, in the Haßberge region in Bavaria, Germany. Hair samples were collected using 300 lure traps deployed across the study area of 50 000 ha during spring 2020.

Genotyping of hair samples identified 73 different wildcats, which were detected up to ten times within the survey period and allowed us to estimate sex-specific wildcat densities using a spatially explicit capture-recapture model. The density of wildcats in the study area was estimated to be 0.16 individuals/100 ha (0.14-0.19), and both densities and habitat selection differed between sexes. Female wildcats were highest in densely forested areas, while males had a more extensive distribution (farther movements) and proportionally higher use of open landscapes with sufficient structure, such as hedgerows and shrubs.

Our results suggested a stable wildcat population within the study area and indicated differences in habitat preferences between sexes. While we detected a selection for forests, particularly by females, the structurally diverse open habitats also appeared to be important for males. Our study exemplifies how lure traps and non-invasive genetic samples can be used to estimate spatial distribution as well as local population densities and thus provide valuable information for conservation of European wildcats.

The impact of fallow deer on the vegetation of calcareous grasslands

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Dry calcareous grasslands are a threatened semi-natural habitat type in Europe. They are exceptionally species-rich, but since their traditional maintenance by sheep grazing is often no longer feasible for socioeconomic reasons, habitat preservation has become increasingly difficult. Therefore, we are searching for new adequate and cost-effective management options. In this study, we aim to evaluate to what extent wild ungulates can contribute to the maintenance of semi-natural calcareous grasslands.

In a ten-year exclosure experiment we tested the effects of ungulate foraging using three treatments: (A) control with combined foraging of herded sheep and wild fallow deer, (B) sheep exclosure with only deer foraging and (C) total exclosure without foraging. Treatments not grazed by sheep (B, C) were characterized by significantly declining species numbers, litter accumulation and shrub encroachment. Despite high population densities, the effect of fallow deer alone (B) was weak: Succession of woody species was only partly inhibited, while annuals, short-growing and rosette-building plant species were strongly suppressed by litter accumulation. Only the combination of sheep and fallow deer foraging preserved vegetation structure and species richness and led to a promotion of target species. However, fallow deer foraging alone was able to slow down successional processes for several years.

Based on our results, and in contradiction to our initial hypothesis, we argue that rewilding projects completely relying on fallow deer browsing will rapidly lead to the degradation of calcareous grasslands, at least in a landscape context where more attractive forage sources are available and hunting serves other goals. We need to continue the traditional land-use forms such as sheep grazing in order to maintain calcareous grasslands. However, we should raise our awareness for wild animals and analyse more in depth their potential contribution to the conservation management of open habitats.

Animal-train collisions: Train frequency and speed increase the risk of collisions with wild mammals but not with domestic mammals

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The modernization and development of railway infrastructure in Central Europe has increased the frequency of train-animal collisions. Collisions have pervasive consequences for both the animals due to severe injury or mortality and the railway system due to delays and damages on vehicles and infrastructure. Mitigating train-animal collisions requires detailed knowledge on the factors influencing collision risks. These factors are so far understudied in Central Europe.

Here, we investigated the factors influencing the probability of train-mammal collisions in Germany using data from the official database of train accidents compiled by the Federal Authority for Railway Accident Investigation. This database contained 118 collisions with mammals between 2010 and 2021. We identified characteristics of the landscape (coverage of three main land-use classes, Simpson diversity index, density of land traffic routes) and train traffic (speed, frequency, proximity to curves) at collision sites and compared them with random points along the railway system, separately for wild and domestic mammals.

Approximately 40 % of the recorded collisions affected domestic mammals mainly horses and cattle. In wild mammals, collisions were predominantly recorded with wild boar and roe deer. Collisions with both species groups mainly happened during night and in the winter half year. In domestic species, collision risk was unrelated to landscape and train traffic characteristics. In wild mammals, collision risk increased with train speed, train frequency, and higher woodland coverage in the surrounding area. The factors influencing collisions risks thus differed between wild and domestic species, with consequences for the establishment of mitigation measures for train-animal collisions. For wild mammals, our results suggest that mitigation measures should be mainly concentrated on tracks characterized by a combination of high train speed, high train frequency, and woodland coverage.

Compensation mediates Farmers' Tolerance for wildlife-related Crop Damage

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Compensation is a common strategy to alleviate financial losses to farms created by wildlife damage, but its effects on human tolerance are poorly understood. Based on structured interviews with farmers in Sweden (n=14) and Germany (n=22) and considering two different scenarios, we assessed how compensation, wildlife value orientation, and socio-demographic variables interact with crop damage tolerance. Tolerated crop damage levels were significantly higher in the scenario with compensation (21.6±33.2 % of total harvest) than in the scenario without compensation (3.3±3.7 % of total harvest). Regression tree analysis provided tentative support for wildlife value orientation to mediate damage tolerance. In the scenario without compensation, farmers with pro-hunting values tended to tolerate more damage, whereas in the scenario with compensation, farmers with more positive relations towards wildlife tended to tolerate more damage. This suggests that compensation increases tolerance for crop damage, and possibly shifts the relative importance of relational vs. utilitarian wildlife values in affecting tolerance.

Behavioural responses of free-ranging wolves to various carnivore and ungulate scents

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Understanding the response of wolves (*Canis lupus*) to intraspecific and interspecific odours is important for understanding the competitive relationships, communication and for conservation purposes, e.g. for odour use as repellents. The aim of this study was to gain basic knowledge about the response of wolves to urine and glandular secretions of different species and to identify scents that elicit a strong response.

We carried out an experiment consisting of two phases (6 weeks each) in three wolf pack territories in Lower Silesia, Poland (Jan.-Mar. 2021). For each experimental phase, 15 locations per pack were selected along forest roads. At each location, we installed three poles in line, with two different scents on the outer poles and control scent on the middle pole. We replicated each scent combination five times per pack and used video cameras to record the reactions of the wolves. In the first phase, we applied the urine of dog (*Canis lupus familiaris*), fox (*Vulpes vulpes*) and wolf and water (control) at the poles. In the second phase, we deployed glandular secretions of lynx (*Lynx lynx*), red deer (*Cervus elaphus)*, wolf and lanolin (control).

Wolves did not favour any of the offered urine scents. However, they showed longer but not more often the group of attraction presumptive behaviours on wolf gland secretion than on the control poles. They were most likely to sniff wolf or red deer gland secretion first than lynx gland secretion or lanolin. The low proportion of interactions with the experimental set-up in the total number of wolves observed suggests that none of the scents or offered combinations is suitable as an attractant. The wolves were not repelled by any scent. In summary, we did not find any particularly attractive or repellent effect of the offered scents, but the differences in the duration of the behaviours suggest some increase in interest in wolf gland secretion.

Diet of wolves in the Holy Cross Forest (Świętokrzyskie) region of central Poland

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We study wolves (Canis lupus) diet in the northern foreland of the Holy Cross Forest (Kielce upland 51°19'12.5"N 20°36'59.1"E - 50°41'35.0"N 20°52'05.6"E, 51°00'37.4"N 20°33'34.0"E - 51°03'56.9"N 21°23'39.9"E) region in central Poland, as a part of the wolf population monitoring program. As is in most of Poland wolves in the region were exterminated in 1950. They started to recolonize the region in 1980 and now the area holds 1012 packs of wolves, 6080 individuals. The area is a mosaic of forest, small scales agriculture, villages, and towns, with a dense network of forest roads, including major highway S7. It is to our knowledge the most densely populated (127 people/km2) area in Europe that holds substantial numbers of wolves. The potential wolf prey are ungulates red and roe deer, wild boar, moose - hares, and beavers, but also introduced muskrats and nutrias.

Between September and December 2021, we collected wolf scats (n=252) in 8 forest complexes, home to 8 wolf packs. After being collected from the site, the samples were stored at negative temperatures, then rinsed to isolate hair and bone from them. These, in turn, were then subjected to microscopic analysis to determine the exact species of prey. The study showed a clear predominance of ungulates in the diet. Deer were present among them in 49.7% of the samples examined, and they accounted for 32% of the hunted biomass. Red deer, occurring in 16,1% of the samples, accounted for 25% of the biomass. The importance in the wolf's diet of wild boar is underscored by the fact that although its remains were found in 25% of the samples examined, it accounted for as much as 37% of the total biomass hunted by the wolves studied. Noteworthy is the relatively large percentage of aquatic rodents recorded. Beavers, nutria and muskrats accounted for nearly 8% of the samples examined. Surprisingly, so far there has been no identified presence of moose remains in the samples, although moose is quite common in the study area. We did not find a single sample that clearly indicated the presence of domestic animals. One sample contained rabbit remains, but the lack of recorded breeding farms in the area reduces the likelihood of an anthropogenic influence of the origin of this prey in the diet.

SESSION 51:

Towards Automated Insect Monitoring

DIY camera trap for continuous automated insect monitoring

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Long-term monitoring of insect populations is essential to investigate potential drivers of insect decline, quantify their impact and design effective conservation strategies. Due to high time and labor costs, traditional monitoring methods are often deployed in low numbers or for a limited period of time. This mostly generates snapshot data with restricted potential for analysis and interpretation. Automated, non-invasive monitoring methods can extend the ecologists' toolbox and are able to yield data with a high spatiotemporal resolution. In the project MonViA (National Monitoring of Biodiversity in Agricultural Landscapes), a camera trap based on low-cost off-the-shelf hardware components and open source Python software was developed for automated monitoring of flower-visiting insects. The OpenCV AI Kit (OAK-1), a camera with a specific chip for real-time AI inference at the edge, enables the deployment of custom detection models, e.g. trained on specific insect groups or backgrounds. Combined with an object tracker, unique tracking IDs are assigned to detected insects, which can avoid repeated counting of individuals. For each insect landing on the standardized artificial flower platform, an image cropped from high-resolution frames is saved every second together with relevant metadata (e.g. timestamp, label, tracking ID). The insects in these cropped images are identified in a second step by a custom classification model on a local PC and the metadata including the classification results is automatically post-processed and analyzed with the provided Python script. Due to its low power consumption of ~4 W, the weatherproof camera trap system can be supplied with enough power by a 9 W solar panel, which enables autonomous insect monitoring during the whole season. Assembling, setting up and modifying the camera trap hardware and software is relatively simple with the provided instructions and documentation website (https://maxsitt.github.io/insect-detect-docs/).

The acoustic niche of insects in the Amazon

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Insects are the most diverse and abundant animal taxon on Earth. They also play a key role in ecosystem functioning and services. Despite their global importance, they are often neglected from national scale biodiversity surveys. This lack of interest is often associated to several causes, from political to scientific impediments. With technological advancements to conduct biodiversity surveys and the rise of ecoacoustics, these shortcomings may finally be addressed. For example, insects dominate nocturnal soundscapes in the tropical region, making them ideal organisms to employ passive acoustic monitoring to better understand their ecology. Here, we propose three main steps to advance insect surveys in the Amazon: (1) describing the primary spectral frequencies occupied by insects, (2) calculating acoustic indices for the dominant frequency ranges utilized by insects, and (3) assessing the associations between acoustic indices values and vegetation variables to determine the relationship between habitat type and insect acoustic communication. We will test two hypotheses: (a) insect acoustic activity varies according to habitat type because different habitats influence insect communities as well as their acoustic communication and behavior, and (b) insect acoustic diversity is positively correlated with vegetation complexity because more complex structure provides habitat for more diverse insect communities and thus a more diverse acoustic environment. We conducted this research in the Viruá National Park, Brazil. Soundscape and vegetation data were collected in 143 sites spanning natural and disturbed habitats. Our initial findings revealed that random forest models could distinguish with high accuracy soundscapes of different habitat types, and that nocturnal soundscapes were significantly different from diurnal soundscapes due more insect sounds at night. Our final findings will contribute to a better understanding of the role of habitat and vegetation structure in shaping insect communities within the diverse Amazonian ecosystem.

AI based insect monitoring with Citizen Science (KInsecta)

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Enhanced monitoring of insects requires additional workload in terms of time or cost. More important, however, is the drawback of conventional traps to remove insects from the habitat, which must be considered for upscaling. Currently, sensor-based monitoring is getting increasing attention as an alternative approach while insects remain alive in the process. A major challenge is to generate sufficiently good data to allow robust AI based species classification.

We present an AI based multisensor monitoring system consisting of an imaging system, a wingbeat sensor and additional sensors for environmental data acquisition. It is developed as a low-cost, scalable and open-source system that is adaptable to classical trap types, but without killing the insects. The image quality meets the requirements needed for classification in the taxonomic tree, since illumination and resolution have been optimized and motion artefacts have been suppressed. The system is evaluated exemplarily on a dataset consisting of 16 insect species of the same as well as different genus, family and order. We demonstrate that standard CNN-architectures like ResNet50 (pretrained on iNaturalist data) or MobileNet perform very well for the prediction task after re-training. Smaller custom made CNNs also lead to promising results. Classification accuracies of 96% have been achieved. Moreover, it was proved that image cropping of insects is necessary for classification of species with high inter-class similarity.

Currently, 25 systems are deployable and will be jointly operated by the project group and Citizen Scientists at various locations. First results indicate that data fusion of imaging and wingbeat data significantly improve classification accuracy of rare species. Even if the overall accuracy seems only slightly improved.

Automated identification of hatching cavity-nesting wild bees and wasps

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Despite their importance, there are still high-resolution data about the state and development of wild bees lacking. To fulfil this gap, in particular in remote or less favored areas, automated recording and species identification through artificial intelligence (AI) could be a promising tool. Wild bees are, however, a complex taxonomic group with numerous species that are very similar to each other and therefore difficult to identify. By focusing on a manageable group of wild bees, we tested whether an automated identification algorithm enabled identifying hatching cavity-nesting wild bees from trap nests down to family, genus and species level. As wasps are colonizing trap nests, too, we included them also into the analyses. In total, the percentage of top-3-accuracy by the algorithm was 84.5 %, whereby the identification success for wasps reached 77.8 % on family and 88.1 % on genus level. 82.4 % wild bee individuals were correctly identified on species level. The percentage of correct identification and the accuracy of the results are largely correlated with the number of training data. We assume that with an increasing training dataset, this approach is suitable for future monitoring activities as it provides timely beyond taxonomic data information on hatching rates and phenology.

Emerging technologies for automated insect monitoring

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Insects are the most diverse group of animals on Earth, but their small size and high diversity have always made them challenging to study and monitor. Recent technological advances have the potential to cause a revolution in insect ecology and monitoring. In this talk, we will discuss the state-of-the-art of four technologies: computer vision, acoustic monitoring, radar, and molecular methods, and assess their advantages, current limitations, and future potential. We will discuss how these technologies can adhere to modern standards of data curation and transparency, and their potential for integration among different monitoring programmes and technologies. We argue that they provide unprecedented possibilities for insect ecology and monitoring, but it will be important to foster international standards via collaboration.

SESSION 52:

Monitoring and Management of Invasive Alien Species

Predicting the timing of ecological phenomena relevant for invasion monitoring using opportunistic records

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Early detection is key for preventing or minimising the detrimental impacts of alien invasive species. However, to be successful, invasion surveillance and monitoring efforts need precise information on when species detectability is higher. This includes knowing when insect species will be in their adult phase, invasive plants will bloom, or other critical life stages occur. Unfortunately, this information is often unavailable or is difficult to obtain, particularly in areas where the species are yet to colonise or are in early stages of colonization, due to the absence of prior observational data. On the other hand, opportunistic time-stamped observations of these phenomena in native regions or previously invaded areas are often available in high numbers from large-scale repositories such as GBIF or iNaturalist. However, a general framework using these observations to predict ecological phenomena across time and regions remains elusive. We introduce such a framework and apply it to predict, in real-time, the adult stage of the invasive Japanese beetle (Popillia japonica) in Europe and North America. The approach is grounded on ecological theory, accounts for spatial and temporal biases in observation data, and uses machine-learning algorithms to distinguish between environmental conditions associated with the observation of the phenomenon and conditions available year-round. The approach accurately predicted the intra-annual timing of occurrence of adult Japanese beetles across Europe and North America. We further validate the approach by successfully predicting the timing of occurrence of adult Japanese beetles in Northern Italy, a recent hotspot of invasion in continental Europe. These results were also largely insensitive to temporal bias in observation effort. Our results highlight the potential of opportunistic observation data to predict the temporal variation of a wide range of ecological phenomena of interest for ecological risk assessment and invasive species monitoring.

Biochar application can mitigate the negative impacts of drought in the invaded experimental grasslands using functional traits approach

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With ongoing climate change, drought events have become more frequent and severe which is affecting species composition, diversity, and ecosystem functions in many ecosystems. Moreover, invasion of invasive species increases which threaten global biodiversity and are often favored by changes in climate and land-use, which can affect the native communities directly by competing for resources (e.g., light, nutrients, water). To illustrate that, we studied the effects of drought and Biochar application as a useful tool of mitigating drought, as well as their combined effect on the functional responses of grassland communities in semi-arid environments comprising of a combination between natural and invasive species. We conducted a greenhouse experiment where we planted three native species and one invasive plant species in artificial communities as of 5 individuals per species per plot. We exposed these communities to four different treatments: Biochar+Drought, Biochar, Drought as well as a control. To assess the performance of plants within treatments, we measured selected plant functional traits "Maximum plant height (Hmax), Specific Leaf Area (SLA), Leaf Dry Matter Content (LDMC), leaf nitrogen content (Nmass), leaf carbon content (Cmass), total chlorophyll (Chltotal) and Root to Shoot Ratio (RSR)" for all individuals occurring in our plots, and additionally assessed the above and belowground biomass for each plant individual. We found that the invasive species showed a higher performance (higher biomass accumulation, taller plants, higher SLA, Cmass, and Chltotal as well as lower LDMC) than the native species under drought conditions. Thus, plant functional traits might be a key factor for invasion success of plant species which will be even more pronounced under ongoing global change.

New ways of monitoring invasive alien species: Citizen science wildlife detection dog teams

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Wildlife detection dogs (WDD) are often used to detect hidden and cryptic species or populations. This provides an enormous potential especially for early detection of invasive alien species (IAS) in the lag-phase. As training WDDs is costly and time-consuming, the amount of experts available is low. Meanwhile, an increasing number of private dog owners are looking for meaningful activities for their dogs. The project IGAMon-Dog therefore educates dogs and their owners to become citizen science WDD-teams to monitor IAS. Using Fallopia japonica, Impatiens glandulifera and Ambrosia artemisiifolia as target species, we aim at evaluating the resources needed to enable successful education of the teams as well as monitoring their efficacy in comparison with citizen scientists without WDDs. First results suggest that training a citizen scientist to become a WDD handler depended on each individual team, their previous experience with dog training and the dogs themselves, but also on the training environment. Once they are properly trained, first results also showed that citizen scientists with WDDs can in fact display a higher efficacy in monitoring IAS even for conspicuous and abundant species than citizen scientists alone and thus provide a valuable support in monitoring schemes. The feasibility of their education is however costly and the training phases need to be monitored meticulously. Thus, the overall efficiency of benefits vs. costs of such a monitoring scheme needs to be evaluated.

The global genomic structure of an invasive plant: an interplay between environmental gradients and non-adaptive demographic process

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The understanding of the genetic bases and modes of adaptation is essential to estimate responses of plants to global change. High throughput data facilitate landscape genomic approaches to infer how dispersal is controlled by adaptive vs. non-adaptive drivers of gene flow. Invasive plant species are suitable study models because non-native populations are often prone to rapid genomic changes as a result of colonizing a novel range. However, many studies on invasive plants compared only few populations in large distributions, underestimating variation within each range, and restricting their ability to predict the native source region and the identification of drivers of gene flow. We explore the genomic structure of 109 native 183 non-native populations Conyza canadensis across the Northern hemisphere using ddRADseq. C. canadensis is an interesting model to investigate global gene dispersal because it is a successful invader with a cosmopolitan distribution and an economically significant agricultural weed. We will test the hypotheses that an interplay between environmental gradients and non-adaptive, demographic processes dictates the global genomic structure of C. canadensis. Preliminary results suggest strong differentiation among populations and low variation within populations. We also found pronounced differentiation between the genomic structures of native vs. non-native populations. Partial Mantel tests showed a significant correlation between genetic distances and both spatial and climatic distances of the populations. However, isolation by environment was more pronounced in the native ranges whereas isolation by distance was predominant in the non-native ranges. Our preliminary results suggest that high selfing rates determine the global genomic structure. Upcoming analyses will be presented at GfÖ including clustering and least-cost corridor analyses to shed more light on how population history dictates biotic interactions across large spatio-environmental scales.

Developing heat eradication methods for seeds of an alien species – Garden lupine (*Lupinus polyphyllus*)

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Road verges are considered important habitats for conservation of grassland plant species as a result of their regular mowing regime. However, as areas disturbed through road construction and maintenance, road verges are highly susceptible to the establishment of invasive alien plants (IAP). Garden lupine (*Lupinus polyphyllus*) is an IAP that benefits from road work disturbances. A large contribution to the dispersal of this species at the landscape scale is the movement of seed-containing soil masses during road construction, ditching and road maintenance. The aim of this study was to develop heat eradication methods for Garden lupine seeds applying dry heat and steam. We compared the effects on seed germination of dry heat and steam at different temperatures and exposure times, as well as effects on dry and imbibed seeds. We compared the viability of seeds of different age exposed to dry heat at different treatment combinations. Finally, we analyzed germination of dry seeds treated in a soil-steaming machine at a constant temperature of 97 °C for 10-17 minutes. There was a significant difference in germination rate between seeds exposed to dry heat or steam, where steam treatment had a larger effect on seed mortality. Seed mortality increased with higher temperatures and longer exposure for seeds treated in dry heat and steam. Lower temperatures and shorter exposure times was needed to kill imbibed seeds, while dry seeds were more resistant to both dry heat and steam. The germination rate of seeds from different years differed significantly, and the highest mortality rate was observed for the oldest seeds. The germination rate of seeds treated in the soil steaming machine was very low (‹0.5 %). Consequently, steaming is a more efficient eradication method than dry heat treatment to kill lupine seeds, and lower temperatures could potentially be used if seeds are physiologically activated before treatment.

Who is reporting non-native species and how? A cross-expert assessment of practices and drivers of non-native biodiversity reporting in species regional listing

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Each year, numerous scientific publications provide information on species distributions. However, the integration of this information into analytical workflows is often hindered due to distinct data reporting structures, storage formats, omission of crucial information, or the use of ambiguous and inconsistent terminology. These challenges are particularly pronounced for non-native species, as reporting practices and invasion-related terminology vary across regions and experts. To understand current practices and drivers of reporting non-native species, we conducted an online survey targeting authors of regional checklists. Of the 112 respondents, 45.5% did not always include non-native species in their lists, and 44.7% of those who did report non-native species did not differentiate them from native species. Moreover, 46.4% of respondents identified invasion-related terminology as an obstacle to reporting non-native species. Most respondents presented checklist information using descriptive text and embedded tables, with non-native species included alongside native ones. Only 13.4% of respondents reported always providing data in automation-friendly formats or publishing it in biodiversity data repositories. Our findings highlight the need for improved frequency, accessibility, and consistency in publishing non-native species data, which should be reported and differentiated from native species.

Impact and control of invasive alien plant species on roads, railways and waterways in Germany

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The invasion and dispersal of alien plant species (neophytes) are often associated with trade and transport. Accordingly, verges of traffic infrastructure show higher numbers of neophytes than surrounding areas and are gateways for the colonization of new regions and habitats. The impact of neophytes on the transport sector and how the sector manages these species remain, so far, largely unexplored. Here, we present results of surveys (based on questionnaires) on the impact of neophytes on the transport sector and the success of control measures along federal roads, railways and waterways in Germany. Our findings show that several neophytes, in particular *Heracleum mantegazzianum*, *Fallopia japonica*, *Robinia pseudoacacia*, *Ailanthus altissima*, are common along transport infrastructure. On roads and railways, neophytes lead to visual obstruction, potentially compromising traffic safety, and substantial higher management efforts, with higher impact on railways than roads. Furthermore, neophytes caused structural damages of infrastructure especially along railways. On waterways, neophytes damaged the technical bank protection, possibly inducing higher erosion. Overall, control measures exhibited little success. About 10 % of control measures eradicated local populations and 25 % only prevented their spread. The success of control measures depended on the applied method and target species. Mechanical methods affecting root systems exhibited highest success, even compared to chemical methods. *F. japonica* was most resistant to control, while 20 % of measures eradicated local populations of *H. mantegazzianum*. Our findings are the basis for providing recommendations on effective control of neophytes depending on the target species. Establishing this knowledge in the transport sector is of increasing significance for the transport sector itself and to minimize that neophytes colonize new regions via the traffic infrastructure.

Non-native raccoons in Germany: Insights from stakeholders about management in different regions

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Raccoons (*Procyon lotor*) introduced from North America continue to spread in Germany and Europe. Their first introductions date back to the 1930s when they were released in Hessen and escaped from fur farms in Brandenburg. We investigated to which degree stakeholders in Germany differ in their perception of this charismatic and at the same time invasive species. For this purpose, we combined three types of approaches: stakeholder interviews, stakeholder surveys, and newspaper analysis. The newspaper analysis covered articles published between 2010 and 2021, and showed a divided pattern with regional differences: While articles in Bavaria were rather positive, featuring raccoons as “cute” and “entertaining”, articles published in e.g. Berlin or Hessen were not only higher in number but also showed more diverse perceptions and its impacts. We observed strong differences in online surveys of eleven different stakeholder groups: animal protection and raccoon owners denied their impacts on ecosystems, whereas other stakeholders did not; there was also disagreement about hunting as a management method. Last, semi-structured interviews with 22 experts from four German states (Berlin, Bavaria, Saxony, Hessen) in the fields of administration, animal welfare, nature conservation, and hunting were conducted in late 2021. They showed that in regions where raccoons are common, a greater diversity of impacts as well as measures is known than in regions where raccoons are less present. While in Hessen and Berlin, the focus is on management for coexistence (e.g. raccoons-safe garbage cans, avoiding house entrances), in Bavaria hunting is focused. In contrast, hunting is said to be counterproductive, and proposals to capture animals, sterilise and release those, are more frequently applied. For a low-conflict coexistence, humans need to be educated about the presence of raccoons and how to deal with this species, especially in regions where they will spread in the future.

The Homogenizing Effects of the invasive plant species *Solidago gigantea* on Native Plant Communities and Soil Dynamics

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Solidago gigantea, an invasive plant species from North America, has become notorious in Europe and Asia. However, the extent of its impact on soil properties and species composition in invaded regions remains debated. To address this, we conducted a fieldstudy encompassing a wide range of soil types with varying nitrogen availability, pH, and plant communities, as they may respond differently to invasion.

We collected soil samples and conducted vegetation surveys in both invaded and nearby uninvaded plots. Soil parameters, including extractable nitrogen (N), pH, and moisture content, were measured, along with species richness, diversity, and average Ellenberg indicator values for fertility, moisture, and acidity of the plant communities. Additionally, we measured stand density and size of S. gigantea in invaded plots.

Our findings revealed that *S. gigantea* strongly influenced extractable-N and pH, with the magnitude and direction of alteration depending on initial soil conditions. The most pronounced effects were observed in acid, nitrogen-poor soils. Species richness and diversity consistently decreased in invaded plots, not primarily through direct competition, but due to the replacement of locally adapted specialist plant communities by less diverse, generalist communities of fertile habitats.

In summary, *S. gigantea* serves as a prime example of an invasive ecosystem engineer, significantly altering soil conditions upon introduction. These alterations not only facilitate the establishment and spread of this invasive plant but also create long-lasting legacy effects, even after its removal. Given the disproportionate impact on oligotrophic, acid soils and specialized plant communities, we propose that management strategies should prioritize preventing the establishment of new *S. gigantea* populations, especially in these less common habitats, rather than focusing solely on eradication efforts.

Validation of Darwin's Naturalization Conundrum in Microcosm Experiments Under Different Temperatures

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As globalization intensifies, biological invasions have emerged as significant socio-economic and ecological challenges, marking them as key environmental issues in the 21st century. Consequently, the field of invasion ecology has become a primary area of focus for both ecologists and environmental managers. A crucial scientific question within this discipline revolves around understanding how differences in phylogenetic relatedness and functional traits between native and alien species influence the mechanisms of biological invasions.

Such impacts were first deliberated upon in Charles Darwin's seminal work, "The Origin of Species" (1859), where he proposed the 'Darwin's Naturalization Hypothesis' and the 'Pre-adaptation Hypothesis'. The former suggests that alien species with marked differences in phylogenetic relatedness and functional traits from native species are more likely to successfully invade due to reduced interspecific competition. The latter proposes that alien species closely related to natives and sharing similar functional traits have a higher likelihood of successful invasion due to similar habitat preferences. These seemingly contrasting hypotheses together constitute what is known as the 'Darwin's Naturalization Conundrum'. However, many earlier studies, often conducted in stable environments, have overlooked the potential influences of environmental changes, leading to non-universal and contradictory findings. Thus, we hypothesize that the impact of phylogenetic distance and functional trait differences on invasions is predominantly contingent on environmental conditions. In hospitable environments, native species suppress the invasion of closely related and functionally similar alien species, in line with Darwin's Naturalization Hypothesis. Conversely, in inhospitable environments, environmental filtering facilitates the settlement of such alien species, aligning with the Pre-adaptation Hypothesis.

We investigated this hypothesis using bacterial microcosm experiments under six different temperature gradients. Our preliminary investigation delves into the contributions of phylogenetic relatedness, functional trait disparities, environmental filtering, and interspecific competition to the outcomes of biological invasions.

Connecting researchers and practitioners to better understand the freshwater biodiversity crisis

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The growing number of publications, datasets, and practical knowledge on freshwater biodiversity necessitates leveraging these resources to comprehend and combat the ongoing crisis. However, this surge in information has made it increasingly difficult for researchers and practitioners to maintain an overview and connect with one another. Within the Hi Knowledge initiative (https://hi-knowledge.org), we aim to address these challenges by developing an interactive atlas of invasion science that can be extended to other disciplines in the future; and within the Alliance for Freshwater Life (https://allianceforfreshwaterlife.org), we aim to extend our efforts to understand, value and safeguard freshwater biodiversity. This will be achieved by creating an online portal that offers users an overview of relevant studies and datasets, while serving as a connecting tool for knowledge-sharing between researchers and practitioners. Our aim is to develop an online portal that (i) provides users with an overview of relevant studies and datasets, and (ii) serves as a connecting tool between researchers and practitioners to share their knowledge. We will introduce our approach and discuss ideas for developing this initiative in line with stakeholders' expectations.

SESSION 53:

Long-Term Data and Global Change

TrendDNA: Studying long-term biodiversity change using environmental DNA contained in the German Specimen Bank

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In the current era of rapid ecosystem change, long-term biodiversity data pose the basis for quantifying trends, predicting consequences, and supporting management actions. However, long-term biodiversity data are scarcely available. A long-term sample collection that has been little explored so far is the German Environmental Specimen Bank (ESB), which contains terrestrial, freshwater, and marine samples collected for decades in a highly standardized manner. Samples are collected monthly or annually using standard operating procedures and are then stored in aliquots in cryotanks at -150°C. The ultra-cold storage condition preserves environmental DNA (eDNA) present in the samples, which is an ideal source for holistic biodiversity assessments. The TrendDNA project aims to test if eDNA-based methods such as DNA metabarcoding and metagenomics are suitable for studying biodiversity change using the ESB samples. One of the ESB sample types is suspended particulate matter (SPM), collected from 13 different sites in the Rhine, Saar, Danube, Elbe, Mulde, and Saale rivers, dating back to 2005. SPM is collected monthly using sedimentation traps, which are then pooled into yearly homogenates. In the project, we are analyzing 211 SPM samples from 6 rivers and 17 years using eDNA metabarcoding targeting fish and invertebrates. We highlight that eDNA data from the TrendDNA project provides comprehensive and plausible taxa lists, shows evidence of the introduction of invasive species, and unveils significant patterns of faunal community changes across years and sites. These results can aid in understanding biodiversity patterns, species turnover, tracking the invasion of species, assessing the progress of endangered species protection, and predicting future change. We provide an outlook on further project results and highlight the potential that the ESB can play in complementing long-term biodiversity monitoring in Germany.

Time trends in phytoplankton diversity of lakes and the Baltic Sea

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The loss of freshwater biodiversity is seen as a particularly severe case in the ongoing biodiversity crisis. However, this decline is not seen in all groups in the same way.

Phytoplankton responds quickly to environmental change and is therefore perceived as a good indicator for environmental state and global change. Interestingly, several long-term datasets on phytoplankton show increases of diversity over recent decades.

In time series of individual habitats, net changes in sample-level taxon richness (temporal alpha) can point at different processes. They may indicate changes in the system's species inventories (temporal gamma diversity), but also changes in persistence over time and turnover (temporal homogenization).

I explore here several time series of larger lakes and of the Baltic Sea, a brackish habitat that hosts many freshwater taxa. I explore how changes in alpha relate to changes in persistence vs turnover. In addition, I test how the BEF relationship between taxon richness and resource use changes with time.

Lake Lunz long-term monitoring: Recent changes in more than a century of observations

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The state of a lake ecosystem reflects both, in-lake processes as well as changes in the related catchment. Hence, lakes can serve as sentinels for environmental change especially with long-term data available.

Lake Lunz has been in focus of scientific investigations since the early 20th century. Along with longstanding metrological and hydrological records the exceptionally long period of limnological observations, make Lake Lunz an outstanding case for ecological long-term research.

The early scientific reports more than a century ago characterized Lake Lunz to be oligotrophic, dimictic, relatively cold and well oxygenated. Thanks to the relatively pristine catchment, the lake remained to be poor in nutrients at a time when many other lakes in Europe faced eutrophication. Still, for most of the recent decade levels of phosphorus increased and water transparency was lower due to higher phytoplankton density. As the lake does not receive wastewater the change in phosphorus content of lake water is most likely due to changes in nutrient export from the catchment.

Untypically for an oligotrophic lake and unseen in more than a century of observations, significant oxygen depletion could be observed in the deep-water zone in recent years. Climate change has had an obvious impact on surface temperature, vertical temperature structuring, duration of ice-cover, duration of stratification, and water column stability. Increased thermal stability hampers vertical mixing and thereby facilitates deep-water deoxygenation. Despite, in Lake Lunz in-lake productivity seems to be the major driver for inter-annual differences in deep-water de-oxygenation.

Lake Lunz is an example case how human impacts directly and indirectly affect a lake ecosystem that is regarded to be relatively pristine.

How flatworm parasite communities changed in response to human-induced ecosystem perturbations in Lake Victoria

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Global change is causing distribution shifts and population declines of countless plants and free-living animals. How parasites are affected by global change is largely unknown, despite their ubiquity and importance for ecosystem functioning (e.g. regulation of host populations, increase of food web connectivity). Human-induced environmental changes are expected to alter parasite abundance and host-parasite interactions (e.g. spillover to novel host species), but the direction of such changes is unclear.

Lake Victoria, the youngest of the African Great Lakes, is a biodiversity hotspot that experienced simultaneous drastic anthropogenic changes: multiple invasions (e.g. Nile perch), eutrophication and overfishing. We use historical fish collections – harboring a hidden parasite collection – to test whether parasite abundance and host range changed in response to anthropogenic changes in Lake Victoria. We analysed ectoparasite infection in 13 cichlid fish species, representing 7 eco-morphological groups, sampled between 1973 and 2014.

Overall parasite abundance, but not parasite diversity, declined after impacts on Lake Victoria. Most ectoparasite species are declining, while few others are increasing in abundance, indicating that parasite species respond differently to ecosystem disturbances. The host range of most ectoparasitic flatworms changed, as they disappeared from some host species and colonized few new host species that they did not infect before ecosystem changes in Lake Victoria. This may suggest that ecosystem disturbances favor host switching.

Since changes that have occurred in Lake Victoria are also occurring in other ecosystems, our results suggest that we can use flatworm parasites as sentinel for ecosystem health, which might contribute to better strategies for linking conservation and ecosystem health.

Long-term data from the North Sea reveal common trends in characteristic epifauna and fish communities associated with environmental and anthropogenic habitat changes (1998-2022)

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The Southern North Sea (SNS) as vulnerable habitat for characteristic species and communities on all trophic levels is changing rapidly since the last decades, i.a. caused by environmental alterations and human activities such as increasing water temperatures as well as decreasing fishing pressure and riverine nutrient loads (de-eutrophication). In our study, we identified and evaluated significant common trends in the characteristic epifauna and fish communities for the German Bight, for which high-quality, high-resolution and full-coverage epifauna and fish databases, current and historical, were available for abundance, biomass and taxa number. As time series technique we applied a Dynamic Factor Analysis (DFA), which extracted and evaluated significant common trends in our epifauna and fish communities in the SNS, and correlated these significant biological trends with biogeochemical, sedimentological and climatic changes (1998-2022). Our results showed that several dominant epifauna and fish species experienced strong annual fluctuations in abundance (1998-2022), e.g. the brittle star Ophiura albida and the shrimp Crangon crangon. In addition, the common trends in our DFA-models showed significant decreases and increases for the characteristic communities in the SNS between 1998 and 2022. For the 'Coast' community, as an example, the common trends showed clear decreases since 1998, which were positively correlated with the abundance of the swimming crab Liocarcinus holsatus and the flatfish Buglossidium luteum, and negatively correlated with the abundance of the flatfish Limanda limanda. With the results of our long-term study we pursue the goal of supporting scientific studies on changes in marine biodiversity and food webs. To achieve this goal, we included global change-induced variations in bottom-up (e.g. primary production) and top-down processes (e.g. predatory fish) of characteristic marine communities in our trend analysis.

Keywords: climate change, common trends, fish-benthos, historical data, human pressure, long-term data, marine communities.

Shortening the outbreak dynamics of the gypsy moth: lessons from long-term observations of primary succession

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Long-term ecological data from monitoring programs, experimental out-door sites, and artificial catchments are now well established and allow to address questions about the temporal changes in the complex processes between abiotic conditions and organisms. There is an ongoing discussion about whether natural ecological systems are more resilient against pest outbreaks than managed semi-natural ones. Here we use data from the artificial watershed Hühnerwasser (Chicken Creek), an ongoing research project on primary succession that was established in 2005 in the Welzow-Süd open-cast mine and serves as a terrestrial observatory for ecosystem development. Gypsy moth (Lymantria dispar) outbreaks have a typical duration of three to four feeding years. We report a fast decease of such an outbreak in the Hühnerwasser catchment, where the decline phase started already after one year. Our data indicate that differences in abiotic conditions, particularly microclimatic peculiarities, caused this shorter outbreak phase. One can conclude that the increase in air temperature associated with climate change is certainly not necessarily benefiting this warmth-loving species. The question that can be derived from this case study is to what extent, in the face of climate change, a new regulatory power of abiotics is also emerging in more mature ecosystems such as commercial forests.

A framework for assessing the vulnerability of long-term ecological monitoring sites to climate and anthropogenic changes in the mountain regions

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Understanding the potential effects is a crucial first step to maintaining healthy forests in the face of changing environmental conditions. Himalayan ecosystems will be increasingly impacted by a changing climate. In the Himalayan region, climate change and anthropogenic disturbances enhanced the vulnerability of forest ecosystems. However, to assess the vulnerability of forest ecosystems, there is a need to assess changes in forest biodiversity components (species richness, diversity, and density) over a longer time period through Long term ecological monitoring (LTEM). In this study, we provide a conceptual framework of IPCC to assess the vulnerability of long-term ecological monitoring sites to weather and anthropogenic disturbances in the Indian Himalayan region by calculating exposure, sensitivity, and adaptive capability. We assessed the data LTEM sites have been established along an elevational gradient (1000–3800 m) covering major forest types (Subtropical to subalpine region) in the western Himalayan region for the time period 2017-2022. We have utilized the data of LTEM sites along an elevation gradient (1000–3800 m) covering major forest types (Subtropical to subalpine region) in the western Himalayan region for the time period 2017-2022. In the lower regions (‹2500m), high anthropogenic activities (forest fire, logging, and invasion) and low adaptive (poor regeneration), and increased temperature enhanced the vulnerability of the region. However, the forest zone located› 2500m is lesser vulnerable to these variables. The present study identified the sites which needed immediate management and mitigation plans to cope with the adverse effects of these changes. The present study identified the sites which needed immediate management and mitigation plans to cope with the adverse effects of these changes. The framework sufficient guide to assessing the vulnerability of LTEM through analysis of long-term data which would help policymakers to take suitable mitigation options.

Changes in bird communities along elevational and vegetational gradients can be similarly detected by expert- and AI-based data

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Climate change is causing shifts in local climatic conditions and altered disturbance regimes which affect vegetation dynamics and structure. Studying shifts in communities along elevation gradients can help to gain a better understanding of relationships between climate and biodiversity and thus, to generate better predictions of climate change effects. Moreover, mountain ecosystems host endemic and threatened species and since climate in mountain ecosystems is changing at rates above average, monitoring and research of mountain biodiversity has become a focal issue. Here, we studied bird communities along independent gradients in elevation from 600 to 2200 m asl. and vegetation cover from open habitats, to disturbed forests and closed forests in Berchtesgaden National Park. Soundscapes were recorded at 215 sites and species were identified by expert taxonomists as well as by an AI approach (BirdNET). The first two axes of NMDS ordinations reflecting changes in species composition along elevation and vegetation gradients were correlated for both expert and AI data ($r = 0.92$ and 0.62, respectively). Similarly, species number based on expert and AI data were strongly correlated ($r = 0.72$). Patterns in species richness, phylogenetic (PD) and functional diversity (FD) were driven by interactive effects of elevation and vegetation cover. Bird communities at low elevations comprised more and more closely related species indicating higher niche packing. Our results show that bird data generated by autonomous sound recorders and freely available AI can adequately capture the changes in species number and community composition along major environmental gradients in mountain ecosystems. This opens various new avenues for mountain biodiversity research, including standardized long-term monitoring, that have so far been hampered by the logistic challenges associated with mountain habitats.

Long-term seagrass recovery in the Northern Wadden Sea: how one seagrass species benefits from the prospering of another

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On a worldwide scale, most seagrass beds undergo a decline. This was also observed at seagrass growing on the tidal flats in the European Wadden Sea, especially in the 1970s – 1990s. However, a long-term aerial and field monitoring revealed that seagrass beds in the northern Wadden Sea have recovered for the last 25 years. This is primarily ascribed to a reduction of nutrient discharges from large rivers commencing in the mid 1980s. From the late 1990s to 2011, seagrasses have increased 5-fold in bed area. Hence, the visible part of the recovery started with a delay of about 10 years after the nutrient reduction measure. After a phase of a rather stable seagrass bed area, a slight but steady increase can be observed again since 2017. A habitat model revealed that suitable areas are by now almost completely occupied and for the last years, seagrass is expanding in areas with marginal suitability.

The seagrass beds are composed of two species: Z. marina which prefers wetter habitats whereas Z. noltei is more tolerant to low tide exposure and the clearly dominant species. However, over the last 7 years, a distinct increase of Z. marina was observed. It is often expanding in areas adjoining tidal channel deltas but the share of Z. marina has also increased in dense beds dominated by Z. noltei. We assume that Z. noltei delays water drainage with their dense canopy and hereby increasing the habitat suitability for Z. marina. The dense Z. noltei cover probably also retains Z. marina seeds in the beds. Z. marina subsequently benefits from the recovery of Z. noltei beds.

Historical Biodiversity Data in the State Archives of Bavaria

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The State Archives of Bavaria are responsible for the management of archival records from Bavarian authorities and other public bodies. Their tasks include the recording, acquisition, permanent storage, but also preservation, indexing, and utilization of the various types of information. The archives, which date back to the early Middle Ages, include analog holdings such as documents, files, and maps, as well as other data carriers and digital records.

Current challenges such as global change and the climate crisis confront biodiversity research with the task of documenting and evaluating the development of ecosystems over a longer period of time. The historical holdings of the Bavarian State Archives such as on agriculture and forestry can make an important contribution to this. The poster would like to draw more attention to these in the context of the GfÖ conference and seeks cooperation partners for a scientific evaluation. In a small pilot project, the inventories from the Bavarian forestry offices from the middle of the 19th century were recently made accessible. In 1845, all Bavarian forestry offices were given the task of recording the forest fauna in the individual districts on the basis of predefined forms. The same was done for the fish populations in the Bavarian lakes. This means that there is a statistical area-wide record of the occurrence of 31 (animal) species as well as the most important fish species for the whole of Bavaria, which goes back almost 200 years and was compiled by experts. Other such treasures are waiting to be processed and scientifically evaluated, such as hunting statistics spanning several decades of the 19th century.

The State Archives of Bavaria are also represented in NFDI4Biodiversity and contribute their expertise in the areas of long-term archiving and interface design. The indexing metadata recorded in the archives' own specialized information system can additionally be made available to the biodiversity research community via an ABCD interface.

A novel tool to detect non-random time trends in assemblages

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Identifying temporal shifts in paleo-assemblage composition is a challenging task, yet it is a highly valuable skill. Accurately recognizing non-random trends in paleo-assemblages is crucial for enhancing our understanding of the impacts of human activities and climate change on biodiversity. However, identifying these trends presents challenges due to temporal variations in the quality of the (sub)fossil record and the scarcity of consecutive samples within the trend period, often falling short of statistical requirements.

To overcome these obstacles, we present a method that addresses these limitations and enables the identification of non-random trends using only three samples within a trend period. Using real data on paleo-assemblages, we demonstrate the method's effectiveness in pinpointing Holocene pollen successional sequences, such as those resulting from fire management practices or occurring in abandoned settlements. Furthermore, we showcase its applicability to Cretaceous rudist chronosequences following documented adaptive radiations and mass extinctions.

While the method is particularly suited for paleo-studies with sample intervals spanning decades or longer, it can also be employed to analyze recent successional sequences and spatial transects by substituting time with space.

SESSION 54:

PopBio for Biodiversity

RegioDiv: The design of generalized seed zones based on multi-species synthesis of spatial genetic structure

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A generalized system of 22 "regions of origin", i.e. seed zones, is in action since 2010 for the production and use of regional grassland seeds in the German Regiosaatgut system. However, the system has been questioned because it is based solely on ecoregions, lacks a foundation in genomics and adaptation, and has purportedly too small seed zones. The RegioDiv project has established a spatially highly resolved empirical data set of genetic structure of >30 grassland species across Germany. Here, we use this dataset for an across species synthesis of spatial genetic structure in order to construct generalized seed zones. We used three parallel approaches to synthesize the genomic structure and to cluster 72 subregions, based on 1) PCA medoids, 2) ancestry coefficients of Admixture analyses and 3) genetic distances. We used kpod, k-means clustering of partially observed data, and multiview spectral clustering followed by consensus partitioning to construct seed zones. We developed a quality descriptor of the amount of genetic variation encompassed by a particular seed zone design which can be used to evaluate and compare design solutions. The quality descriptor of the current 22 zones is used as benchmark to find solutions that are 1) as least as good as the current system and 2) have a lower number of zones.

We find first, that algorithmic cluster solutions often are spatially coherent as a result of both cross-species similarities of spatio-genetic structure and the general pattern of isolation-by-distance. Second, we find that seed zone systems with not more than 16 zones can be constructed with the same quality as the current one based on our quality descriptor. Third, the rather shallow structure of the multi-species dataset allows for many valid design solutions which gives flexibility and allows for the integration of stakeholder interests in order to develop a practical seed zone system.

Matching patterns of genetic variation in a common grassland species to existing seed transfer zones

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Introduction of large amounts of seeds is essential for restoration success in temperate grasslands. As in many countries, seed transfer of herbaceous plants in Germany is based on a seed transfer zone system. So far, these seed transfer zones are based on abiotic parameters and it is largely unknown to what extent these seed zones represent the patterns of genetic variation within plant species. Incorporating empirical data on genetic structure is crucial to avoid detrimental effects of seed transfer like outbreeding depression, maladaptation and homogenising cryptic diversity. The ongoing RegioDiv project produces nation-wide data of genetic structure of representative common and widespread grassland species and will propose alterations to the current seed zone system. Future climate conditions are likely to impact adaptation of grassland species. It is therefore imperative to consider climate change when evaluating seed zones from a genetic structure perspective.

Here, we used RegioDiv's SNP marker data set of Galium album and freely available climatic and edaphic data to conduct redundancy analysis (RDA). We selected environmental variables, partitioned genetic variance (into neutral structure, environment, geography), identified potentially adaptive loci, calculated adaptive indices across the landscape and deduced the genomic offset, largely following a published procedure.

We selected eight environmental variables and found 58 loci to be associated with them. Judging from the adaptive index, some adaptations will lose their value in future climate, while on the other hand there will be novel climatic conditions for which no adaptations exist within Germany. According to the genomic offset, climate change will undermine adaptation of G. album more in the east of Germany than in the west with an additional area of increased risk in the South German Scarplands. We discuss the relevance of these predictions for the current seed zone system and point to directions future research could take.

Differences in plasticity among forest tree species and populations can inform future management strategies

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21st-century climate models predict changes faster than forest trees' natural migration capacity. Hence, phenotypic plasticity is vital for the viability of species and populations in their current location. Additionally, within the conservation and forestry communities, there is growing interest in assisted migration to adjust in advance forest species composition to future climatic conditions.

We investigated the phenotypic plasticity of five economically and ecologically important forest tree species (Fagus sylvatica, Picea abies, P. engelmannii, Pinus contorta, Pseudotsuga menziesii) by using data originating from large networks of international provenance trials. We found a significant effect of the provenance of the trees on their growth performance, in addition to the effect of the trial site. This indicates that genetic differences within tree species might be relevant for future efforts of reforestation of assisted migration.

In order to quantify the phenotypic plasticity of the provenances in exam, while accounting for the vastly different range of trial conditions within and among species, we calculated the Environmentally Standardized Plasticity Index (ESPI, Valladares et al. 2006) for their height growth. We found significant differences in ESPI among species, and more importantly among different provenances of the same species. The choice of tree provenances for planting can have important implications. One may aim to maximize yield stability (low ESPI) or ensure higher adaptability (high ESPI) to local conditions as an insurance strategy against future climate uncertainties. Lastly, we investigated the correlation between ESPI and climate at the origin of the provenances, finding no clear pattern.

The ESPI is a relatively simple index to calculate, and can be used to supplement information on average growth performance in order to better guide the choice of provenances to adapt the forest of the present to climate change.

Net root growth in winter is higher than in summer in a dominant European forest tree

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Belowground biomass in forest ecosystems contributes substantially to net primary production. In the temperate zone, roots are potentially able to grow throughout the entire year and do not experience winter dormancy, but several studies show decreased growth during the cold season.

Here, seasonal patterns of root growth in Common beech were analysed at its north-eastern distribution range at nine sites along a natural gradient in mean winter temperature of >4 °C. Roots of mature trees were observed using minirhizotrons and root scans were taken in autumn, at the end of winter as well as in summer. Additionally, monthly root growth data for the equivalent seasons at one site within the gradient were analysed to get a better understand of fine scale growing patterns in each season.

Surprisingly, a positive net root growth was observed in winter (M = 0.79 mm/cm²100d), while net root growth during the main growing season was negative (M = -0.78 mm/cm²100d). Root growth in winter (M = 1.78 mm/cm²100d) was higher than in summer (M = 1.29 mm/cm²100d). Root decay was relatively low in winter (M = 0.99 mm/cm²100d) and more than twice as high during summer (M = 2.08 mm/cm²100d). Temperature data show that no soil frost occurred within the observation period (minimum temperature in 8 cm depth: 0.5 °C).

The high winter root growth of Common beech may be risky because new fine roots are vulnerable to unexpected soil frost events, but on the other hand it indicates a big potential to adapt to dry summers that are predicted by climatic models. The study expands our knowledge about root growth dynamics considerably and is also important for biogeochemistry and the global carbon budget.

Assessing Winter Cold Sensitivity and Growth Dynamics of European Broadleaf Species in Response to Changing Winter Climate

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Climate change is a challenge for tree species to adapt to increasingly changing and unpredictable environmental conditions. While studies have predominantly focused on the effects of higher summer temperatures and drought events on tree health and mortality rates, the proven influence of varying winter temperatures on tree growth has been neglected. Warming winter seasons result in a decrease in insulating snow cover, exposing soil and associated vegetation to still-occurring frost events. The aim of this study is to gain insight into the phenological and physiological responses of trees in different realistic soil frost scenarios. We do so with juveniles of three broadleaf tree species commonly found in the European temperate zone (Fagus sylvatica, Betula pendula, Quercus petraea), representing different levels of cold sensitivity and both central and cold-marginal provenance. We exposed the individuals to either harsh (-8°C), mild (-2°C) or no-frost (+2°C) conditions in a two-weeks climate chamber pot experiment. The trees' above- and belowground material was harvested on three different dates throughout the subsequent growing season.

While no significant differences were observed among the treatments after the first leaf-out, the -8°C treatment showed significant differences in total masses at the end of the growing season, exposing a total decrease by 46% in beech and 82% in oak compared to no-frost conditions. Furthermore, mild frost even seems to stimulate root growth. Which root compartment was more sensitive depends on the sampling date and species. In general, aboveground biomass exhibited a similar decrease to that of belowground. The harsh frost treatment caused moderate leaf-out delay in oak and strong delay in beech, while no delay was observed in birch. Winter climate change is likely to impact root growth, highlighting the importance of conducting further research to enhance our understanding of how it influences forest growth dynamics in the future.

Three types of drought – effects of experimental treatments and initial plant size on plant responses

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In many parts of the world, drought events are expected to become more frequent under global change, and the effects of drought on plants are thus frequently studied in experiments. However, the way how drought is applied may influence plant responses and the effects of drought on plant performance may depend strongly on plant size. We subjected small and large individuals of five herbaceous plant species (Dactylis glomerata, Plantago lanceolata, Sanguisorba minor, Sinapis alba and Trifolium repens) to a control and three different experimental drought treatments in a greenhouse. Plants either received regular but low amounts of water (continuous drought), or were subjected to periods without watering until most individuals of a species were wilting (periodic per species) or until each specific individual was wilting (periodic per individual). We measured the performance and several functional traits of the plants in response to drought. Plants responded plastically in several traits, e.g. by increasing their root mass fraction (all species), reducing leaf size (Trifolium) or leaf width (Plantago). However, these responses were much stronger under continuous drought than under the two periodic drought treatments. Reproduction was either increased or delayed by the different types of drought depending on species. Moreover, the drought treatments had very different effects on the size distribution of plants. Larger individuals started to wilt earlier than smaller individuals. At harvest, size variation was reduced under continuous drought, but remained high under control conditions and under individual periodic drought. Our results highlight that how drought is applied can strongly influence the results of ecological experiments. In particular, phenotypic responses measured under continuous drought treatments may not be representative, and the drought tolerance of individuals may only partially be due to genetic pre-adaptations, but also due to their smaller size at the beginning of the drought treatment.

A drought year favored drier-adapted origins over local origins in a reciprocal transplant experiment along a rainfall gradient

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When plant populations show local adaptation along climatic gradients, climate change may displace them from their current fitness optima. Unclear is whether foreign genotypes originating from sites that approximate future climatic conditions can attain higher fitness and support existing populations, because foreign genotypes may lack important adaptations to other local conditions besides climate.

We conducted a fully reciprocal transplant experiment with the winter annual Biscutella didyma across four sites along a steep natural rainfall gradient in Israel. It experienced an exceptional drought event that approximated future climatic conditions. This unique opportunity allowed to test whether genotypes transplanted from drier sites outperform local genotypes under a drier climate.

The four population origins showed consistent clines in germination fraction, phenology, and vegetative biomass that suggest local adaptation along the rainfall gradient. In terms of fitness (survival, seed number), however, local origins were outperformed by genotypes originating from the next-drier site along the gradient.

Our results suggest that the experienced drought conditions favored origins from drier conditions over local origins despite local biotic interactions. Genotypes originating from drier sites may thus support existing populations and reduce their vulnerability to climate change. Moreover, we conceptualize under which conditions foreign genotypes may benefit local populations in general, which adds to clarify the importance of local adaptation to climatic and nonclimatic factors for populations under climate change.

Evolution of plasticity prevents post-invasion extinction of a native forb

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Exotic plant invaders pose a serious threat to native plants. However, despite showing inferior competitive ability and decreased performance, native species often subsist in invaded communities. The decline of native populations is hypothesized to be halted and eventually reversed if adaptive evolutionary changes can keep up with the environmental stress induced by invaders, i.e., when population extinction is prevented by evolutionary rescue (ER). Nevertheless, evidence for the role of ER in post-invasion persistence of native flora remains scarce. Here, I explored the population density of a native forb, Veronica chamaedrys, and evaluated the changes in the shade-responsive traits of its populations distributed along the invasion chronosequence of an exotic transformer Heracleum mantegazzianum, which was replicated in five areas. I found a U-shaped population trajectory that paralleled the evolution of plasticity to shade. Whereas V. chamaedrys genotypes from intact, more open sites exhibited a shade-tolerance strategy (pronounced leaf area/mass ratio), reduced light availability at the invaded sites selected for a shade-avoidance strategy (greater internode elongation). Field experiment subsequently confirmed that the shifts in shade-response strategies were adaptive and secured post-invasion population persistence, as indicated by further modeling. Alternative ecological mechanisms (habitat improvement or arrival of immigrants) were less likely explanations than ER for the observed population rebound. These results suggest that V. chamaedrys survived because of adaptive evolutionary changes operating on the same time scale as the invasion-induced stress, but the generality of ER for post-invasion persistence of native plants remains unknown.

Rapid adaptation of the plant species *Galium wirtgenii* to novel conditions in restored meadows

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The environmental conditions of degraded sites commonly differ from the natural ones. The success of ecosystem restoration of such habitats might significantly depend on whether restored populations are able to rapidly adapt to these novel conditions. However, rapid evolution during restoration has been only rarely studied. Here, we tested for rapid adaptation of a short-lived perennial plant Galium wirtgenii in restored alluvial grasslands. The grasslands have been restored 20 years ago on former arable land by the transfer of hay from nearby natural meadows. The restored sites are more productive than the natural ones, and are mown one to two months earlier. To test for rapid adaptation, we collected seeds from 48 restored and 18 natural sites that served as hay donor, and grew the offspring plants in a common garden. To simulate mowing, we clipped half of the plants when they have been in full bloom. Plants from restored sites grew slower during the first weeks, and flowered earlier. This suggests rapid evolution of an escape strategy, when plants at restored sites hurry to complete their life cycle before they will be mown. We did not detect any differences in regeneration after mowing, probably because regenerating plants rarely produce seeds in the area and thus, rapid regeneration does not enhance fitness. In summary, we found evidence for rapid adaptation to the novel environmental conditions in restored sites, which probably contributed to successful restoration of Galium wirtgenii populations in the restored grasslands.

Early flowering phenology reflected in organs belowground

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Perennating organs can allow herbs to store carbon. Herbs exhibit interspecific variation in the proportion of biomass allocated to perennation organs and competing hypotheses have been proposed to explain this variation. Storage has been considered a means for some species to support growth when resources are not sufficient to cover demands. Alternatively, storage has been interpreted as surplus carbon that cannot be used for growth when a plant is limited by availability of nutrients or water. To test these hypotheses, we analyzed relative investments of biomass into rhizomes in 20 temperate herbaceous species and asked first whether rhizome biomass scales with biomass of organs aboveground and then whether clonal growth traits, phenology or environmental conditions can explain variation in relative biomass allocation into rhizomes. We found isometric scaling between rhizome biomass and leaf biomass. Having taken this scaling relationship into account, we showed that interspecific differences were largely explained by differences in phenology, with relatively larger biomass investment into rhizomes in early flowering species. Rather than representing a deposition of surplus carbon when conditions limit growth, we associate the greatest relative investments into rhizome biomass with a capital breeder strategy where storage allows temporal separation between acquisition and reproductive allocation. Such a strategy facilitates flowering at a time and in conditions when available resources are otherwise insufficient for reproduction.

Ring-formation in grasses along the Namib Desert: from regional drivers to local habitat constraints

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Ring-formation in plants occurs worldwide in the more arid regions. However, it is not a well-studied phenomenon and only few plant species within a larger eco-region may actually form such circular rings. We have recently discovered a dozen of ring-forming grass and forb species along the Namib Desert but surprisingly, these plant rings have never been studied before.

Within a new DFG-funded project, we focused here on two exemplary perennial grass species, Eragrostis nindensis and Stipagrostis namaquensis, that both form so-called tussock rings due to a central dieback. The Eragrostis species forms large palatable tussocks in the moister interior of Namibia but towards the drier western part of the country, doughnut-like rings form due to increased aridity stress. Across 900 km, we mapped the outer diameter of this grass and the interior ring diameter at more than 20 study sites, spanning a rainfall gradient from 90 to 250 mm mean annual precipitation (MAP). Somewhat unexpectedly, there was no correlation between the size of the grasses or their ring diameters and rainfall variation, indicating that variation in local habitat conditions must have been a more dominating determinant of ring-formation than MAP per se.

In a second part of the study, we investigated in detail the distribution and ring-formation of Stipagrostis namaquensis, which primarily occurs in drainage channels. We drone-mapped this grass species within a 200 m × 200 m study plot at a very high image resolution, and we generated a fine-grained digital terrain model of the habitat. Furthermore, we undertook soil-moisture measurements within the entire study plot and also measured the differences in water infiltration at and around the plant rings. Using spatially-explicit statistics and pattern analysis of the grass rings, relative to the distribution of soil moisture and topographical variation, we will demonstrate how local habitat constraints may shape plant ring-formation in arid Namibia.

Phylogenetic relationships of plants affect priority effects via niche preemption and modification

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In recent years, there has been increasing interest in the role of order of species arrival in community assembly research and priority effects were shown to play a significant role in assembly processes of various communities. However, very little is known about the underlying mechanisms, which can be categorized into niche preemption and niche modification, and how these are affected by evolutionary processes.

In this study, we investigated the role of phylogenetic distance and biogeographic history for the priority effect of an early arriving plant species (resident) on different life stages of a later arriving one (invader). For this purpose, we conducted two multispecies greenhouse experiments, one focusing on niche modification and the other one focusing on niche preemption and modification. For both experiments, we created 10 species "triplets" representing a gradient of phylogenetic distance between resident and invader from 5 to 270 Myr of evolutionary history. Each triplet consisted of a native invader, a native resident, and an exotic resident, allowing us to create one sympatric and one allopatric resident-invader pair per triplet. The invader's performance was assessed by monitoring the emergence and survival of invader seedlings and measuring of the per capita biomass of adult individuals.

We found evidence for stronger priority effects between closely related species. The application of structural equation models allowed us to identify some of the underlying pathways. The biogeographic history, however, did not affect the outcome of interspecific interactions.

Our study provides experimental evidence for the importance of phylogenetic distances for the strength of priority effects and emphasizes the relevance of belowground processes as well as the invader's ontogeny for more precise predictions of interspecific plant interactions.

Seasonal effects on herbivory and predation in a subtropical tree species richness experiment

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Biodiversity loss is an urgent challenge globally affecting ecosystem functions. Much is still not known on how it affects two of the fundamental ecosystem processes, herbivory and predation in forests. Especially, seasonality is often overlooked in studies of plant species richness effects on higher trophic levels.

BEF-China is the world's largest BEF (Biodiversity-Ecosystem Functioning) experiment, located in mountainous area in subtropical China. As part of the research consortium TreeDi «Tree Diversity Interactions: The role of tree-tree interactions in local neighborhoods in Chinese subtropical forests», we focused on how tree richness, plant nutritional quality, topography, and forest structure influence herbivory and predation pressure across tree richness gradient. We repeated predation estimation across seasons from early spring to autumn, and estimated herbivory from the same trees at the end of rainy season in mid-summer and again after dry season close to end of the growing season. Predation estimation was done using artificial caterpillars, from which attack marks by various predator groups were identified, and herbivory was estimated as the lost leaf area.

Herbivore damage accumulated more during the rainy than dry season, but differences between trees of varying nutritional content, most pronouncedly between deciduous and evergreen trees, increased during the dry season. This also led herbivory to respond seasonally to tree species richness more than predation. Our results also showed that the response of predation to forest structure and topography varied seasonally, with predation pressure being higher in areas of presumably lower amounts of direct sunlight and higher humidity during the dry season. In contrast, herbivory increased in drier and more sun prone conditions. Our study demonstrates that seasonality is an important factor to take into account to improve the understanding of how primary producer species richness shapes ecosystem functions.

Tri-trophic interactions affect resource diversity in foraged patches, but not resource diversity at landscape level: studies on a predator-rodent-seed system

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Greater diversity of species at the resource level increases ecosystem stability. Although this pattern is recognised in ecology, it is important to further our understanding of the processes that maintain resource diversity. In this study we investigated how tri-trophic interactions affect local and regional diversity of a resource over time, using a tri-trophic predator - rodent (consumer) – seed (resources) system. With (empirical) experimental and modelling methods, we assessed how consumer density, behaviour, and resource functional traits influenced diversity at the resource level, using the novel DivGUD method, which measures diversity of resources remaining after a consumer quits harvesting. We found that diversity at the resource level was affected by indirect tri-trophic effect of predation (risk while foraging) on consumer behaviour, via affecting the preference of consumers for functional traits of resources. Resource communities in risky foraging microhabitats had higher diversity compared to those in safe foraging microhabitats. Meanwhile, a modelling study of the same system suggested an additional effect of consumer density on diversity in patches and on landscape level that developed with time, but this same effect was not detected in our short term empirical experiments. Regional diversity remained similar between density treatments empirically, but model results suggested an effect over longer time periods. Taken together, our results show that consumer decisions, that are affected by predation risk and/or consumer competition, can act as a mechanism determining species diversity on the resource level.

Theoretical assessment of persistence and adaptation in weeds with complex life cycles

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Perennial weeds like Sorghum halepense cause significant economic losses and pose a major challenge to weed management due to their ability to spread quickly through sexual and asexual reproduction. Conventional agriculture has primarily relied on herbicides for controlling weeds since the late 1960s. However, overreliance on herbicides has led to the widespread evolution of herbicide resistance in various weed species. Herbicide resistance in perennial weed species like Sorghum halepense poses particular challenges due to their two pathways of reproduction and threatens global food security. Mathematical modelling has proven valuable in studying the long-term population dynamics and herbicide resistance adaptation of weeds. However, few models have dealt with perennial weed species due to their complex life cycle. We present a theoretical study assessing the persistence and adaptation of perennial weeds, incorporating the whole perennial life cycle along with control measures of herbicide application and tillage.

Our model captures the occurrence of target-site resistance against the applied herbicides. The study shows that integrating tillage with herbicide application effectively reduces weed densities and the risk of control failure without delaying resistance adaptation. Combining two herbicides with different modes of action delays resistance evolution and suppresses such seed- and rhizome-propagated weed populations to a level that escapes from control are unlikely. An outstanding feature of our model is the simplicity of the approach while capturing the complexity of the perennial life cycle in sufficient detail to inform sustainable agricultural practices.

A variety of individuals in a population: individual heterogeneity and individual measures of fitness from an evolutionary demography standpoint

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Whilst there has been tremendous progress, over the past twenty years, in the statistical analysis of the differences between the individuals of a population, the evolutionary and demographic consequences of these differences are still poorly understood. This is true in varying environments where such individual heterogeneity leads to response diversity. Some of these difficulties, however, stem from a problematic theory, already, in the much simpler framework of constant environments. These problems are, in part, caused by the lack of a general agreement, in the field of evolutionary demography about the decomposition of individual heterogeneity into a fixed and dynamic component.

Consequently, while a population is nothing more than the sum of its individuals, there is yet no explicit connection between individual and population measures of fitness. For instance, we are still lacking a satisfactory definition for an individual measure that can be properly related to the population growth rate. Much more consequential for epidemiology and population ecology is the fact that the current state-of-the-art formula for the so-called Net Reproductive Rate (R0), the population "equivalent" to the number of offspring a new-born individual is expected to produce during its lifetime, does not correspond to its definition. Similarly, generation time, which directly connects growth rate and net reproductive rate, has recently started to appear as an individual measure in the literature (characterising intraspecific slow-fast continuum); still, in such papers, one does not relate generation time of individuals and population generation time.

During this talk, we will briefly present a set of model-based definitions for fixed and dynamic components of individual heterogeneity. These will then allow us to put forward formulas for the individual contribution to the asymptotic growth rate and its generation time, as well as a corrected formula for R0.

Do flower visitors carry a more conspecific pollen load at night?

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Studies on plant-pollinator interactions are biased towards diurnal interactions. However, studying nocturnal interactions is crucial to advance our understanding of global change threats. Nighttime temperatures will increase faster than daytime temperatures. Moreover, some nocturnal pollinators are long-distance migrants that can rapidly respond to climate change. Nocturnal and diurnal pollinators can therefore be impacted differently by climate change. In Swiss meadows, we analyzed pollen loads carried on the body of nocturnal and diurnal flower-visiting insects during 24-hour cycles. To study whether nocturnal pollinators have a comparable potential to transfer conspecific pollen (i.e. same species as the visited plant) to diurnal pollinators, we compared the percent conspecific pollen carried by nocturnal and diurnal insects. We identified 1322737 pollen grains carried by 3626 flower visitors of which 21.5% were captured at night. Each flower visitor carried between 0 and 20742 pollen grains from up to 18 plant species. Flower visitors carried fewer pollen grains at night, and pollen load was correlated with pollen diversity. Over a 24-h cycle, percent conspecific pollen was always larger than 40%. Time significantly explained the variation in percent conspecific pollen. A drop in percent conspecific pollen in the morning corresponded to the peak of Diptera visits, and peaks of percent conspecific pollen in the afternoon and at night corresponded to peaks of Hymenoptera and Lepidoptera visits, respectively. Our results indicate that nocturnal flower visitors may non-negligibly contribute to pollination, and may be as efficient as or even more so than diurnal ones. Unraveling the importance of nocturnal pollinators will not only help to understand the likely disproportionate threats from global change on nocturnal plant-pollinator interactions, but will also provide a relevant basis for future guidelines for crop pollination under insect declines.

An NGS-based approach to investigate the evolutionary dynamics of myrmecophytism in the Southeast Asian *Macaranga* (Euphorbiaceae) ant-plant lineages

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Generalist ant-plant interactions brought about by extrafloral nectaries and elaiosomes are known to impact macroevolutionary patterns by enhancing diversification rates in plant lineages that possess them. However, there is little evidence to suggest that myrmecophytism, a highly specialised ant-plant symbiosis, similarly promotes higher diversification rates in host plant lineages. In our pursuit, we investigated the evolutionary dynamics of myrmecophytism in the pioneer plant genus Macaranga (Euphorbiaceae), one of the most species-rich ant-plant groups with ~30 myrmecophytic species. We generated the most comprehensive phylogeny of myrmecophytic Macaranga and its closet non-myrmecophytic relatives to date using sequence data derived from genotyping-by-sequencing, a next-generation sequencing technique. Molecular dating and historical biogeography revealed that myrmecophytism in Macaranga evolved ~18 mya on the island of Borneo in aseasonal tropical Sundaland. Ancestral state reconstruction supported a case of a single origin of myrmecophytism in the genus with at least four independent losses, suggesting that the trait may be easily lost. Both trait-dependent and trait-independent diversification rate analysis methods did not support the hypothesis that myrmecophytism enhanced diversification rates in Macaranga. In fact, phylogenetic patterns in clades that are overly specialised in terms of ant partners point to higher extinction risks, suggesting that myrmecophytism may potentially be an evolutionary dead end in these cases. An integrative analysis of phylogeography, ecology of host plants, and Sundaland's complex geological history reveals that the diversity of myrmecophytes in Macaranga is more likely tied to Sundaland's topographical past, especially to the emergence of Crocker Range in the late Miocene in northeast Borneo, further evidencing that myrmecophytism did not play a straight forward role in enhancing diversification rates in this group.

Sex-specific lifespan in insects: a comparative analysis based on published data

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Determinants of lifespan (= longevity) are of broad theoretical and applied interest. There are large intraspecific differences as well as vast variability among related species, e.g., between sexes. While lifespan patterns and determinants in vertebrates are well understood, similar studies on invertebrates, including insects, are scarce. In our work, we focus on sex differences in adult lifespan in insects, i) synthesizing patterns across major insect orders, and ii) asking to which extent are these sex differences in adult lifespan driven by sex differences in body size (sexual size dimorphism).

We conducted a comparative analysis focused on patterns and determinants of sex differences in longevity. For this purpose, we collated a detailed database of published sex-specific data on insect longevity. Across the examined insect taxa, females had a significantly longer lifespan. When focusing on specific orders, this trend could be confirmed for two orders out of five studied - Hemiptera and Hymenoptera. In the rest of the orders, the sexes showed no obvious differences in lifespan (Coleoptera, Lepidoptera), or there was a tendency for a longer female lifespan (Diptera).

Another part of our work aims at the relationship between sexual size dimorphism (SSD) and sexual differences in longevity. While we can find many publications predicting this association (larger-bodied individuals live longer, which could also be expected at the interspecific level), no significant relationship was found, although there was a tendency for sex differences in longevity to increase with sexual size dimorphism.

Provision of nectar resources compensates for loss of potential fecundity arising from warmer spring temperatures for a overwintering butterfly

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Declining butterfly abundance over recent decades is associated with habitat loss and increasingly warmer springs. Warmer temperatures pose a problem for capital breeders, especially those species that enter diapause as a pupa or adult, since a higher metabolic rate depletes lipid store reserves used for egg production at a greater rate. While the adults can collect additional carbohydrate and amino acid resources from nectar plants upon emergence it remains unclear to what extent access to flowering plants can limit the predicted loss in potential fecundity. To investigate this relationship, we undertook a three-way factorial experiment on Pieris napi, a model butterfly species that overwinters as a pupa, to evaluate the consequences for fitness of access to sugar solution (ad libitum vs. water control) for pupae exposed to varying post-diapause temperatures (6 vs. 2 °C) and duration times (12 vs. 6 weeks). We found a that a warmer and longer post-diapause time significantly increased the proportion of body mass lost between initial pupation of adult emergence. This proportional loss was found to limit individual fecundity of females, and was equal in effect size to the influence of body mass itself. However, since 1) access to sugar solution had such a strong effect on lifespan and rate of egg laying and 2) warmer spring temperatures increased rate of egg laying during the first week, the consequences of a loss in potential fecundity had limited impact on individual fitness. We support our empirical findings with a structural equation model to integrate both the direct and indirect effects of these treatments on fitness. We conclude that the greatest risk to fitness of a warmer spring may arise from a potential phenological mismatch in emergence time and nectar plant flowering rather than the costs of greater resource depletion during the post-diapause quiescence period.

Towards understanding mobile link movements in agricultural landscapes – An experimental assessment of energy expenditure in European brown hares

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Mobile link movements play a crucial role for connecting habitats and maintaining biodiversity. In fragmented agricultural landscapes, wildlife species such as European brown hares (***Lepus europaeus***) facilitate dispersal of e.g. plant species across habitat remnants. Previous work has shown that space use and overall activity of hares depend on the structural diversity of the landscape and sudden resource changes through mowing or harvesting. To understand the movement capabilities and decisions that lead to vital mobile link movements, it is necessary to quantify the energetic costs of these movements. Directly measuring energy expenditure of wildlife without impeding their natural behavior is virtually impossible, hence a proxy must be used. It has been established that energetic cost increases with overall dynamic body acceleration and heart rate, however the available data does not allow to infer the energy expenditure of a species without prior calibration, particularly when using acceleration measurements of tagged animals as a proxy. In our study, we therefore measured daily energy expenditure via doubly labeled water, body acceleration, and heart frequency of captive hares, in two seminatural enclosure experiments. Classifying their activities based on continuous video observations and accounting for intra-specific differences in personality, we calculated a species-specific calibration relationship. Our calibration enables a precise estimation of the activity-specific energy expenditure of wild hares and facilitates the assessment of the immediate influence of different agricultural practices and landscape structures on hare movements. Our study also offers vital data for researchers studying similar species to comprehend the relationship between acceleration data, heart rate, and energy expenditure.

The effects of wildfire on spider and land bug communities in an unmanaged heathland wilderness area

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Extreme droughts result in higher fire frequencies and severities in Germany and half of the burned forest area in 2019 was located in the federal state of Brandenburg. In June 2019, forest and bog habitats were affected by a severe wildfire in an unmanaged heathland area (Lieberoser Heide) which is a former military training site, that is now protected as wilderness area under natural succession. In Lieberoser Heide, eight replicated locations with triplets of three habitat types (unburned forest, burned bog, burned forest) were sampled monthly over ten months using emergence traps to determine the effect of wildfires on spider (Araneae) and land bug (Heteroptera) communities in heathland areas. Spider and land bug abundance and species richness were significantly higher in the unburned forest controls compared to the burned forest and bog habitats. The two taxonomic groups differed significantly in their species composition between the unburned forest and the two burned habitats types, but not between the two burned habitat types. Agyneta rurestris (spider) and Eremocoris abietis (land bug) were characteristic species for the burned forest and bog habitats, Pardosa lugubris group (spider) and Taphropeltus contractus and Kleidocerys resedae (land bugs) were characteristic for unburned forest sites. Spider abundance and diversity peaked towards summer in the end of the sampling period, while land bug abundance was high in autumn at the beginning of the sampling period and in summer. Both, spider (N=7) and land bug (N=5) communities included red listed species, for example Xysticus luctuosus (spider) and three land bug species in the burned habitats and five spider species and Acalypta nigrina (land bug) in the unburned habitat. Our results highlight the importance of wildfires in unmanaged heathland habitats for the conservation of rare or endangered species, but also document the initial negative effects of wildfires on spider and land bug diversity.

Adaptive evolutionary, transgenerational, and plastic shifts in flowering time in Mediterranean annual species along a rainfall gradient

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Earlier flowering is considered a key pathway how annual plant species adapt to increasing aridity. Later flowering, in contrast, is assumed to confer better competitive ability under mesic conditions. Here, we add more facets to this notion by investigating changes in flowering time at different spatial and temporal scales.

We sampled 12-15 populations of 5 Mediterranean annual species along a natural rainfall gradient in Israel (89-926mm annual rainfall; large spatial scale) and for each population from corresponding North (wetter) and South (drier) exposed hill slopes (small spatial scale). We raised these plants under standard conditions in the greenhouse. For two species, we raised also a second generation under drought, competition, and control treatments.

In line with theory, all species showed earlier flowering toward drier populations, with a total difference of 10-25 days along the large-scale rainfall gradient. Similar patterns were found at small spatial scale where plants from drier South slopes tended to flower 1-2 days earlier than their conspecifics from corresponding North slopes. However, the difference between North and South slopes vanished in the second generation, suggesting that the first-generation difference was caused by adaptive transgenerational plasticity. Also matching theory, plants under competition postponed flowering plastically by 3-5 days while plants under drought advanced flowering by 3 days compared to control plants, thus indicating adaptive plasticity in response to both treatments.

Our results suggest that plants adjust flowering time via evolution, transgenerational plasticity, and within-generation plasticity to match their environmental conditions.

Fungal ectoparasites increase winter mortality of ladybird hosts despite limited effects on their immune system

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Winter represents a challenging period for insects inhabiting temperate regions. A plethora of studies have investigated how environmental conditions such as temperature affect insect overwintering success. However, only a few studies have focused on biotic factors and the mechanisms affecting the overwintering performance of insects. Here, we investigated the effects of the parasitic fungus *Hesperomyces virescens* on the overwintering performance and immune system functioning of the invasive ladybird *Harmonia axyridis*. Winter survival was significantly lower for infected than for uninfected ladybirds. Body mass loss during overwintering tend to be higher for infected individuals compared to uninfected ones and for larger ladybirds. In addition, parasitic infection reduced post-winter longevity without food in male but not female ladybirds. Total haemocyte and protein concentration as well as antimicrobial activity against *Escherichia coli* significantly decreased during ladybird overwintering. However, haemolymph parameters were only poorly affected by *Hesperomyces* infection, with the exception of antimicrobial activity against *E. coli* that tended to be higher in infected ladybirds. Interestingly, none of the pre-winter haemolymph parameters were good predictors of ladybird winter survival. Overall, our results indicate that energy exhaustion unrelated to immune system challenge is the most probable explanation for increased overwintering mortality in infected ladybirds.

Overestimated importance of plant-soil feedbacks for Janzen-Connell effects in natural grasslands: Evidence from the field

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Janzen-Connell effects state that host-specific seed predators, herbivores and pathogens act in a density and/or distance dependent manner to reduce the survival of seeds, seedlings and juvenile plants close to conspecific adults. So far, most evidence for Janzen-Connell effects comes from trees. Negative plant-soil feedbacks (PSFs) are often considered Janzen-Connell effects. However, most PSF experiments are performed under highly controlled and artificial conditions without spatial context. We tested the Janzen-Connell hypothesis in natural grasslands using *Jacobaea vulgaris*, which shows a strong negative PSF. Our hypothesis was that in the field, the density of rosettes near flowering *J. vulgaris* plants will be lower than expected from a random spatial distribution due to negative PSFs. To test this, in 27 plots of 8 × 8 m with varying densities of *J. vulgaris*, we mapped the spatial distribution of all seedlings and adult (flowering) plants. The density of rosettes was generally lower than expected from null models at close distances from flowering plants. We then collected soil underneath and 0.5-meter away from flowering *J. vulgaris* plants, and we measured seed germination and plant growth in these soils in a growth chamber experiment. Seed germination was higher in away soil than in soil from underneath adult plants. Biomass, however, did not differ between the underneath and away soil. Our study provides field spatial-based evidence for Janzen Connell effects of *J. vulgaris*, and suggests PSFs play a minor role in mediating Janzen-Connell effects.

Vegetation and arthropod responses to bird, bat and ant exclosure experiments across forest strata in Japan

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Top-down (predation) and bottom-up (plant defenses) effects are between the factors known to influence the herbivory of trees and the composition of invertebrate communities. These forces can have a different impact in different forest strata. To study their relative importance, we performed full season predatory exclosure experiment in Tomakomai experimental forest, in Japan. We selected 8 plant species per forest understory and forest canopy and exposed them to six different treatments (exclusion of: vertebrates; vertebrates and ants; ants; birds; bats; and control treatments, N = 10 per plant species and treatment in each forest strata). We collected the invertebrates before and after the experiment, sorted them to guilds and sizes. We marked before, and collected after, the experiment 30 leaves on each of the focal branches and saplings to study the herbivory which we analyzed using Adobe Photoshop and ImageJ software. We revealed a strong vertical gradient in the abundances and diversity of beetles, caterpillars, and other arthropods, with some of the groups having directly opposite vertical patterns. In canopy, only vertebrate exclusion led to a significant increase of arthropod densities by 265 % in comparison to control. Similarly, in forest understory, only vertebrate exclusion led to significantly increased arthropod densities by 84 % in comparison to control. Effect of ant exclusion did not differ significantly from control neither in canopy nor in understory. Vertebrate exclusions led to significant increases of herbivory damage by 42-36% % in canopy, and by 42-35% in understory. Our experiment thus reveals an important role of plant defenses and traits on trophic cascades, which may lower the overall very strong effect of predators on arthropods.

SESSION 55:

Mapping of Plant Traits

Plant diversity and flower colour spectra across an altitudinal gradient in the European Alps - Bee vision vs. human vision.

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Elevational gradients in high mountain ranges are particularly suitable to study patterns and drivers of plant community diversity, including plant functional trait distribution relevant for trophic interactions. However, there are only few studies that explicitly address, for example, flower resources for pollinators across the European Alps. Pollination plays an important role in structuring plant communities, yet pollinators are not evenly spread along elevational gradients. Since flower colour is under selection by pollinators, it is also expected to change with elevation. Recently, the significant discrepancy between flower colour vision by human eyes versus pollinator eyes has been discussed, which must be taken into account when considering the relationships between flower colour diversity and pollinator availability. We surveyed the plant diversity and measured flower colour spectra within three highly diverse limestone grasslands across an elevational gradient in Bavaria: (1) Hohe Leite near Bayreuth (500 m, Germany), (2) Brunnenkopf Alm in the Ammergebirge (1600 m, Germany) and (3) Hohe Mut at Obergurgl in the Otz Valley (2600 m, Austria). The plant communities were sampled according to the Eurasian Dry Grassland Group (EDGG) standardized sampling method. Additionally, we collected flowers or petals of all locally occurring, insect-pollinated plants and measured their light reflectance property using ocean optics spectrophotometer. We used the 'bumblebee color vision model', because bumblebees are representative insect pollinators from low to high elevation in the European Alps. Total species richness on 10m² ranged from 33 to 39 and showed a unimodal relationship with elevation, with a maximum at 1600m. The discrepancy between human and pollinator vision increased with elevation: while for human eyes 'white' and 'yellow' flowers increased with elevation, for bee eyes 'blue' and 'green' flowers increased.

Testing the influence of herbarium storage on the Near-Infrared Reflectance Spectroscopy-based analysis of leaf traits

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Plant responses to changes in environment can be captured through the analyses of functional traits; and accelerating environmental change increases the interest in long-term studies of trait changes. Herbaria offer large collections of samples gathered in diverse locations and times. Due to the need to preserve these specimens, options for conventional, destructive laboratory analyses are restricted. Near-Infrared Reflectance Spectroscopy (NIRS) can unlock the potential of herbaria for long-term functional studies since the measurements are fast and non-destructive. However, it requires well-calibrated models, and the unique characteristics of herbarium specimens must be accounted for. We present here a method to use NIRS for the analysis of leaf nitrogen and phosphorus content in herbaria specimens. To test whether storage conditions and herbaria treatments have an impact on spectral readings and thus the derived leaf nutrient data, we carried out three experiments in a greenhouse, and with samples that were stored in the herbarium or subjected to simulated herbarium treatments. NIR measurements were taken in different states, and partial least squares regression was used to build calibration models for each set of trait and specimen treatments, either fresh and dried, new and old, or dried and treated. Results indicate that for leaf nitrogen content, reliable calibration models can be created. For leaf phosphorus content, accuracy was comparatively lower but still useful. The experimental treatments did not negatively impact the accuracy of spectral data or predictions. Our results showcase the suitability and reliability of this NIRS-based approach on herbarium specimens for functional trait analysis.

From spectra to functional plant traits: Transferable multi-trait models from heterogeneous and sparse data

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Plant functional traits play a critical role in assessing functional diversity and its impact on the Earth system. However, obtaining extensive field measurements of these traits is challenging due to environmental variability. The emergence of space-borne hyperspectral missions offers promise for mapping these traits. Nonetheless, we still lack efficient methods to translate hyperspectral data into comprehensive plant trait information across diverse biomes, land cover types, and sensor technologies are still lacking.

Yet, the absence of globally representative data sets on reflectance data and the corresponding in-situ measurements represents a bottleneck to develop empirical models for estimating plant traits from hyperspectral reflectance. Initiatives like EcoSIS provide a growing source of hyperspectral data and plant trait observations from various vegetation types and sensors. In this study we integrated 29 datasets covering four ecosystem types across Europe and North America. By combining these diverse datasets, multi-trait models based on Convolutional Neural Networks (CNNs) were proposed to simultaneously infer multiple plant traits from canopy spectra.

We targeted 20 structural and chemical traits related to light harvesting, growth, propagation, and defense. The multi-trait CNN models outperformed single-trait CNNs and the state-of-the-art partial least squares regression (PLSR) models across various vegetation and sensor types. We found that including trait-trait correlations significantly improved overall prediction performance in the multi-trait CNN models.

This study highlights the potential of weakly supervised approaches and Deep Learning to simultaneously predict multiple traits. Such approaches address the scarcity of in-situ measurements and enhance large-scale mapping of plant traits, particularly with the increasing availability of hyperspectral Earth observation data.

Addressing the effectiveness of trait imputation methods for island vascular plants

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Island researchers are increasingly incorporating functional traits into island research, and a trait-based perspective has been shown important to determine how colonization and evolution took place on islands. Despite their importance, the lack of trait data on islands represents a significant challenge. Further, removing species with missing trait data is not ideal, as this may bias the analyses. To address the issue of missing trait data, several methods for trait imputation have been developed, particularly based on allometric and phylogenetic relationships. Nonetheless, the effectiveness of these techniques might be reduced for native island species, which are prime examples of evolutionary trait shifts in response to insularity and consequently often exhibit distinct trait combinations compared to mainland ancestors, so-called island syndromes.

In this study, we aim to improve our understanding of functional traits in islands. Particularly, we evaluated five widely used trait imputation methods: k-nearest neighbors, multivariate imputation by chained equations (mice), missForest, Phylopars, and Bayesian Hierarchical Probabilistic Matrix Factorization (BHPMF). We selected species lists and functional traits (plant height, leaf width and length, seed and fruit sizes) from the GIFT database (http://gift.uni-goettingen.de), for seven subtropical archipelagos of volcanic origin, and evaluated the performance of each method for each functional trait and for different species subsets: island endemics, island native non-endemics and mainland species. Our findings will enhance our ability to study functional traits in island ecosystems and help to understand which plant traits respond most strongly to insularity and enhance our ability to study functional traits on islands.

Functional traits of habitat-specialized (succulent) plants on edaphic islands

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Edaphic islands commonly host high numbers of habitat-specialized or endemic plant species. In the case of quartz islands in South Africa, many of these species are additionally characterized as dwarf succulent shrubs with unusual growth forms. Quartz islands form a distinct habitat island system characterized by arid edaphic conditions; and they are home to a remarkable and biodiverse flora that is found nowhere else. However, the functional traits of these plants are poorly represented in trait databases and the distinctive succulent growth forms necessitate innovative approaches to trait measurement in addition to conventional protocols. In this study, we investigate whether and how the plant functional and biogeographic traits correspond to the specific soil abiotic and spatial characteristics of the edaphic islands, in comparison to the surrounding matrix. We collected quantitative data on various traits of the most abundant perennial plant species (n = 195) found on a quartz island archipelago in the Knersvlakte nature reserve. Additionally, we supplemented these measurements with biogeographic traits obtained from existing literature. Our findings indicate that habitats on the quartz islands exhibit higher salinity levels and lower soil pH values compared to the surrounding areas. Furthermore, they are characterized by a greater proportion of leaf-succulent species with smaller growth forms, along with discernible differences in dispersal characteristics. Thus, similar to other special soils, quartz islands serve as habitats for unique plant species with distinct traits. We discuss how the soil's environmental conditions (salinity, acidity, and aridity) and selected island parameters (area and habitat diversity) might contribute to the observed trait patterns. Additionally, we explore how a functional approach can enhance the comparison of different types of edaphic islands, enabling us to gain further insights into their unique or shared characteristics.

Effects of light quality and quantity on SLA in herbs separated: mostly just quantity matters and is explained by plant traits

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Specific leaf area (SLA, inverse of LMA) is regarded as a good correlate of relative growth rate. As it is easy to measure, it has become one of the basic traits in analyses of ecological data. It is typically correlated with leaf longevity (which is much more difficult to measure) and thus is informative on "photosynthetic return on investment" balance of individual leaves. While SLA differences have been used to capture inter-specific differences in such return on investment, we know much less on intraspecific differences in it, namely in response of SLA to competition for light. Generally, plants increase their SLA when shaded, but we do not know how this varies across species and functional groups, or whether this response is due to reduced light availability or due to change in spectral light composition (as a signal of shading).

We performed an experiment with 59 herbaceous perennial species where we separately manipulated the light amount and the light quality (red/far-red ratio, RFR). The results show that variability in SLA is mostly driven by changes of photosynthetic radiation (PAR); in contrast, the effect of changed RFR was small and affected reaction of a handful of species only. There was a large inter-specific variation in their magnitude of response, ranging from almost no response to tripling or quadrupling the SLA value. The plasticity in SLA was much higher in taller plants and in plants with low mean SLA. Taller plants generally face stronger competition for light, and thus are bound to discard their lower-positioned leaves sooner, requiring faster return on investment. Lower plasticity in high-SLA species is probably due to physiological limits on leaf construction, which precludes pushing SLA values too high.

SESSION 56:

Plant Regeneration Traits

High-throughput assessment of pollen traits and variability using multispectral imaging cytometry

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Pollen functional traits allow for exploring developmental, evolutionary or community assembly processes in plants. In contrast to commonly assessed vegetative traits, however, the availability of pollen traits depicting also generative processes is relatively limited because of labor and time consuming methodological constraints. These data gaps can be addressed by multispectral imaging flow cytometry (MIFC), which allows for high-throughput assessment of morphological traits (e.g. pollen grain size) and physiological traits (e.g. fluorescence) across temporal and spatial scales. Thus, we analyzed ›635,000 single pollen images of ›500 individual plants including ›140 species that were sampled across 6 years. To validate our method we compared size estimates of pollen with literature values, which are usually based on not more than fifty measured pollen (R^2adj › 0.86). However, by measuring several hundreds to thousands of pollen per sample, we are able to derive a robust statistical measure of multiple trait values, inter- and intraspecific trait variability and even within-individual trait variability relating to ecological functions such as dispersal in air (size) or attraction of pollinators (fluorescence). Hence, our approach allows, not preventing by sampling effort, to address broad ecological questions across temporal and spatial scales.

Inferring community assembly processes from functional seed trait variation along elevation gradient

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Assembly of plant communities has long been scrutinized through the lens of trait-based ecology. Studies generally analyze functional traits related to the vegetative growth, survival and resource acquisition and thus ignore how ecological processes may affect plants at other stages of their lifecycle, particularly when seeds disperse, persist in soil and germinate.

Here, we analyzed an extensive data set of 16 traits for 167 species measured in-situ in 36 grasslands located along an elevational gradient and compared the impact of abiotic filtering, biotic interactions and dispersal on traits reflecting different trait categories: plant vegetative growth, germination, dispersal, and seed morphology.

Abiotic filtering impacted mostly the vegetative traits and to a lesser extent on seed germination and morphological traits. Increasing low-temperature stress towards colder sites selected for short-stature, slow-growing and frost-tolerant species that produce small quantity of smaller seeds with higher degree of dormancy, high temperature requirements for germination and comparatively low germination speed. Biotic interactions also filtered certain functional traits in the study communities. The benign climate in lowlands promoted plant with competitive strategies including fast growth and resource acquisition (vegetative growth traits) and early and fast germination (germination traits), whereas the effects of facilitation on the vegetative and germination traits were cancelled out by the strong abiotic filtering.

The changes in the main dispersal vector from zoochory to anemochory along the gradient strongly affected the dispersal and the seed morphological trait structure of the communities. Stronger vertical turbulence and moderate warm-upwinds combined with low grazing intensity selected for light and non-round shaped seeds with lower terminal velocity and endozoochorous potential.

We clearly demonstrate that, in addition to vegetation traits, seed traits can substantially contribute to functional structuring of plant communities along environmental gradients. Thus, the ‚hard‘ seed traits are critical to detect multiple, complex community assembly rules.

Effects of veterinary antibiotics, single and in mixture, on seed germination and early root growth of six temperate grassland species

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Worldwide veterinary antibiotics are extensively used to treat bacterial infections of livestock species. Many antibiotics are only weakly metabolised and released in large quantities to the environment through animal excretion and slurry application. There they potentially threaten seed germination and seedling recruitment of wild plant species; an aspect of land use that has hardly been studied so far.

For this reason, we tested impacts of the commonly used antibiotics sulfamethazine and tetracycline, single and in mixture, on seed germination and early root growth of six typical plant species of temperate European grasslands. In standardised germination experiments, we assessed three germination variables (final germination percentage, mean germination time, synchrony of germination) and one post-germination variable (root length) in relation to different environmentally realistic concentrations of the tested antibiotics (0.1, 1, 10 mg l-1).

Both germination and post-germination processes were significantly affected by antibiotics. With regard to tetracycline, effects on root length were much stronger and more regular than effects on germination. Among the test species, Dactylis glomerata was most sensitive to tetracycline with root length reduced on average by up to 81 % in the 10 mg l-1 treatment. However, its germination behaviour was almost insensitive to both test antibiotics. In the sulfamethazine treatments, both germination and root length were only irregularly and weakly influenced. There was virtually no indication of mixture effects of the two antibiotics on the response variables.

These results show that regeneration of wild plants from seeds may be compromised by the agricultural application of veterinary antibiotics. Within the recruitment process, especially the trait `root length´ is negatively affected, which could reduce root-soil contact in natural habitats with possible consequences for plant population growth and community assembly.

Germination and early seedling establishment of diploid & tetraploid *Centaurea stoebe*.

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Germination and early seedling establishment form the most vulnerable life stage of plants and have cascading effects on the performance in all later life stages. However, surprisingly little is known on the eco-evolutionary processes determining invasive success in this recruitment life stage.

We performed germination experiments with and without simulated drought stress and monitored early seedling development in diploid and tetraploid Centaurea stoebe. While diploids are the majority cytotype in the native Eurasian range, only tetraploids became invasive in North America. Thus, C. stoebe is an excellent model species to test simultaneously both, pre-adaptive differences in the native range (diploid vs. tetraploid) and post-introduction evolution in the invasive range (native tetraploids vs. invasive tetraploids). To acknowledge broad spatio-environmental variation within cytotypes and ranges, we sampled seeds from 202 widely distributed populations.

We found, tetraploids to germinate better than diploids with invasive tetraploids germinating even better than native tetraploids. However, these differences were not apparent under simulated drought stress. Early seedling traits did not differ between the cytotypes in the native range. Yet, seedlings from the invasive tetraploids had a higher biomass and developed the first true leaf earlier than those from the native range. Our results suggest, that a combination of pre-adaption related to superior performance of polyploids (greater and faster germination) and post-introduction evolution towards higher performance in the invasive range (greater and faster germination, greater and faster accumulation of seedling biomass) may contributed to the invasion success of tetraploid C. stoebe in North America.

Early life stage matters – effects of nitrogen and litter on germination and seedling growth of 75 grassland species

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Agricultural grasslands play an important role in conserving the biodiversity of the European cultural landscape. Land-use intensification such as increased fertilization as well as abandonment led to a loss of grassland biodiversity. However, little is known about how germination and the early plant life stage are directly influenced by nitrogen fertilizer and litter addition singly or in combination.

Therefore, we studied the effects of fertilization (100 kg N per year and ha) and litter addition (250 g per m^2) on the germination and seedling growth of 75 grassland species (16 grass species, 51 forb species, 8 legume species) in a full factorial common garden microcosm experiment. Seedlings were counted monthly and harvested as soon they had developed the first two true leaves to measure traits and seedling biomass. In general, nitrogen fertilizer reduced, while litter increased, the number of germinated seedlings. Fertilizer addition increased seedling height and biomass; and the combination of fertilizer and litter resulted in even stronger responses. While the overall direction of treatment effects was similar across functional groups, the strength of treatment effects was mostly weaker in grasses than in non-legume forbs and legumes. Seed mass mostly had a positive relationship with growth-related traits (height, biomass). In summary, a moderate litter layer may have protective effects on germination and does not alter seedling growth, while increased nitrogen may inhibit the germination of many grassland species, but promotes seedling growth. Our results show that grassland species already respond sensitively to land-use factors in the seedling stage and that varying strength of their response may contribute to changes in grassland diversity and composition under land-use changes.

Dose-dependent effects of formulated moxidectin on seedling emergence and plant growth traits of temperate grassland species

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Anthelmintics are excreted by livestock species into grassland habitats via faeces. Side effects on plant's regeneration by seed have only recently been found and rarely been studied. Therefore, we examined anthelmintic effects on both seedling emergence out of faeces and growth of seedlings colonising soils contaminated with anthelmintics.

We carried out two experiments. In experiment 1, we treated a group of sheep once with the recommended dose of moxidectin oral formulation. Hereafter, this group and a non-treated control group were fed with seeds from four different temperate grassland species at three time intervals. We exposed sampled faeces under common garden conditions and determined the number and timing of emergent seedlings. In addition, faecal moxidectin content was determined by HPLC. In experiment 2, we studied seedling growth of the same four species in pots over nine months while administering solutions of formulated moxidectin with different concentrations (0; 0.1; 1; 5 $\mu g\ g^{-1}$) and measured three growth traits (aboveground dry weight, specific leaf area SLA, plant vigour).

In experiment 1, we found significant differences for seedling emergence and mean emergence time between the groups. Seedling emergence was decreased at high moxidectin concentration (-27.1 %) but increased at lower concentrations (+68.8 and +45.2 %). In contrast, a high concentration was not associated with a change in mean emergence time, while low concentrations were related to lowered mean emergence times (-1.7 and -3.6 d). In experiment 2, we found significant effects of high concentrations of formulated moxidectin on dry weight (-20 %) and SLA (+12.9 %) in some test species.

We conclude that even with advanced faecal elimination of moxidectin, seedling emergence of eaten seeds can be compromised. In addition, prolonged contact with formulated moxidectin can have significant detrimental effects on seedling growth indicating that plants were nudged out of their comfort zone.

High-temperature stress effects on gametophyte performance and their consequences for seed reproduction in wild plants

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Sexual reproduction in vascular plants is highly sensitive to temperature stress. Yet, most of the existing research has mainly focused on cultivated or model species. Thus, it is unclear whether the results of such studies can be applied to natural populations.

Here, we investigated a) the effects of chronic heat stress (CHS; 17 days) at 35/30°C and 40/35°C on male and female gametophyte performance and b) how these effects were translated into seed quantity and quality. We measured six traits relating to male (anther length, pollen production, and size) and female (ovary length, ovule production and size) gametophyte performance and leaf chlorophyll fluorescence (Fv/Fm) in four wild *Silene* species (*S. coeli-rosa*, *S. gallica*, *S. laeta*, and *S. noctiflora*). The ripe seeds of the treated plants were used to measure seed size and production.

Fv/Fm decreased significantly in the 35/30°C and 40/35°C CHS treatments compared to the control (30/25°C), confirming a negative effect of CHS on overall plant performance. All three male gametophyte traits decreased significantly in the CHS treatments. Ovary length and size were significantly smaller in the 40/35°C treatment than in the 35/30°C and control treatments, while ovule production decreased significantly in both the CHS treatments compared to the control. Thus, these findings confirm the higher sensitivity of male gametophytes to heat stress compared to their female counterparts. The negative effects on gametophyte performance translated into significantly fewer seeds in the 35/30°C and 40/35°C treatments compared to the control. The CHS treatments did not affect seed size.

The high sensitivity of vascular plant gametophyte to high-temperature stress implies that climate change-associated heat waves will have significant impacts on seed reproduction in wild plants. The altered seed quantity might have potential consequences for the long-term survival of the wild plant populations and granivores performance.

SESSION 57:

Plant Carbon Allocation in a Changing Climate

Variability in plant litter decomposition responses to warming: Insights from a global meta-analysis

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Climate change is expected to accelerate the decomposition of plant litter and consequently carbon emissions and nutrient mineralisation, but empirical studies show a high degree of variability in plant litter decomposition responses to warming. To test the overall effect of warming on decomposition and potential moderators of the effect we performed a meta-analysis on experimental warming studies from all seven continents, using natural and standard organic material.

We found no significant effect of warming on litter decomposition overall. However, we observed significantly larger decomposition responses to warming in experiments with a higher degree of warming, that is, a larger increase from ambient temperature. Lower precipitation at warm sites resulted in lower decomposition with warming but had no effect at colder sites. The decomposition response to warming did not differ between different plant growth forms (i.e., forbs, nonvascular plants, woody species), but graminoid decomposition significantly decreased with warming. Further, decomposition of root litter of graminoids was stimulated by warming, whereas decomposition of their shoot and leaf litter was slower with warming compared to ambient conditions.

Our results suggest that warming has the potential to accelerate plant decomposition when reaching about 5.2°C. However, projected increases in intensity and frequency of drought events with climate change may lead to a decrease in decomposition rates. Ecosystems where biomass is mainly located below ground may respond by increasing decomposition rates, but data on root decomposition are sparse. More research is needed on below-ground decomposition of root litter to gain a full understanding of decomposition responses to climate warming, as its response appears to follow an opposite trend to that of aboveground litter and is therefore unlikely to be generalisable.

The significance of large old trees and tree cavities for forest carbon estimates

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Large old trees have declined worldwide, even though they play a prominent role in biodiversity and also in carbon stocks of forests. We were interested in the contribution of large old trees to aboveground stand biomass and the role of wood decay inside the trunk and tree cavities for biomass and thus organic carbon stocks. We investigated this question using the example of old-growth oak forests, since oak is the tree species with the highest proportion of large old trees in Germany. Although we studied oak stands with a strongly above-average proportion of large old trees (with an aboveground biomass of 563 Mg ha^{-1}), internal stem decay and tree cavities resulted in only about 1% overestimation of stand biomass. This was determined by subtracting biomass losses from internal stem decay from conventional biomass estimates derived from allometric regression. The extent of internal stem decay was measured using sonic tomography. Internal stem decay is thus negligible for stock density, but should be considered for continent-wide or global analyses where even small percentages add to large absolute errors. If trees of a stem diameter ≥7 cm were included in the analysis, the 11% largest trees of the stands accounted for 50% of the aboveground biomass. This result differs from recently published values of a global analysis suggesting that the 1% largest trees represent 50% of the stand biomass, but this difference is influenced by the minimum diameter at which young trees are included in the analysis. We suggest excluding young growth with diameters so small that their biomass does not significantly affect stand biomass from such analyses.

Identical costs for structural and non-structural carbon of branches along the vertical canopy profile of mature trees

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The structure of mature tree canopies causes significant light gradients that potentially change the carbon (C) allocation patterns and cause differences in the seasonal C balance between sun and shade branches. Previously, we found similar tissue concentrations and seasonal dynamics of starch between the uppermost and the lowest branches of mature trees of 9 temperate species growing in a mixed-deciduous forest stand at the Swiss Canopy Crane II (SCC II) facility. This result suggested that either shade branches allocate proportionally more C assimilates to reserves or are completely acclimatized to low light conditions. Here, we combined a light-driven photosynthesis model with branch functional growth analyses to test whether the relative C investments in structural biomass and C storage differ between sun-exposed, upper vs. shaded, lower branches of the different tree species at the SCC II site. To feed our model, we used in situ measurements of the climate, light and leaf gas-exchange, as well as end of summer measurements of SLA, total leaf area and wood biomass of one-year old branches at the highest and lowest areas of the canopy. The analyses revealed that the C costs for the biomass of a new branch relative to the leaf-lifetime C assimilation of all leaves on that branch are astonishingly similar across species and between the canopy positions, within ca. 15 and 25 % of the total C assimilation in all cases. We could further show that the proportion of C that is used to refill the starch reserves of a branche relative to its current photoassimilation differs significantly among species but is identical between upper and lower branches within a species. Our results suggest a high level of acclimatization to the canopy light gradient at the branch level, that is mainly achieved by changes in SLA and the leaf area to branch biomass ratio, emphasizing the equal significance of branches for a tree's C balance across the vertical canopy profile of mature trees.

Effects of nitrogen availability, pH, tree size and season on tree carbon allocation to root exudation

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Root exudates shape the formation of soil and the microbial community depending on environmental influences. A tree's social status (dominant or understory) majorly influences its C assimilation, and soil N availability often limits plant responses to rising atmospheric CO2. Simultaneously, human activities introduce N as both nutrient and acidifier to the biosphere. Investigating how exudation varies with tree status and nutrient availability can improve our understanding of belowground carbon allocation.

We sampled exudates from a long-term N x pH manipulation experiment in a mature primary forest in New York to test if root exudate C is changed under increased N availability and low pH. Exudates from mature Acer saccharum and understory A. saccharum and Fagus grandifolia trees were sampled in four treatments: control, two forms of N addition that either raised or lowered soil pH, and elemental sulfur to acidify without N addition. We quantified root exudation in dependence of N availability and pH across a seasonal cycle.

Throughout the season, trees exuded less C on plots with N fertilization. Decreasing pH significantly increased exudation, while a simultaneous addition of N and a decrease in pH had no impact on exudation compared to controls. Mature trees tended to be less responsive to N fertilization, pH alteration or seasonal cycling than understory trees. All trees significantly reduced exudation rates in the winter and increased root exudation in the spring.

Our results demonstrate that more carbon is released when N is limiting, and pH is low. While exudation rates remained relatively constant during the growing season, C allocation was significantly reduced in the winter, but not in the fall, when leaves were already shed. Further studies are planned to understand if differences in exudate quantity correlate to differences in functioning of released exudates and if stored C is used for root exudation when no C is assimilated by the trees.

Novel effects of low air pressure on alpine plants along climate change induced upwards migration

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Climate change is affecting the composition and functioning ecosystems across the globe. In alpine environments, rising temperatures are pushing upwards elevation range limits of many species and entire ecosystems. Specifically, as plants migrate along elevational gradients to track their thermal niche, they might experience no changes in temperature but decreasing air pressure and increasing water deficit, the higher they migrate. Lower air pressure is known to impact CO2 partial pressure, water availability, and correspondingly VPD (vapor pressure deficit) and so we hypothesize that an altered pressure will have consequences on metabolism, physiology and morphology of plants with remarkable consequences for organisms and species interactions. Here, using a next generation controlled environmental facility (terraXcube) we reproduced an air pressure gradient from 260 m up to 4000 m (above sea level) to disentangle the effects of air pressure from other elevation-dependent climate parameters like temperature or air humidity. By studying different alpine plant species we found that lower air pressure led to a general decrease of chlorophyll content and SLA (Specific Leaf Area) especially in two of them, Hieracium pilosella and Trifolium pratense. But, different to expect, SLA significantly increases at 4000 m a.s.l. in Trifolium p. We also notice that lower air pressure affects resources allocation such as plant carbon (C) and nitrogen (N) content leading to a decrease in above-ground biomass production. Even if these are just preliminary results of a heavily underexplored research field, our findings already confirm that low air pressure is a pivotal stress factor for plants at higher elevations. Our results provide new baseline knowledge to anticipate yet overlooked effects of climate change in alpine ecosystems that may be used as a starting point for further analyses on how reduced air pressure affects upwards-migrating organisms.

Water availability and hydraulic strategies determine heat stress impacts in temperate broadleaved tree species

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Heat waves and co-occurring droughts are increasing in frequency and magnitude in Central Europe. Thus far, our understanding of how common temperate broadleaved trees respond to summer heat and particularly the combination of heat and drought is limited. This study focuses on the impacts of differences in soil water availability during increasing summer temperatures in three temperate broadleaved tree species Acer platanoides, Quercus robur and Fagus sylvatica. Using single-tree-chambers, we investigated how leaf temperature, tree carbon and water relations as well as leaf senescence were affected by a step-wise air temperature increase from 25°C to a maximum of 45°C in a well-watered control or drought treatment.

In all species, transpiration increased along air temperature resulting in leaf cooling under well-watered conditions, while leaf temperatures exceeded air temperatures in the drought treatment. With increasing temperatures net assimilation declined while overall root and shoot respiration were maintained. Drought caused respiration to exceed assimilation already at 25°C in Q. robur and A. platanoides, whereas the control treatments of all species were able to keep a positive net carbon uptake even beyond 40°C air temperature. The negative impact of drought was also visible in higher leaf senescence compared to the control treatment, except for Q. robur which did not show signs of leaf damage.

In summary, our findings highlight the critical importance of water availability during heat stress to mitigate high tissue temperatures and sustain a positive net carbon uptake. Further, our results indicate a potentially better heat stress resistance of the rather anisohydric responding species F. sylvatica and Q. robur in both net carbon uptake and tissue vitality compared to the more isohydric A. platanoides, which regulated water use more strictly.

The overarching role of tissue duration in plant carbon allocation

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Carbon is rarely allocated alone and C investment is potentially far more influential on growth than unit leaf area photosynthesis. A multitude of trade-offs and developmental states constrain a plant's investment 'policy'. Growth form (the genotypic architecture), its translation into life form (plant stature) under environmental control, long-term (ontogeny) and shorter-term (phenology) developmental controls all-together define the framework within which resource supply, climate and disturbance regimes can modify allocation in certain directions, and thus, affect growth rate. Since carbon and nutrient allocation are intimately linked, the starting point for C allocation must be nutrient availability. A central issue is tissue duration, because C and nutrient investments, must be weighted by their time integrated role, as illustrated in leaf trait syndromes. When perennial dead tissue is excluded from fresh allocation patterns in woody plants, they hardly differ from herbaceous plants, causing final total plant dry matter allocation to reflect dead tissue duration. In evergreen and seasonal foliage, initial dry matter investment defines the time till amortization. In grassland, it is not below ground biomass (up to 85 % of total) but the annual rate of its renewal (less than 20%) that sets NPP, with root duration the main cause. In reproductive allocation it is not the seeds produced, but the entirety of structures and metabolism that contributes to reproduction, in some cases, over the entire life of a plant for a single mass fruiting event. In fact, most patterns of dry matter allocation are explained by tissue duration, rather than the allocation process per se. Whether resource allocation has a function for plant growth depends on whether the resource is limited, which has to be shown in the first place, before making a case for growth control. Since carbon is rarely a limiting resource, the focus needs to be directed to nutrients.

Linking genome size to carbohydrate storage

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Several lines of evidence indicate that carbohydrate storage in plant belowground organs might be positively related to genome size because both these plant properties represent resource sinks and can affect cell size, cell cycle time, water-use efficiency, or plant growth. However, plants adapted to disturbance, such as root sprouters, could be an exception because their strategy would require higher carbohydrate reserves to fuel biomass production but small genomes to complete their cell cycles faster. We conducted a pot experiment with 10 pairs of congeneric herbaceous species with different genome size and sprouting ability, and measured root non-structural carbohydrate concentrations and pools at the end of a growing season. We observed that both total non- structural and water-soluble carbohydrates (mainly fructans) were positively and non-linearly related to genome size, regardless of sprouting strategy. The concentrations of mono- and disaccharides and all carbohydrate pools had no consistent link to genome size, and starch was absent in large-genome species. For only four species pairs, we observed that the congener with the larger genome also had higher concentrations of total non-structural or water-soluble carbohydrates than the small-genome congener. Large-genome species with presumably large cells and vacuoles could accumulate more water-soluble carbohydrates at the end of the growing season in to fuel their growth and perhaps protect vulnerable organs from freezing early next season.

SESSION 58:

Water in Plants in a Changing Climate

Tree survival under drought depends on water loss after stomatal closure: a quantification of leaf minimum conductance in 9 temperate tree species

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Canopy residual water loss (Emin_canopy) is a key physiological trait that determines trees' survival time under drought after stomatal closure. However, because it is difficult to obtain trustworthy vapor loss rates from leaves in situ after stomatal closure, the method of choice is to determine minimum leaf water conductance (gmin) under controlled lab conditions and then use in situ climate to scale to Emin_canopy. Here we studied gmin for 9 European tree species in a mature forest. We investigated the seasonal variation and high temperature response of gmin, and assessed the species-specific relationship between gmin and leaf cuticular and stomatal traits. Additionally, we applied our results to the conditions during the 2022 hot drought and estimated Emin_canopy. Our results revealed that gmin did not change across the season in most species and ranged from 0.9 to 5.1 mmol/m^2/s among the species, which corresponded to only 1 % of the species-specific maximum stomatal conductance. Leaf trait analyses suggested that smaller stomata, thicker leaf cuticle and higher gas exchange capacity were positively correlated with higher gmin. Importantly, gmin increased on average two-fold between 25 and 50 °C in all species. For each unit of projected leaf area, the average daily Emin_canopy assessed for a typically hot summer day in 2022 drought was about 15 ml in evergreen conifer species and 44 ml in deciduous broadleaf species. And Emin_canopy increased exponentially under simulated hotter temperatures, showing a strong impact from increased gmin. Our study revealed large species differences in Emin_canopy, suggesting that tree species with higher gmin or lower thermal stability of gmin being more vulnerable to damage and dieback by hot summer droughts.

Drought resistance and leaf thermal tolerance of temperate tree species

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Climate change is causing more frequent and severe drought and heat events with the potential to accelerate tree mortality. How the vast diversity of tree species copes with this increase of extreme events is still unclear. In this study, we focus on plant traits with a high predictive power to explain drought and heat responses. We investigate whether drought-related physiological traits correlate with thermal tolerance and sensitivity traits, or if they co-vary within different tree-functional types classified by differences in morphological and physiological leaf traits. The study was carried out in the Traunstein Forest Dynamics Plot of the ForestGEO network in Germany. Leaf traits were measured on 15 different species. We found a large interspecific variation, in particular, of the thermal tolerance and sensitivity. From the 15 species that were investigated, European ash was the most heat-sensitive species, while Wild cherry was the least heat-sensitive species. Species with a more negative πtlp tended to have a higher breaking point temperature than species with a less negative πtlp. A lower thermal sensitivity characterized species with a higher leaf mass area, and high percentage loss of leaf area was found in species with low thermal sensitivity. Accordingly, species with thicker and tougher leaves have lower thermal sensitivity which coincides with a lower wilting point. We conclude that species that develop drought-adapted foliage can cope better with heat stress. Further, they might be able to maintain transpirational cooling during combined heat and drought stress, which could lessen their mortality risk during climatic extremes.

Beyond Leaf Loss: Unraveling the Influence of Browsing Herbivores on Tree Transpiration in Southern African Savannas

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Plant transpiration is a fundamental ecophysiological process, which is known to be largely influenced by abiotic factors such as soil moisture, vapor pressure deficit, and solar radiation. However, we believe that the potential additional impact of browsing herbivores has not been acknowledged adequately thus far. Herbivores, abundant in Southern African savannas, can drastically reduce transpiratory surface by removing leaves, potentially causing transpiration rates to decline. To assess this effect, we measured sap flow densities half-hourly in response to controlled levels of artificial gradual browsing (9-11 levels) in three common woody savanna species (Colophospermum mopane, Senegalia mellifera, Catophractes alexandri) in a game reserve bordering Etosha National Park, Namibia. We employed the well-established thermal dissipation method by Granier, further adjusted by the cyclic heat dissipation method as proposed by Lubczynski. Despite expected sap flow density reductions at high browsing levels, we observed a consistent and unexpected pattern across all species: Sap flow densities were stimulated at low browsing intensities and even exceeded those of non-browsed individuals, indicating some compensatory behavior. We attribute this compensation to stomatal adjustments in response to browsing, which we were also able to show through porometer measurements conducted approximately one week after browsing. Consequently, our results suggest that browsing-induced changes in transpiration extend beyond overall leaf area reduction. While previous studies have provided some evidence for a non-linear transpiration response to leaf removal, yet a comprehensive understanding has been hindered by a limited range of treatment levels. From a global perspective and within a conceptual framework, our study contributes to a better understanding of how herbivores shape the interconnectedness of Earth's spheres by modifying water fluxes from the soil to the atmosphere.

Root embolism formation and refilling after experimental drought in temperate trees revealed by X-ray µCT

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Drought-induced embolism formation is a process where water stress causes air to enter the water-conducting plant tissue, which leads to reduced hydraulic conductivity and can impair the plant's productivity and vitality. This phenomenon has been mainly studied in leaves and stems, but roots have been largely neglected due to methodological difficulties. In this study, we investigated root embolism formation in saplings of four temperate tree species (Fagus sylvatica Quercus petraea, Pinus silvestris and Pseudotsuga menziesii) subjected to experimental drought followed by re-watering to investigate potential refilling of the conduits.

We used X-ray microcomputed tomography (X-ray µ-CT) on saplings grown in specially designed pots to visualize their roots and quantify the embolism formation and refilling dynamics inside the xylem. Our results show that root embolism formation occurred in all four species. The embolism frequency tended to increase with duration of drought treatment and was related to the soil water content, indicating a relationship between the level of water stress and the extent of embolism formation in roots. Interestingly, in at least one case we could also observe apparent refilling of embolized conduits after the saplings were re-watered. These observations suggest that embolism formation and potential refilling are important regulatory mechanisms following severe depletion of soil moisture and differences in xylem structure between species can influence the drought resistance of roots in temperate trees.

Our study provides novel insights into the mechanisms underlying tree survival under drought stress, highlighting the importance of root systems in maintaining plant water status. We also demonstrate the potential of X-ray µ-CT as a non-invasive tool to study root water dynamics in trees. Such information is useful to improve our understanding of how trees respond to drought stress and help determining water-stress thresholds for common forestry species.

Shrink, Swell, Repeat: A Tree's Daily Business and Powerful Drought-Stress Indicator

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Forest ecosystems are likely to face future environmental conditions and variability that have no analogy in the recent past. Yet, although environmental science is becoming increasingly "data-rich", there is still a strong necessity for monitoring. Particularly, as water limitation in forests is increasing worldwide, there is a clear need for continuous monitoring efforts that provide insights on the tree-specific level of drought stress and elucidate risks for growth and survival.

Here, we present parts of our research activities at the Swiss Canopy Crane II (SCCII) site, which focus on better understanding the impact of drought on temperate European trees. The SCCII site is equipped with a canopy crane and rain exclusion roofs, with which we aim to identify changes in tree-specific physiological, anatomical, and morphological mechanisms in roots, stems, and the canopy that constitute a species-specific drought response strategy.

We show novel results on the impact of the 2022 summer drought on the sub-daily physiological functioning of 78 trees, encompassing 9 common European tree species. We found that the shrinkage dynamics, recorded with high-resolution point dendrometers, were effective in quantifying species-specific stem rehydration issues during the 2022 drought and provided indications for species that show higher drought tolerance. Moreover, daily shrinkage patterns agreed with the sap flow measurements and revealed which species showed stronger water-use regulation to avoid excessive water loss.

Besides providing key insights into species-specific drought tolerance, our intense research activities are geared towards understanding tree physiological mechanisms, both in carbon and water use, which can benefit other forest monitoring research. By better understanding the underlying mechanisms of the signals detected with automated sensors, such as dendrometers, we hope to support drought response monitoring across Switzerland and Europe.

Hydraulic strategies of Alpine shrubs and dwarf shrubs

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Shrubs and dwarf shrubs are an essential component of high mountain ecosystems and form extensive communities in the subalpine and alpine vegetation belt. The growth form is adapted to extreme environmental conditions such as long lasting snow cover, a short vegetation period, and high temperature amplitudes. However, little is known about the hydraulic architecture as well as summer and winter water relations of this growth form, mainly due to methodological challenges and limited economic interest.

Here we present recent advantages in better understanding the hydraulic functioning of Alpine (dwarf) shrubs, such as Vaccinium myrtillus, Arctostaphylos uva-ursi, or Juniperus communis. Analyses focused on the safety and efficiency of xylem water transport, patterns of conduit dysfunctions and refilling, and effects of summer heat waves and reduced snow cover on plant water status and survival. Therefore, flow measurements, staining of conductive conduits, micro-CT observations, and complementing physiological and anatomical analyses were performed.

Measurements revealed a surprisingly high proportion of non-functional xylem conduits in analysed species, although they were not exposed to water stress during the summer season. Dysfunctions were assignable to two characteristic cross sectional distribution patterns and resulted in strongly reduced hydraulic conductivities. Water potential at 50% loss of conductivity was highly species-specific and ranged between -1.8 and -2.9 MPa.

Results show that xylem function is definitely more dynamic than presumed and water transport capacities may be of minor importance for shrubs due to their low growth height. The relatively low hydraulic safety seems to be sufficient during summer, probably due to the extensive root system of Alpine shrubs, but during winter, missing snow cover can cause severe hydraulic failure and cell damages. Studying this overlooked growth form can reveal new structural and functional insights in plant hydraulics and also help to better understand the effects of ongoing and expected climatic changes on high Alpine ecosystems.

The effect of species identity and interspecific interaction on tree water us

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Understanding tree water use strategies is highly relevant considering the ecohydrological impacts of climate change. Especially species identity and interaction effects on water use potentially provide important information on drought resilience of different tree species and forest ecosystems. This study compares the water use strategies of four temperate tree species in the Black Forest; European beech (Fagus sylvatica, n=18), Norway spruce (Picea abies, n=18), Sessile oak (Quercus petraea, n = 5) and Silver fir (Abies alba, n = 5) using high temporal measurements of sap flow, radial stem variation and stem water content. Continuous in-situ stable water isotope measurements are used to further investigate the temporal and spatial distribution of precipitation and its effect on the water use of P. abies and F. sylvatica. During wet conditions in 2021 species interaction effects between F. sylvatica and P. abies led to decreased water fluxes in P. abies caused by light competition in the crown from co-existing F. sylvatica trees. Contrarily, F. sylvatica trees increased their water use when growing with P. abies due to an altered root water uptake pattern, using water from deeper soil layers. In 2022, during extreme drought, all species strongly regulated their water fluxes, except for Q. petraea. Interestingly, Q. petraea showed a dynamic response to VPD and stem water content in different sap wood depths, shifting sap flow from outer to inner xylem vessels under more stressful conditions. During peak drought, an labelling experiment with enriched deuterium (^{2}H) revealed an immediate increase in water fluxes and use of irrigated water in F. sylvatica. P. abies showed a more persistent positive effect of the irrigation due to a slower increase in water fluxes. Our results demonstrate the species-specific variability of water use strategies and their dynamic responses to interspecific competition and climate conditions.

Species richness and drought-tolerance traits interactively influence tree growth and physiological stress responses to drought

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The increasing occurrence and intensity of droughts will severely affect forest functioning during the 21st century. Increasing the number of tree species is promoted as a forest management strategy for climate change adaptation. However, whether species-rich forests are generally more resistant to drought than monospecific forests is unclear. Especially, the trait-based mechanisms responsible for the effect of species richness on tree responses to drought remain elusive. To address these questions, we examined the radial growth and physiological stress responses (measured by an increase in wood carbon isotopic ratio; $\delta^{13}C$) of trees to drought using tree cores from a large-scale biodiversity experiment. We analysed tree responses to changes in climate-induced water availability (from wet to dry years) across gradients of neighbourhood tree species richness and drought-tolerance traits. We hypothesised that neighbourhood species richness increases growth and decreases $\delta^{13}C$ and that these relationships are modulated by abiotic (i.e. water availability) and biotic contexts (i.e. functional traits). Tree growth increased with neighbourhood species richness. However, we did not observe a universal relief of water stress in species-rich neighbourhoods. The interactive effects of neighbourhood species richness and climate on growth and $\delta^{13}C$ depended on the traits of focal trees and the traits of their neighbours. During dry and wet years, species responded in opposite directions at both ends of each drought-tolerance gradient. These contrasting, trait-driven growth responses of tree species to wet vs dry climatic conditions scaled up and stabilised community-level productivity in mixtures. Our study reveals that assessing drought-tolerance traits is crucial for understanding biodiversity-ecosystem functioning relationships under drought. Mixing tree species can promote growth and growth stability but may not necessarily alleviate drought stress.

Drought resistance, resilience and legacy effects of mature trees in a beech/spruce forest

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This paper addresses the knowledge gap on what determines tree and stand responses to drought, their resilience and survival after drought release, integrating physiological and morphological responses at the whole tree level. I will highlight some key results from 10 years of research on a drought and recovery experiment in a mixed forest of European beech and Norway spruce. We studied about 100 trees of 70 to 80 years of age, growing in either monospecific or mixed species interactions. For five consecutive years, the trees were exposed to an experimentally induced summer drought by total throughfall exclusion in the growing seasons. During the first two drought summers, drought stress intensity peaked with pre-dawn leaf water potentials below -2.0 MPa and severe reductions in e.g. tree growth and leaf gas exchange. Acclimation of the whole tree leaf area in spruce helped to overcome the critical first two years of drought, resulting in alleviation of physiological stress as evidenced by increased stomatal conductance towards the end of the five-year drought period. Reduced water use by spruce, and thus increased water availability, also for neighboring beech, significantly alleviated drought stress in both species. After drought release, physiological parameters such as leaf water potential or xylem sap flow density recovered within hours or a few days, including the rapid recovery of sugar transport in the phloem. Prioritized belowground C allocation restored spruce fine root growth within a few days. Other morphological responses, such as regrowth of leaf area, were much slower to recover and were not complete after three years. During the natural drought of 2022, the drought legacy resulted in reduced water use in mature spruce and significantly reduced drought stress compared to previously unstressed control trees. Recovery and drought legacy effects should clearly be considered when evaluating tree and stand responses to drought.

Neighborhood effects on drought-induced tree mortality

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The extreme 2018 summer drought in Central Europe resulted in unprecedented tree dieback events throughout Europe. The risk of each tree to die in such an event depends on a suite of physiological traits and risk factors that have often been addressed in the recent literature. Less is known about how the size and species composition of trees in the immediate neighborhood affect the mortality risk of a tree.

In my talk, I will address this topic based on the results of a study from the IDENT tree diversity experiment in Freiburg, where about one third of the trees succumbed to the 2018 drought. Based on a Bayesian hierarchical model using data from 9435 young trees of 12 temperate species, we assessed how individual tree mortality risk is driven by hydraulic traits, carbon dynamics and susceptibility to pests, and how it is modulated by tree height and neighborhood effects.

We found that pronounced neighborhood effects remained after accounting for the effects of hydraulic traits, changes in non-structural carbohydrate pools, insect infestation and size. On average, trees benefited of the sheltering effect of having larger neighbors, with lower mortality risk for individuals with more and larger neighbors, though some competitive species were exceptions to that trend. In general, species that suffered more from the drought, especially *Larix* spp. and *Betula* spp., tended to reduce the mortality risk of their neighbors and vice versa. However, the interactions between neighbor trees strongly depended on the identity of both involved species.

Our results illustrate that for an improved understanding of individual drought-induced mortality risk, it is necessary to not only focus on the size and drought adaptations of single trees, but also on their neighborhood. In the presented framework, it is not only possible to estimate the direction and magnitude of neighborhood interactions, but also to test quantitative hypotheses about niche complementarity and diversity effects.

The impact of species interactions on ecohydrological processes under droughts in forests

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Global change-type droughts increasingly endanger forest functioning. Generally, mixed forests comprising different tree species are considered more resistant towards droughts, however, little is known about changes in species interactions (i.e. facilitation and competition) under increasing drought severity. In particular, knowledge on the regulation of ecohydrological processes, such as tree water fluxes, is lacking. We investigated responses in a temperate pine forest (2018-2023) and in an experimental drought and competition treatment in a cork oak forest (2017-2020).

The heavily impacted Scots pine (*Pinus sylvestris* L.) forest in the upper Rhine valley (ICOS Hartheim), hit a tipping-point during the 2018 drought showing very negative water potentials, and over 47% pine mortality until 2020. Net carbon exchange indicated slow recovery of NEE and a vegetation shift to a broadleaved understory.

The rain exclusion and shrub invasion (*Cistus ladanifer* L.) experiment in a Mediterranean cork oak (*Quercus suber* L.) ecosystem in Portugal showed that the combination of imposed drought and invasion amplified stress during an extreme drought, with strongly reduced tree transpiration. Contrarily, the imposed drought reduced the shrubs' competitiveness in the recovery period, which buffered the negative effects of shrub invasion on *Q. suber*.

A literature review on the impact of species interactions on tree resilience underlined that interactions can shift with increasing drought severity: beneficial species interactions, i.e. improved water relations, were prevalent under mild droughts. However, with increasing drought, interspecific competition increased and prevailed under extreme droughts, where even trees with complementary resource use strategies competed for water. Our results demonstrate the highly dynamic and non-linear effects of interacting stressors on ecosystems and urge for further investigations on biotic interactions in a context of climate induced alteration.

Leaf physiological adaptations of Eucalyptus and Acacia trees to aridity result from increased photosynthetic capacity but not reduced stomatal conductance

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Understanding the mechanisms that allow trees to exist in regions with limited water supply is of critical relevance for understanding the biology and distribution of trees and forests, in particular in the face of a changing and dryer climate. Leaves play a critical role for aridity adaptations as leaves are the organs where carbon is gained for the expense of water. It is therefore often hypothesized that trees adapt to arid environments at the leaf level, where water is conserved at the cost of carbon gain.

We tested this hypothesis for Eucalyptus and Acacia trees that grew along an aridity gradient in northern Australia ranging from 300 to 1700 mm of annual precipitation. The climate is characterized by a wet and a dry season, where trees maintain their leaves through both seasons. We investigated specific leaf area, leaf nitrogen content, foliar carbon isotope composition, diurnal patterns of stomatal conductance, pre-dawn and midday leaf water potential as well as osmotic potential in trees of both genera along the gradient. We performed our measurements once in the wet and once in the dry season.

Our data show that stomatal conductance per unit leaf area was surprisingly constant in Eucalyptus and Acacia trees along the aridity gradient. In contrast, photosynthetic capacity, indicated by increasing nitrogen concentrations per unit leaf area, and thus the trees carbon gain increased with aridity. Also, leaves remained physiologically active in the dry season and show no (Eucalyptus) or only slight (Acacia) reductions in stomatal conductance compared to the wet season. Trees compensated lower pre-dawn and leaf water potentials in the dry compared to the wet season by increasing their osmotic potential.

Our study shows that Eucalyptus and Acacia trees adapted to aridity by optimizing carbon gain but not by reducing stomatal conductance or water loss per unit leaf area. The cost of optimized carbon gain comes at a higher nitrogen concentration per unit leaf area. This strategy allows to maintain while tree carbon gain by producing fewer leaves and thus reducing the total water needed per unit of carbon gain.

Tree growth responses to the 2018-2020 drought as modulated by diversity, mycorrhizal type, and drought-tolerance traits

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Climate change scenarios predict an increasing frequency of consecutive drought years, likely having negative impacts on tree growth in Central European forests. Although mixing tree species has been found to increase the temporal stability of growth in tree communities, the results of different studies are still inconsistent with respect to extreme drought events. Recent studies show that besides climatic conditions, it is the biotic context, i.e. the traits of focal trees and their local neighbors, that modulates biodiversity–ecosystem functioning (BEF) relationships. However, it is not yet clear if functional trait identity and/or diversity can mitigate the impacts of extreme drought events. Here, we studied how tree growth is influenced by tree diversity before, during, and after the 2018-2020 drought. In addition, we explored how these relationships are modulated by mycorrhizal association types and other functional traits. We used annual growth data (2015-2022) of 5,120 tree individuals growing in a young tree diversity experiment in Germany (MyDiv) and measured functional traits related to drought tolerance and resource use of 10 broad-leaved tree species to model BEF relationships under drought. We found a positive response of individual tree growth to diversity in the pre-drought period and the first drought years. Nevertheless, this relationship reversed in the last drought year and the early post-drought period. Further, these relationships were modulated by the mycorrhizal type of the tree species; most strongly in the post-drought period. Tree species' drought-tolerance traits and traits related to resource use formed a joint trait syndrome. We found two axes of trait variation mainly driven by cavitation resistance and stomatal control, respectively. Analyses on the modulation of diversity–productivity relationships by these trait syndromes are ongoing. This study contributes toward understanding the biotic context dependency of BEF relationships under drought.

Calibrating the TreeTalker© xylem sap flow system for coniferous, diffuse porous and ring porous trees.

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The effects of drought and heat on the water balance of trees and forest stands are still poorly understood. Xylem sap flow measurements are an important tool for measuring the water use by individual trees and forest stands. However, there is often a problem with power supply in remote experiments. Therefore, the TreeTalker© system (TT+) developed by Nature 4.0, was used in the KomKon project at TUM, to remotely monitor the water balance of different tree species mixtures as a silvicultural method to increase the climate resilience of forests. The TT+ is a novel battery-operated IoT-based system that combines measurements of sapwood moisture, radial growth, microclimate data, tree stability and xylem sap flow using the transient thermal dissipation method (TTDP). The main focus of the KomKon project is to monitor sap flow with TT+. So far, the capability of TT+ to measure sap flow has been validated using a hydraulic bench filled with sawdust. To increase the accuracy of the measurements, a species-specific calibration was performed using freshly cut stem segments from three different xylem structures: diffuse porous (Fagus sylvatica L.), ring porous (Quercus robur L.) and coniferous (Abies alba MILL.) under controlled conditions. For this purpose, the xylem sap flow of the TT+ was calibrated against gravimetric measurements using a balance. After submerging the segments (DBH = 8-10 cm, length = 30 cm (Fagus, Abies), 70 cm (Quercus)) in degassed water for 24 h, the segments were placed in a Marriott system and measured at 5-7 different pressures, which were applied by a water column. The flow index (K) was evaluated from the TT+ data and converted to sap flux density (SFD) based on the actual gravimetric flux measured. Finally, the equations for calculating xylem sap flux density were adapted for each xylem structure type.

Water consumption of mature European beech and Douglas fir trees growing in pure and mixed stands

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In recent decades, the frequency and intensity of hotter droughts have increased, posing a serious threat to our forests. During hot droughts, increasing evapotranspiration depletes soil moisture reserves and thus exposes the trees' xylem to critical water potentials. Several of Central Europe's major timber species have been found to be especially susceptible to repeated summer droughts. Therefore, the forestry sector is increasingly considering the establishment of mixed stands and the inclusion of putatively more drought-resistant non-native tree species. However, silvicultural decisions about increasing the cultivation of non-native species and planting them in mixture require empirical data on species-specific water consumption in pure and mixed cultures in order to assess climate risks and to avoid potential negative competition effects.

To address these questions, we installed 32 dual-method-approach type sap-flow sensors capable of measuring the entire range of sap flow rates in pure European beech and Douglas fir stands as well as in a nearby mixed beech-Douglas fir stand on deep sandy soil in northern Germany. Additionally, heat-field-deformation type sap-flow sensors were used for measuring the radial sap flow profile in the xylem of each individual tree. The trees equipped with sensors covered a broad DBH range which allowed extrapolating to stand-level water consumption. Sap flow, soil moisture, soil matric potential and weather conditions were monitored over the wet year 2021 and the dry year 2022. Stand-level water consumption was higher in the pure beech stand than in the Douglas fir stand; the mixed stand consumed even more water than the two pure stands. The findings of this study are crucial for supporting foresters in silvicultural decision-making and for better understanding the water cycle dynamics in forest ecosystems in the face of climate change.

Contrasting hydraulic strategies and dynamic shifts in radial sap flow in a drought-avoiding and a drought-tolerant tree species

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Knowledge of hydraulic strategies is essential to understand the response of forest ecosystems to changing environmental conditions. Therefore, we investigated the water use strategies of a drought-avoiding (*Abies alba* Mill.) and a drought-tolerant tree species (*Quercus petraea* (Matt.) Liebl.) during a moderately warm and wet (2021) and during a hot and dry year (2022). We conducted a study in a mature forest measuring sap flux density (Js) and stem water content (WCstem) in two different depths as well as tree water deficit (TWD) to identify responses to varying meteorological conditions.

Both species showed a high drought tolerance, albeit with differing strategies: Js of *A. alba* decreased 70-80% after onset of the summer drought in 2022 and remained reduced 80-90% compared to maximum Js until the end of the vegetation period. *Q. petraea* did not regulate Js in response to the hot drought in 2022 and even increased Js compared to 2021. TWD of both species was low and only increased slightly in *A. alba* during severe drought. During both years a dynamic shift in radial Js of *Q. petraea* was observed: under high VPD Js of the inner sapwood exceeded Js of the outer sapwood from around 8 am to 5 pm, whereas under low VPD outer Js generally superseded inner Js. This radial shift in Js was associated with a threshold of ~ 30% reached in outer WCstem. Both species showed large daily fluctuations in WCstem indicating an important role of water storage to supply transpiration. High nighttime Js (15-30% of daily Js) and constant maximum WCstem of both species showed a high ability to refill water reserves.

In conclusion, we found, that a high ability to withdraw stored water for transpiration during the day and refill water reserves during the night might enhance species tolerance to drought. Dynamic shifts in radial patterns of Js might be a useful strategy of water-spending species to uphold high transpiration rates during drought and should be investigated further.

SESSION 60:

Belowground Functional Diversity

Towards a holistic view of belowground plant functioning

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Plant functioning – determined on the basis of functional traits – is of major interest for plant ecologists of various sub-disciplines. Over the last 20 years different concepts of plant economic functioning have been formulated and build upon each other. The root economics space (Bergmann et al., 2020) encompasses belowground fine root economics with the collaboration and the conservation gradient. An integrated framework of plant form and function (Weigelt et al., 2021) has linked these gradients to aboveground functional variation in resource economics on a global database. Yet, these concepts of plant functioning are limited to resource uptake strategies by fine roots so far. As belowground biodiversity encompasses many more organs and functions, the question remains how many dimensions of variation we need for a holistic understanding. In particular, functions like storage, anchorage, regeneration and multiplication are linked to variation in rooting depth, belowground clonal organs or bud-banks. Until today, those traits have been studied as disparate realms. The synthesis of these realms, knowledge and data with existing concepts of plant resource economics hold the opportunity to gain a holistic understanding of belowground functioning. Furthermore such an integration could help us to understand global plant distribution patterns and ecosystem resilience under global change.

Take it slow, grandpa! Ontogeny-driven fine root trait variation in the field

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Fine roots can vary in their morphological traits, which usually leads to shift in function. The variation happens on species level, but also on the population or individual level. Despite a recent progress in the study of fine root trait differences, most of our knowledge remains confined to interspecific comparisons. Whereas non-clonal species' roots are restricted to a single spot, clonal species can often explore wider area thanks to more extensive root system spread along a rhizome. However, whether this property leads to within-individual root trait shifts is poorly understood.

In this study, our main aim was to assess the differences of fine root traits between roots originating from young and old part of rhizomes. To address this goal, we conducted field diggings in Czech Republic and obtained 10 specimen of 10 eudicot herbaceous species. In each plant we took fine root samples from young and old part of the rhizome. We scanned the samples and used an image analysis software to obtain data on specific root length (SRL) and root tissue density (RTD).

In half of the species, roots in the young part had higher SRL and lower RTD than roots in the old part, suggesting a more acquisitive economy in the young part. In other species, the trend was less marked or absent, possibly due to field soil heterogeneity. Trait variation was often correlated with diameter in SRL, but only rarely in RTD. In conclusion, some rhizomatous species are capable of division of labor (root functions) along a rhizome, which might be a competitive advantage. Also, these findings imply constraints on the use of average species trait values.

The role of root traits and the Root Economics Space for soil fungal guilds and ecosystem functioning

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Ecosystem functions are affected by a variety of factors. While the importance of biodiversity in sustaining ecosystem functioning is widely recognised, there is a significant knowledge gap regarding the role of belowground plant traits. Past trait-based concepts have focused predominantly on aboveground traits, resulting in a disproportionate bias and a lack of understanding of the role of belowground traits. The recent proposal of the Root Economics Space (RES) has enabled us to better integrate root traits into functional strategies of plants and biodiversity–ecosystem functioning research.

Soil mutualists and antagonists are expected to mediate diversity–productivity relationships. Due to the close association of roots with the microbial community in the soil and the link of the collaboration gradient of the RES with mutualistic mycorrhizal fungi, it is likely that root traits are also entangled in these relationships. We hypothesize that plant diversity and root trait strategies along the collaboration and conservation axes of the RES affect the composition of soil fungal communities and thus ultimately ecosystem functioning. For instance, we expect plant pathogenic fungi to decrease in abundance in more diverse plant communities, but also in communities with plants that are well defended. Typically, higher plant defences are associated with root traits linked to high mycorrhization (‘outsourcing’) and high tissue density (‘slow’). Therefore, in our study, we investigate the interactive effects of root trait gradients and plant species richness on soil fungal communities and how these affect ecosystem functioning.

In plots of the Jena Experiment, varying in plant species richness, we measured root traits at the community level and sampled soil microbial communities. Using PLFA analyses and functional guild annotations of sequenced soil fungi, we calculate relative abundances and proxies for absolute abundances of mycorrhizal mutualists, plant pathogens, and saprotrophs. Preliminary results suggest that plant pathogenic fungi significantly decrease in their diversity and relative abundance in plant communities with more outsourcing root strategies, highlighting the importance of the root collaboration axis.

Why there are two when one could be enough? The story of two rhizome types

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Rhizomes are the most common clonal organs that allow plants to multiply, horizontally occupy space, protect regenerative buds belowground, store carbohydrates, and distribute resources among connected ramets. There are two types of rhizomes that differ in their ability to spread laterally, multiplication rate, and rooting depth. They also determine, to some degree, plant habitat preferences regarding moisture and disturbance. Hypogeogenous (belowground-borne) rhizomes exhibit higher values in all the aforementioned traits - lateral spread, multiplication, and rooting depth - than epigeogenous (aboveground-borne) rhizomes. This fact might make hypogeogenous rhizomes appear more capable, useful, or advantageous. However, even in very closely related taxa, both types of rhizomes can be found. In the present study, we ask: Could the presence of epigeogenous rhizomes be justified by more efficient carbohydrate storage or better nutrient management within and among seasons?

During our three-year greenhouse experiment, we observed the ontogeny of 10 herbaceous congeners that differ in rhizome types. We analyzed the concentration of phosphorus, nitrogen, carbon, non-structural carbohydrates, and total carbohydrate storage throughout ontogeny, and we linked the ontogenetic changes with species' habitat preferences for moisture and disturbance.

We did not find any differences between epigeogenous and hypogeogenous rhizomes in intra- and inter-seasonal carbohydrate storage and concentration or nutrient content, although specific dynamics of some traits during ontogeny emerged. However, these ontogenetic changes were not linked to species' habitat preferences.

Contrary to our expectations, the two types of rhizomes do not differ in their storage of carbohydrates and nutrient content. Therefore, we should seek an explanation for their different strategies elsewhere. We will discuss potential explanations in the conference contribution.

Linking root economics traits and plant soilfeedbacks

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In recent years, several quantitative reviews have improved our understanding of plant soil feedbacks. They show that negative plant soil feedbacks (PSFs) dominate, which suggests an important role for pathogens. In addition, the strength and direction of PSFs can vary substantially, and factors such as plant functional group and growth form, plant native status, evolutionary relatedness, plant abundance and local environmental conditions can explain the outcome of PSFs. Nevertheless, large parts of the variation in PSFs remained unexplained in previous meta-analyses, suggesting that we need to consider additional predictors of plant-soil feedback strength.

Here, we introduce a framework based on functional fine roots traits and the root economics spectrum. We predict that the strength and direction of the biotic feedback between a pair of species is determined by the dissimilarity between them along each axis of the root economics space. The collaboration axis is expected to link more strongly to mutualistic effects and 'outsourcer' species should accumulate mutualists in their home soils. The conservation axis on the other hand, more strongly links to pathogenic effects and fast species should accumulate pathogens in their home soils. This results in four belowground strategies each with a unique combination of soil pathogens and mutualists. Each strategy shows specific feedback, that can be measured using different metrics.

Using data from two case studies, we show how the framework can be applied. The direction of the PSF depends on which strategies are compared and we find evidence for the predicted changes in mutualistic and pathogenic communities along the axes in root economic space. Finally, we highlight further areas where our framework could be developed and pro-pose study designs that would help to fill current research gaps.

The effect of plant above-and belowground functional diversity on biotic interactions and ecosystem functioning in drylands

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Dryland ecosystems are a key terrestrial biome. Their functioning and the services they provide are vulnerable to land degradation and desertification, which are exacerbated by global change drivers such as land use intensification and climate aridification. These changes influence dryland functioning directly through their impact on abiotic conditions, and indirectly through effects on the vegetation. Dryland vegetation is known to strongly depend on biotic interactions. However, we know little about how plant-associated soil organisms, such as mycorrhizal fungi that form symbiosis with 90% of all land plants, will respond to global change, and how their responses will feedback on plants and ecosystem functioning. One can expect a general positive effect of mycorrhizal fungal abundance and diversity on dryland functioning, as different fungal taxa provide different ecosystem functions. The contribution of mycorrhizal fungi to dryland functioning will also depend on the host plants dominating the vegetation, as plants vary in their responsiveness to mycorrhizal fungi. Plant functional leave and root traits describing the plant involvement into the mycorrhizal symbiosis can be used to estimate the responsiveness of plant communities to mycorrhizal fungi. Mycorrhizal fungal abundance, diversity, and their contribution to dryland functioning should thus increase with plant functional diversity in resource economy due to a high availability of mycorrhizal niches in a functionally diverse vegetation. The latter could be one factor leading to the positive relationship between plant functional diversity and functioning in drylands. To discuss this hypothesis, I will present the results of a full-factorial greenhouse experiment measuring ecosystem functioning of simplified annual dryland plant communities, that form a gradient of diversity in leaf and root resource economy, growing in soils with and without mycorrhizal fungi.

Linking structural arrangement and storage ability in temperate herbs

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Plants store carbohydrates for future use, e.g. seasonal sprouting, regeneration after damage, flowering, fruiting, and also for osmoregulation and signaling. The non-structural carbohydrates (NSCs; e.g. glucose, sucrose, fructose, fructans, and starch) are stored in parenchyma cells, and also in the secondary xylem and living fibers. In trees, the concentration of NSCs correlates with the proportion of those tissues on stem cross-section, and therefore the amount of storage may be predicted knowing the anatomical structure of the stems. In herbs, NSCs are stored in specialized belowground storage organs, such as rhizomes and tuberous roots, with variable morphology and anatomy. The relationship between the proportion of storage tissues and carbohydrate concentration remains unknown. We studied nine herb species from temperate grasslands to examine whether similar relationships exist in herbs. The storage organs were processed by usual protocols in plant anatomy. Carbohydrates quantification (glucose, fructose, and sucrose) was performed from fresh frozen samples by liquid chromatography. No clear link between carbohydrate concentration and parenchyma area percentage was observed. All species, with the exception of Clematis recta, showed a predominance of parenchymatic tissues in their belowground storage organs. The proportion of parenchyma varied between 58-95% in stem-derived organs and 78-98% in root-derived organs. Those values exceed values for total parenchyma reported in woody stems and roots (≈ 20%). This may imply different strategies in carbohydrate storage among the growth forms that deserve further study.

Does root foraging account for root density variation in the field? A tale of bivalent cations.

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It is a well known fact from pot experiments that roots are able to forage for nutrients by proliferation in stable nutrient-rich patches. In the field, root densities indeed vary at a centimetre scale, but we have no information on whether this variation is linked to variation in nutrient availability. The key nutrients (namely nitrogen) are too mobile temporally and spatially to elicit any kind of such response under realistic field conditions. Where then does the fine-scale root density variation in the field come from? (And is it species-specific?)

We used a combination of soil solute sampling at a centimetre scale, species-specific root biomass identification using quantitative PCR, and pot foraging experiments to determine to what extent fine-scale root density variation is driven by individual species, whether it can be attributed to differences in nutrient concentrations, and to the ability of species to forage for it. We worked in a species-rich grassland where qPCR markers have been developed for 14 most common species.

We found that calcium and magnesium (and to a lesser degree phosphorus and potassium) showed fine-scale patchiness stable over 6 weeks consistent over all these elements. These patches were strongly associated with high occurrence of roots of species with low tissue concentrations of Ca and Mg. These species also differed in the ability to forage for these elements in pot experiments. This fine-scale root response was in stark contrast to plant-level root system shapes which were primarily driven by species-specific root system shape blueprints.

These results imply that calcium and magnesium play an important role in forming soil heterogeneity at a scale where root densities vary. They also imply that species-specific differences in Ca+Mg tissue concentrations are an important driver of root responses. As these cations affect a number of plant functions, these findings confirm their role in growth dynamics of terrestrial ecosystems.

Species phylogeny, ecology and root traits as predictors of root exudate composition

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Root traits including production of root exudates are key factors affecting plant interactions with soil and thus play an important role in determining ecosystem processes. Drivers of their variation remain poorly understood. We determined relative importance of phylogeny and species ecology in determining root trait variation and analyzed extent to which root exudate composition can be predicted by other root traits.

We measured root morphological and biochemical traits including root exudate profiles of 65 introduced plant species grown in controlled system. This allowed us to explore differences in trait values without confounding effects of environment in which plants are currently growing. We tested phylogenetic conservatism in traits and disentangled individual and overlapping effects of phylogeny and species ecology on the traits. We also predicted root exudate composition using other root traits. We did so as root exudate composition is difficult to measure and it would be useful to find easier to measure proxies of root exudation. Finally, we explored differences in all the traits among invasive and non-invasive species.

Phylogenetic signal differed greatly among root traits, with the strongest signal in phenol content in plant tissues. Interspecific variation in root traits was also partly explained by species ecology, but phylogeny was more important than species ecology in most cases. Species exudate composition could be partly predicted by specific root length, root dry matter content, root tissue density, root biomass and root diameter, but large part of the variation remained unexplained. Root exudation thus cannot be easily predicted based on other plant traits and more comparative data on root exudation are needed to understand their diversity. Invasive species did not differ in root traits from non-invasive species, but the group of invasive species was more similar in their traits to each other than non-invasive species.

Intra- and interspecific changes in leaf and root defence traits along a plant diversity gradient

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The positive effect of biodiversity on ecosystem functioning (BEF) often increases through time. This may be explained by the dilution of antagonists and the accumulation of mutualists in more diverse communities. If antagonists play a role in the BEF relationship, the reduction of plant antagonists in more diverse communities, could allow plants to reduce allocation to defence. In this study, we examined the effect of plant diversity on the expression of plant defence traits for 16 species to test the hypotheses that (1) allocation to defence is reduced with increasing plant diversity, (2) this reduction is higher in roots compared to leaves and (3) that this effect is species-specific.

We quantified leaf and root, physical and chemical defence traits in communities with varying plant species richness in a 19 year old biodiversity experiment, using standard methods and a novel metabolome approach. We tested the interactive effects of plant diversity and species identity on defence traits using linear mixed models.

We found mixed results for our first hypothesis, as only some leaf defence traits were reduced along the diversity gradient (leaf mass per area, leaf dry matter content and hair length). In contrast to our expectation, allocation to defence in some root traits increased along the diversity gradient (root tissue density and nitrogen content). This might be related to the fact that these traits are related to other functions, possibly masking the effect of decreasing antagonists on plant defences. We did not find evidence for our third hypothesis, suggesting that after two decades, plant species synchronize their response to biotic and abiotic effects of the plant diversity gradient. Despite the lack of strong evidence for a reduction in defence trait expression along the diversity gradient, our results again highlight the complexity of BEF relationships and the need for more research to improve our understanding of the underlying mechanisms.

Trash or treasure: Rhizome conservation during drought

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Researchers currently disagree whether plants intentionally store carbon (i.e. storage carbohydrates) for later use or if these carbohydrates are just passively accumulated in belowground storage organs. To understand plant carbon economy, we performed an experiment with the aim to trigger rhizome senescence and assess if plants relocate storage carbohydrates from senescing organs or lose them to decomposition. We grew eight species from a variety of families and habitat types in a split-pot design: one pot compartment contained the younger rhizome end and the other compartment contained the older end. Both compartments were either watered (control) or the older one was left un-watered (drought treatment) to trigger rhizome senescence. Plant growth, root traits, and nonstructural carbohydrate types and concentrations were assessed in four sequential harvests. Drought treatment plants had higher rhizome dry-matter content while younger rhizome parts produced higher new rhizome and aboveground. Carbohydrate concentrations in rhizomes remained consistent for both treatments, younger and older rhizome parts, and all harvests, probably because of translocation of water from the watered to the dry compartment to prevent senescence. The invariant composition and concentration of carbohydrates found in this study suggest that despite stress, plants conserve the rhizome as an important and essential part of the body and carbon is stored intentionally and preserved for future use by the plant.

Increasing root/shoot ratio with decreasing aridity in five annual plant species along a natural aridity gradient

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Root traits play a central role in plant adaptation to drought as they are responsible for the uptake of water and nutrients. The theory of optimal resource partitioning predicts that root growth and subsequent belowground biomass production should increase when water is limited.

Consequently, the root:shoot ratio should increase with increasing aridity. However, only few studies have tested this prediction among ecotypes within species. And those that are available revealed contrasting results, suggesting that intraspecific patterns in root investment may be less straightforward and need clarification.

For this reason, we collected seeds of 12 – 15 ecotypes of five different plant species on north- and south slopes along a natural aridity gradient in Israel. We grew them in a greenhouse under standard conditions to measure root biomass and root/shoot ratio. We hypothesized that arid ecotypes show higher root biomass and root/shoot ratio than mesic ecotypes.

Contrary to our expectation and theory root biomass and root/shoot ratio decreased slightly with increasing aridity for 3 of 5 species, and no species showed the expected increase. This was also not the case when slope was included in the analysis, and results varied among species between north- and south slopes. We discuss these results and provide alternative explanations for the observed patterns.

Functional distinctness of soil seed banks – do they differ from aboveground vegetation?

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A rich reservoir of viable seeds stored in the soils (soil seed bank) of wetlands can play an important role in vegetation reestablishment after severe disturbance events such as drought, flooding or agricultural plowing. Soil seed bank composition will not only affect initial taxonomic composition, but also ecosystem functioning during vegetation regeneration, especially when other dispersal mechanisms such as seed rain or clonal growth are limited. In semi-natural systems like temperate wet grasslands, management prior to disturbance might alter certain features of the soil seed bank such as density, functional diversity and taxonomic similarity to the established vegetation either directly via controlling seed entrance or storage conditions or indirectly by affecting the seed shedding established vegetation.

To investigate the effects of management on the soil seed bank and the established vegetation of wet meadows, we used a 26 years split-plot experiment in North-western Germany. Management treatments included mowing once (either early or late), mowing twice and leaving fallow with removal of woody plants. Vegetation was recorded every second year and in the final year, the soil seed bank in the upper 10 cm was sampled. To gain insights into the deterministic assembly processes and strategies of soil seed bank compared to the aboveground vegetation, we calculated functional composition (CWMs) and diversity (Rao's Q) for plant functional traits related to persistence, regeneration and seed bank formation.

Soil seed banks of the studied temperate wet meadows were taxonomically and functionally distinct from the established vegetation, yet they held a substantial share of the species pool present at the site. Common soil seed bank species were adapted to ensure seed production and dispersal in time and space, yet less to resprouting after mowing. Seed banks were not functionally more diverse than the aboveground vegetation, yet diversity patterns depended strongly on individual traits. Management affected the soil seed bank parallel to, albeit weaker than the aboveground vegetation, presumably because all abiotic and most biotic filtering occurred in the aboveground vegetation.

Predicting future scenarios of soil microbial communities and functions.

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Soils are responsible for the provision of countless ecosystem functions and services, vital for the well-being of diverse communities of organisms. Soil microbial diversity and community composition especially have a key role in carbon and nutrient cycling, as well as ecosystem multifunctionality. The stability of microbial communities and related soil functions is however threatened by expected changes in climate and land-cover. It is therefore crucial to refine our understanding of these relationships to better predict future trends in soil biodiversity and functions. Using a global collaboration network of experimental platforms, we performed a sampling campaign to link long-term standardized decomposition measurements with other soil functions and diversity measurements to unravel the context-dependency of these relationships. We used measured and extracted climatic and soil properties to define the direct and indirect roles of these components on the diversity-functionality relationship and evaluated future trends in soil multifunctionality based on different Shared Socioeconomic Pathways (SSP).

Belowground plant morphology as a clue for plant distribution along environmental gradients

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Plants possess large variety of belowground non-acquisitive organs, ranging from short-lived transporting roots in annuals, through different types of rhizomes, tubers and bulbs in clonal plants to long-lived storage and transporting roots in nonclonal perennials. These belowground non-acquisitive organs (hereafter belowground growth form, BGF) determine a whole set of functions that may be decisive in coping with climate, productivity, disturbance and neighbour interactions. They may participate on obtaining a limiting resource, enable survival in disturbed habitats and allow coexistence in a community. We examined relationships of the BGF to environmental gradients on species and on community level. We assembled data on BGFs and optima along gradients of moisture, nutrients, pH, light, disturbance frequency and disturbance severity of 1712 Central European species, and linked it with species co-occurrence data in 30115 vegetation plots from the Czech Republic. The strongest gradients determining occurrence of individual BGFs were disturbance severity and frequency, light and moisture. Surprisingly, nonclonal plants, both perennial and annual, occupy much smaller parts of the total environmental space than major types of clonal plants. Species- and community-based analyses yielded similar results, and their differences are largely attributable to correlations of these gradients in Central European landscapes. Morphological categories of belowground non-acquisitive organs capture important part of plant strategies how to deal with environmental factors, disturbance, and biotic interactions.

The root economics space provides unifying predictions for trait-functioning relationships

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Global change is driving biodiversity change at unprecedented rates. One key way in which changes in local community composition may manifest is through changes to the relative proportion of functional traits represented in the community which may have disproportionate effects on ecosystem functioning. Yet, studies that aim to understand ecosystem functioning from a trait perspective have had mixed success so far. This might be linked to the fact that most studies so far focused on species level and not community data as well as on aboveground traits. We capitalized on recent advances in belowground trait relationships and use the collaboration and conservation gradient of the root economics space (RES) to predict belowground trait ecosystem-functioning relationships.

We use a deliberately assembled meta-dataset across experimental and observational studies in grasslands and forests to confirm the existence of the RES at the community level and understand how the RES relates to ecosystem functioning. We found that 6 out of our 10 functions were correlated with the RES. In our analysis of the entire RES, more functions fell on the collaboration axis than on the conservation axis. However, in our analysis of individual traits there were 10 trait-by-function relationships with collaboration traits and 12 with conservation traits. Furthermore, our predictions were more often correct for conservation traits than for collaboration traits.

Our findings highlight the importance of both the conservation and the collaboration axis for belowground ecosystem functions and aboveground biomass production across a wide range of sites. These findings suggest that shifts in the relative abundance of different trait syndromes may alter how ecosystems function. Further, these trait by function relationships may be especially likely in a changing environment which acts simultaneously on both the traits and the functions together.

Vertical root distribution of four common temperate forest tree species examined by excavation to 4 m depth

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Germany's forests have suffered under the extreme 2018/2019 and 2022 hot droughts. Soil water storage capacity and the dynamics of soil water depletion with root uptake are important factors that determine tree species' hydrological thresholds in the face of climate warming. While fine roots absorb water and nutrients, thicker root diameters are mainly responsible for transportation, storage and anchorage. How much water is available for tree uptake depends to a large extent on maximum rooting depth and the distribution of absorbing roots. This is, however, not well studied for our main timber species, especially not for the deeper subsoil.

The aim of this study was to investigate the vertical root distribution of fine roots (< 2 mm diameter), small roots (2-5 mm) and coarse roots (> 5 mm) for the four main timber species *Fagus sylvatica*, *Quercus petraea*, *Pinus sylvestris* and *Pseudotsuga menziesii* on deep sandy soils. For every tree species, three pits of 1.5 m x 1.5 m were excavated to a depth of 3.8 m in the Lüneburger Heath (northern Germany) on glacial till. Volumetric soil water content was continuously monitored with FDR sensors in the year 2022 to a depth of 4 m to conclude the maximum depth of root water extraction.

Roots of all species and diameter were found even in depths of 3.8 m, although the majority of fine root biomass (90 %) was present in the first 50 cm of topsoil. Throughout the whole soil profile, coarse roots usually accounted for at least half of the total biomass, while the proportions of fine and small roots varied considerably with depth.

In an increasingly warmer and drier climate, it is likely that these deep roots are of particular importance, since they may allow maintaining water uptake during dry spells. Our data help to define empirically based soil water availability thresholds for the main timber species and contribute to a better understanding of the soil water dynamics in sandy soils in their dependence on different tree species.

Resource sharing strategies of clonal plants

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Clonal growth helps plants to cope with environmental heterogeneity through resource integration via connecting organs, such as rhizomes or stolons. Such integration is usually understood to balance heterogeneity by the translocation of resources from rich patches to patches with lower resource availability. However, such an 'equalisation' strategy is only one of several possible strategies. For example, under asymmetric competition for light, horizontal escape from shaded conditions and thus the translocation of resources toward ramets in unshaded patches may be a better strategy. We discuss various possible strategies of resource sharing and hypothesise that the strategies may differ among species from different habitats.

To examine such differences, we traced the translocation of carbon and nitrogen under a light gradient in two closely related species from habitats of contrasting productivity. We examined bidirectional translocation between mother and daughter ramets by stable-isotope labelling. The two studied species indeed behaved differently. *Fragaria viridis* with the 'equalisation' strategy supported shaded ramets, whereas *Potentilla reptans* with an 'escape' strategy translocated resources toward younger established ramets in favourable conditions.

Our results confirmed that different species may have different resource-sharing strategies. These differences are possibly linked to species' habitat conditions. The generally known 'equalisation' of resources is thus not the only option for clonal plants.

Nitrogen fertilization strengthen belowground biodiversity effect on productivity in a tree diversity experiment

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Biodiversity increases ecosystem functions such as productivity. Whether and how belowground biodiversity mediating aboveground biodiversity effect on ecosystem productivity remains to be elucidated, especially under global changes. Here, we conducted a manipulation experiment by planting 76,500 trees in plots with varying tree species richness (ranging from 1 to 16 species) under both control and nitrogen fertilization treatments. We found that increased species richness positively influences productivity. SEM models showed direct and strong contributions of functional diversity and identity to increases in productivity, but species richness indirectly affected productivity through its positive impact on soil bacterial diversity. However, nitrogen fertilization diminishes the relationship between tree species richness and productivity particularly through promoted productivity in monocultures. Importantly, nitrogen fertilization diminishes the direct effect of functional diversity and weakens the effect of functional identity on productivity. Furthermore, nitrogen fertilization shifts the weak positive links between productivity and soil bacterial diversity towards a strong positive relationship with soil symbiotic fungal diversity. This shift suggests that nitrogen fertilization influences the composition and functioning of soil microbial communities, which in turn impacts productivity. In conclusion, our findings provide insights into the nitrogen fertilization effect on the complex interplay among tree diversity, soil microbial diversity and ecosystem productivity. Nitrogen fertilization was found to weaken aboveground biodiversity-productivity relationships while simultaneously strengthening belowground biodiversity-productivity relationships in subtropical plantations. Our findings contribute to our understanding of the intricate dynamics between biodiversity and ecosystem functioning under changing environmental conditions.

HOW MANAGEMENT OF GRASSLAND AFFECTS PLANT CLONAL TRAITS

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Clonality is an important way by which plants can reproduce and spread vegetatively and clonal structures can also serve as storage organs. Organs such as rhizomes, tubers, bulbs, and stolons serve not only for clonal growth but also as storage and regenerative organs. Most of the study so far has been focused on how clonality improves plant fitness and how different clonal traits respond to disturbance and environmental gradients, but less is known about how clonal plants affects ecosystem function such as carbon, nutrient, and the water cycle, erosion protection or biomass production. We hypothesize that grassland management affects below-ground plant organ production and longevity. This might happen on an intraspecific level due to phenotypic plasticity and an interspecific level due to changes in species composition. We will test this hypothesis in sere of the pot and field experiments where we will assess how grassland management affects rhizome biomass production, longevity, and composition and through those changes how it affects ecosystem functions provided by rhizomes, namely their contribution to the carbon cycle through the decomposition of rhizome biomass.

Originally standing and lying dead phytomass effect plant species differently in disturbed and undisturbed soil

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Dead plant phytomass commonly falls to the ground at the end of the vegetation season and is decomposed, but large part of it may remain standing or unshed (marcescent), making it significantly less accessible to decomposers, and instead be photodegraded. In arid zones, the large part of marcescent phytomass can be decomposed without touching the ground. In temperate zones, decomposition of marcescent phytomass by photodegradation is low but marcescent phytomass prompts important chemical changes, which increases its subsequent decomposability in the soil. This phenomenon is common among the temperate flora. It is unknown, however, whether altered decomposability affects plant growth, and how it depends on soil conditions. In a pot experiment we compared the effects of originally marcescent and shed (originally lying on the ground) dead phytomasses on three grassland species (*Bromus erectus, Filipendula vulgaris, Plantago media*) with the soil from long term stable ancient grassland and grassland restored on arable land 20 years ago. Dead phytomass was exposed to the decomposition on the pot surface on which the grassland species were sown (each species to separate pots). Marcescent phytomass contained more nutrients, but we found only one species (*F. vulgaris*) responding to it and producing more biomass. Biomasses of other species were unaffected by dead phytomass type. Effect of dead phytomass type on soil properties was low. Soil was largely affected by plant species identity. Effect of sown species on microbial community was stronger in undisturbed soil of ancient grasslands while in disturbed soil of restored grasslands plants affected mainly soil chemical properties. Effect of marcescence, i.e. whether plant phytomass remain standing over the winter and later falls down in vegetation season, seems to affect plants in species-specific manner. Marcescence also seems to have larger effect on plants growing in disturbed soil.

Functional alliance of diverse crops and belowground microbiota

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Interspecific interactions among plants occur widely in nature and can have profound impacts on belowground biodiversity and functionality. In agroecosystems worldwide, crop diversification often leads to the improvement of agricultural sustainability and productivity through plant–soil feedback. Understanding how crop diversity effect on plant plasticity and subsequent feedback effect on soil microbial assembly would benefit the manipulation of soil functional response to support ecosystem service in managed ecosystems. Over the past 10 years, we investigated the long-term crop diversity experiment in the South of China and found ethylene and flavonoids-mediated chemical recognition and rhizosphere microbial assembly between legume and non-legume crops. Such plant-microbial interactions subsequently enhance the belowground function including nitrogen fixation, nutrient resource activation and pathogen resistance. Moreover, based on the long-term nutrient resource regulation in the Chinese National Ecosystem Research Network, we found that in systems with low resources, soil functional trait stability was achieved by interactions between organisms occupying the same trophic level of their food web and soil biodiversity. In contrast, systems with high resources achieved stability through microbial interactions across different trophic levels. Our results highlight the importance of above-belowground community assembly and their biological and biochemical feedback effects on the maintenance of sustainability of soil diverse functions.

Unexpected diversity of biosynthetic gene clusters in a peatland microbiome

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The microbiome in peatlands have been extensively studied with a focus on carbon sequestration, methane emissions, and nitrogen cycling, shedding light on their global significance in ecosystem functioning. However, the interplay among the microorganisms within these ecosystems remains poorly understood, mainly due to the limited cultivability of peatland bacteria. While the biosynthetic gene clusters from the Proteobacteria and Actinobacteria are known well-known, the biosynthetic potential of common peatland taxa such as Acidobacteria, Verrucomicrobia, and Planctomycetes remains unexplored. To better understand the potential role of natural products in a shaping the peatland microbiome, we employed deep metagenome sequencing and genome binning to investigate the biosynthetic potential of the common taxa groups in the peatland microbiome. We generated 1034 metagenome-assembled genome bins, with the Acidobacteria accounting for approximately 40% of the binned reads in across all samples. The Proteobacteria were the second most abundant group with around 20% of reads in all samples, which mostly belonged to uncharacterized genera in the Alpha and Gammaproteobacteria. In total, 3591 biosynthetic gene clusters were identified, with no clear relationship between depth and the number of gene clusters. We identified a substantial number of non-ribosomal peptide synthases (NRPSs, n=914) and type I and III polyketide synthase (PKS, n=634) gene clusters. The majority of these clusters were from the Acidobacteria (n=671) and the Proteobacteria (n=401) and had limited similarity to any known clusters, indicating the potential presence of novel biosynthetic pathways. Furthermore, we identified arylpolyenes, implicated in oxidative stress protection, and ranthipeptides, predominantly antimicrobial peptides, as common features in Acidobacteria genomes. This suggests a significant role of these compounds in shaping microbial communities within peatlands. Our findings highlight the untapped biosynthetic potential of previously unexplored bacterial lineages such as the Acidobacteira, prevalent in peatland environments and further suggests that the compounds produced by these BGCs potentially play a large role in shaping peatland microbiomes.

SESSION 61:

Soil Biodiversity and Functions

Temporal stability of multidimensional traits of soil Collembola over 13 years under different forest management regimes

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Stability is a fundamental property of ecosystems to provide sustainable functioning and services. Stability is essentially based on the performance of species in a given habitat, which is associated with multiple functional traits. Compared to spatial variation, the temporal stability of soil fauna has received less attention. Temporal dynamics of functional diversity in a multidimensional niche space of trophic, morphological and life history traits can provide a mechanistic understanding of community stability. Taking advantage of a 13-year observational study in Biodiversity Exploratories, we collected Collembola community data from four forest types (coniferous forest and young, old and natural beech forest) in three regions of Germany from 2008 to 2020, with an interval of 3 years. We investigated the temporal stability of the multidimensional ecological niche and quantified community parameters of morphological traits (body length, furca development and antenna-to-body ratio, which indicate locomotion, and number of ommatidia, body color pattern and pigmentation, which indicate habitat preference), trophic niche (13C and 15N) and reproductive mode. Contrary to our expectations, the temporal stability of the multidimensional niche was weaker in coniferous forests than in beech forests. There was no significant difference in stability of the ecological niche between regions, although one region (SEW) had the highest temperature fluctuation. Over the years, Collembola communities varied more in their locomotion traits than in other aspects of the niche. There was a significant increase in locomotion in coniferous forests in 2017, but not in beech forests. These results suggest that the temporal dynamics of soil animal trait are influenced by forest type rather than region, and depend on the function of the trait. Our study highlights the importance of considering trait functions in priori when studying community stability and functioning using trait approaches.

Over 30 years of soil biodiversity monitoring in Germany – trends and drivers

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The decline in biodiversity in conjunction with global and climate changes poses a threat to mankind and human well-being. Soil biodiversity represents a third of terrestrial biodiversity but our knowledge of soil biodiversity change and its drivers is limited. Long-term monitoring data are needed but are scarce or have not yet been analyzed. Here, we present time-series analyses of over 30 years of soil biodiversity monitoring in Germany.

In roughly 800 plots, distributed across Germany, physico-chemical and biological parameters of soils have been monitored, partly since 1985. These plots were established in three major land-use types, i.e., agriculture, forest, and grassland. All plots are monitored in set intervals every few years. We have aggregated and harmonized all data and used time-series and meta-analytical tools to statistically analyze the data.

We show how earthworm diversity, soil microbial biomass, and organic carbon changed over time. In addition, we link changes in these soil biodiversity variables to important drivers, such as soil pH, nutrient concentrations, and eco-toxin concentrations. We are able to show how these drivers interact with land-use type. Lastly, we present a statistical approach to deal with heterogeneous monitoring data.

Taken together, we present the first time-series of soil biodiversity change for Germany and make a case for the importance of soil monitoring. Furthermore, we show how our results can inform assessments on the state and change of biodiversity, potentially resulting in policies to protect and restore soil biodiversity.

Management intensity and harvest type but not organic farming alter soil microbial diversity in managed grasslands

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Managed grasslands are a major agricultural land-use type and not only play a major role for global food production but also provide a great number of vital ecosystem services, many of which are mediated by the soil microbiome, e.g., by influencing plant growth, nutrient cycling, and decomposition. Regarding the importance of soil microbes, it is necessary to understand how they are affected by grassland management, which mainly, includes three aspects: a) management intensity, i.e., fertilized (intensive) or not (extensive), b) harvest type, i.e., predominantly grazing (pasture) or mowing (meadow), and c) production system, i.e., organic or non-organic farming practices. We used a metabarcoding approach of ribosomal markers to measure soil fungal and prokaryotic community structure of 86 grasslands with differing management strategies on cattle farms in the Canton of Solothurn, Switzerland. Management intensity and harvest type showed significant effects on microbial alpha diversity and community composition, whereas organic management did not. For instance, fungal alpha diversity was higher and bacterial diversity lower in extensively compared to intensively managed grasslands. Pastures showed a higher ratio of copiotrophic to oligotrophic bacteria then meadows. Soil and topographic conditions also strongly influenced microbial communities, and a substantial part of the variation in microbial alpha (7% for fungi and 11% for bacteria) and beta diversity (4% and 2%) was jointly explained by both the environmental variables and grassland management. This highlights the interrelatedness of environment and management in real-world settings. We conclude that maintaining grasslands of differing management intensity and harvest type can greatly contribute to promoting soil microbial diversity at the landscape level.

Collembola in floodplains: biodiversity, community structure and litter decomposition rates as affected by hydrology and forest management

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Hardwood floodplain forests act as important carbon sinks and are biodiversity hotspots, increasing the importance of floodplain restoration in fighting climate change and biodiversity loss.

In the MediAN project we analyzed population structure of Collembola, soil fauna activity (Bait lamina test) and litter decomposition rates (minicontainers) along two gradients at the Lower Middle Elbe floodplain in northern Germany. First, a hydrological gradient ranging from sites actively flooded during flood events to the fossil floodplain and hydrologically independent tributaries. Second, a gradient representing forest restoration starting at managed floodplain grassland to young forests (20 years) and further to dense and sparse old forests (200 years).

Although no recent flood event occurred, population structure of Collembola differed between actively flooded and non-flooded sites. Surprisingly, Collembola communities in the active floodplain were not characterized by higher proportions of hygrophilous but instead of woodland species, although active floodplain forests were smaller and less dense than forests in the fossil floodplain or near tributaries. Forest size, structure and age therefore affected Collembola community composition much less than hydrology. In contrast, soil fauna activity increased with forest age due to high fauna densities, but was not affected by hydrology. Overall, decomposition of leaf litter was very low due to drought effects, but the comparably high proportion of faunal part in litter decomposition indicates soil fauna activity being less affected by drought than soil microorganisms.

As the main project goal is making recommendations for future restoration projects, we conclude that in terms of soil fauna biodiversity the active floodplain is a better place to restore hardwood floodplain forests than the fossil floodplain, by providing a more specialized faunal community. Further, decomposition processes are supported by increased forest age.

BioDivSoil: Soil Biodiversity in the Agricultural Landscape - Patterns or Chaos? An Integrative Approach to Describing Ecological Soil Quality

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Increasing human populations lead to intensive land use in agriculture, which has direct and indirect effects on soil organisms. A biodiverse soil community protects against the loss of necessary soil functions. Conservation and assessment of soil organisms is complex but essential. A combined approach of morphological- and DNA-based methods will provide a suitable data basis for the assessment of soil biodiversity in agricultural systems.

Twenty-six sites were sampled throughout the 2021 growing season using soil cores, pitfall traps and spade samples. Samples were processed using either morphological identification or DNA-based approaches. Oribatids, springtails, lumbricids, carabids, spiders, bycatches, soil parameters, management data form a highly dense dataset for the analysis of agricultural soil quality.

The combination of these methods opens up the possibility of a spatially, temporally and methodologically condensed soil monitoring. It includes above- and below-ground interactions, the enlightening of food webs, and the analysis of characteristic soil communities. The results showed clear differences between the grassland, field margin and arable communities. However, the different taxonomic groups were poorly correlated with each other, suggesting few strong mutualistic relationships. The DNA-based methods provided valuable complements to the other morphologically based data. In the future, the integration of standardised metabarcoding into comprehensive biodiversity monitoring should play an important role.

Comprehensive monitoring of soil biodiversity can provide a good basis for assessing soil quality. However, organisms are not necessarily an indicator of particularly sustainable agricultural practices. Rather, the crops grown and the type of tillage appear to have a major influence on the biotic communities. The ecological impact of fertilisers and pesticides, for example, can only be inferred to a limited extent from faunistic diversity.

Ecosystem services of soil biota in agriculture - Results from the SoilMan Project

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Soil biodiversity is pivotal for delivering food, fibre, biofuels, clean air, drinking water and carbon storage to society. However, as stated by the European Commission Soil Thematic Strategy and the Soil Framework Directive our understanding of how soil biodiversity is linked to soil functions and ecosystem services is still very limited. SoilMan aimed to identify supporting impacts of land use vs. soil biodiversity. Framed within the simple equation: A for B = B for A (if agriculture cares about soil biodiversity, soil biodiversity will work for agriculture) SoilMan identified and quantified detracting vs soil biodiversity supporting agricultural practises as well as threatening vs. beneficial impacts of soil biota on arable farming. SoilMan was especially focused on agroecosystems as the majority of the European land area is used for agriculture and land use is among the main global change factors detrimentally affecting biodiversity. Via a broad ecological, economic and political valuation of soil biodiversity soil biota was placed into a social-ecological context. SoilMan worked in 5 European countries and based on the A for B = B for A – matrix transdisciplinary activities were carried out to mediate the win-win-impacts of land use and soil biodiversity to stakeholders and policy. SoilMan outcomes were presented in the Biodiversa - Policy brief: "How soil biodiversity can strengthen resilience and ecosystem services in gricultural landscapes" summarising a number of beneficial soil biodiversity impacts on sustainable land use.

Ants and other athropods - studying the little things that run the world through citizen science

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Arthropods rule the animal kingdom in terms of species richness and biomass, but their diversity also makes them notoriously difficult to study. Yet their importance for ecosystem services and functioning and the mounting evidence that arthropods are under pressure from anthropogenic changes makes it vitally important that we do so. Based on results from two concrecte projects, the German citizen science project “MikroSafari“ and the international citizen science project scheme “The Ant Picnic”, we discuss the opportunities and challenges that doing arthropod citizen science presents in terms of experimental methodology, spatial and temporal scale, taxonomic coverage and participant engagement and outcomes.

Monitoring soil biodiversity with citizen science in Europe: current initiatives, challenges and opportunities

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To achieve the large-scale monitoring of biodiversity, the inclusion of multiple actors is required, notably of citizen scientists. Citizen science programs not only enlarge the spatial and temporal coverage across taxonomic groups, but they also have strong societal impacts with increased knowledge and empowerment of the participants. As in traditional ecological research, the vast majority of participatory biodiversity monitoring is focused on aboveground diversity and non-invertebrate, non soil-related taxa. Here, we performed the first synthesis of citizen science projects targeting soil biodiversity at the European scale. Combining a classic literature review on Web of Science and an online search using keywords in different languages, we identified more than 40 projects, in addition to national monitoring schemes led by natural history societies. The projects take place in at least 12 countries spanning an important latitudinal gradient from Spain to Norway, although the majority of the projects are from the United Kingdom and France. Taxa studied are only large-size animals (macrofauna) of different trophic groups (detritivore, predator, herbivore) with an overall strong focus on earthworms. An important diversity in terms of protocols and type of data collected show the adaptability potential of citizen science to different audiences and their level of expertise to ensure the best knowledge production. In the future, main challenges are the need for interoperability between projects, improved taxonomic coverage, as well as increasing the integration of citizen science methods and data into classic research programs and studies. Citizen science will contribute importantly to soil biodiversity monitoring and raising awareness on soil life that is extremely poorly represented in conservation programs and legislations.

Variations in trophic niches of soil microarthropods with elevation in two mountain regions in Eurasia as indicated by stable isotopes (^{15}N, ^{13}C)

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Knowledge on the trophic niche of animal species is important for understanding their coexistence and hence animal diversity. Trophic niches have been shown to vary with environmental conditions, but consequences of trophic niche shifts for food-web structure and functioning is little studied and this applies in particular for belowground communities. Here, using stable isotopes (^{15}N, ^{13}C) we investigated shifts in trophic niches of oribatid mites as model soil animal taxon along elevational gradients of two mountain ranges in Eurasia, the Alps in Austria and Changbai Mountain in China. The results showed pronounced shifts in the use of basal resources ($\Delta^{13}C$ values) and trophic levels ($\Delta^{15}N$ values) between the two mountains due to the different parent rocks between the calcareous soils in the Alps and basalt bedrock in Changbai Mountain, which also induced the shifts in trophic levels with altitudes. Functional traits such as body mass and reproductive mode strongly shifted oribatid mite trophic niches, in part related to the local bedrock. Additionally, stable isotope values strongly correlated with body mass underlining the importance of morphological characteristics and defense mechanisms for variations in trophic niches. Moreover, trophic niche shifts were more pronounced in parthenogenetic than sexual species indicating higher trophic plasticity in the former. Overall, our findings highlight the decisive role of parent rock in structuring soil food webs and provide novel insight into factors responsible for shifts in trophic niches in soil invertebrates.

Trophic reorganization in soil-living oribatid mites unveils resource alteration in food webs by introduced tree species

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The degradation of ecosystem functions due to biodiversity loss requires a critical evaluation of the impact of humans on forest ecosystems. Management practices based on stand diversification represent a possible solution to biodiversity loss in forests, but those practices often involve plantations of non-native tree species. However, the consequences of planting mixed and non-native forests on below-ground biodiversity have been poorly studied. There is a particular lack of knowledge on the functional diversity of key groups of animals such as soil microarthropods, despite their functional significance in soil structure formation and nutrient cycling. Here, we investigate the taxonomic and functional diversity of oribatid mites (Oribatida, Acari), one of the most abundant and diverse groups of animals in the soil food web. We studied oribatid mites across forests of native and introduced tree species in Northern Germany, characterizing a broad range of traits, from trophic to life-history traits. Using native European beech as a reference, our study focused on economically important conifers including native Norway spruce and non-native Douglas fir, as well as mixtures of beech with either of the conifers. The pure and mixed stands of Douglas fir had a minor impact on the abundance and diversity of oribatid mites. By contrast, Douglas fir changed the species and trait composition of oribatid mite communities, resulting in a trophic reorganization with more primary decomposers and more surface-living oribatid mites in Douglas fir than in European beech. Mixed stands mitigated the impact of conifer monocultures on the taxonomic and functional composition of oribatid mites. Overall, the results suggest that Oribatid mites broadly maintain a high level of functional diversity (i.e., the presence of a diverse range of traits) regardless of forest types, but compositional shifts in trophic guilds indicate a functional shift towards more intensive use of litter-based resources in Douglas fir forests. Mixed stands demonstrated the potential to support decomposer communities in conifer plantations closer to those in native stands. We also highlight that a functional description of soil biota based on a variety of traits is needed to reveal the impact of forest management (especially the introduction of tree species) on the structure and functions of the soil food web.

Tropical land use alters functional diversity of soil food webs and leads to monopolization of the detrital energy channel

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Agricultural expansion is among the main threats to biodiversity and functions of tropical ecosystems. It has been shown that conversion of rainforest into plantations erodes biodiversity, but further consequences for food-web structure and energetics of belowground communities remains little explored. We used a unique combination of stable isotope analysis and food-web energetics to analyze in a comprehensive way consequences of the conversion of rainforest into oil palm and rubber plantations on the structure of and channeling of energy through soil animal food webs in Sumatra, Indonesia. Across the animal groups studied, most of the taxa had lower litter-calibrated $\Delta^{13}C$ values in plantations than in rainforests, suggesting that they switched to freshly-fixed plant carbon ('fast' energy channeling) in plantations from the detrital C pathway ('slow' energy channeling) in rainforests. These shifts led to changes in isotopic divergence, dispersion, evenness, and uniqueness. However, earthworms as major detritivores stayed unchanged in their trophic niche and monopolized the detrital pathway in plantations, resulting in similar energetic metrics across land-use systems. Functional diversity metrics of soil food webs were associated with reduced amount of litter, tree density, and species richness in plantations, providing guidelines on how to improve the complexity of the structure of and channeling of energy through soil food webs. Our results highlight the strong restructuring of soil food webs with the conversion of rainforest into plantations threatening soil functioning and ecosystem stability in the long term.

Explaining the contrasted responses of soil food webs to nutrient enrichment with a stoichiometrically-explicit model

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Soil ecosystems are perturbed by the alteration of their resource supplies due to human activities but empirical studies have documented widely varying responses of soil fauna to organic and mineral nutrient enrichment, so that the mechanics behind this response remains unclear. In this modelling study, we hypothesized that the multi-channel structure of soil food webs might provide an explanation for the strong context-dependence of empirical findings. Indeed, bacteria tend to be favoured over fungi by nutrient enrichment due to their stronger limitation by nutrients but soil fauna is expected to interfere with the response of microbes because of trophic interactions and the processing of the litter by detritivorous macro-invertebrates that alter its stoichiometry. We derived a stoichiometrically-explicit soil food web model to assess whether such hypotheses might lead to emerging patterns compatible with empirical findings. Our simulations predict that the response of bacteria and fungi is conditioned by the stoichiometric limitation of detritivorous macro-invertebrates and that trophic cascades occur between the bacterial and fungal channels because of their coupling by generalist predators. In addition, we found that low quality litter (high C:N) promotes the fungal channel and has a stronger effect on macro-invertebrates than the bacterial channel (promoted by high quality litter with low C:N). This stronger effect on macro-invertebrate is due to shorter food chain length of the fungal channel containing fungivorous invertebrates. Our results advocate for the consideration of soil fauna in ecosystem models that only consider the biological activity through microbes.

Defining fungal-feeding soil microarthropods by ecological traits – are there any?

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Organisms that inhabit the soil are the main agent of soil organic matter transformation and translocation. Together, different taxa of soil fauna form soil food webs, which are very complex systems of trophic interactions, which attracted much of attention in recent decades. However, its modeling, as well as the identification and assessment of individual trophic relationships of soil organisms, allows the most complete understanding and evaluation of the processes of base resources transformation and energy flows redistribution in the soil. Traditionally divided bacterial and fungal energy channels, which mediate a significant portion of the matter and energy inputs from both fresh and dead organic matter to soil invertebrates, remain a key topic across the studies on soil food webs. The contribution of soil fungi to the diet of soil invertebrates is proven to be high, yet the fungivory of detritivores is commonly shown as a component of omnivory.

Functional analysis based on a set of several general characteristics of organisms, or traits, is another widely used conceptual approach to study of soil invertebrate communities. This approach allows assessing the presence of common features and characteristics of different taxa performing similar functions in the soil. In the present study, this methodology was used to analyze own and published data on the contribution of fungi to the nutrition of individual soil invertebrate taxa in order to identify common features among fungivorous soil microarthropods (Collembola and Oribatida).

Data were collected and analyzed for 22 families of invertebrates, including 49 species of soil-dwelling Collembola and 11 species of Oribatida. Data on basic morphoecological traits such as average body size, body shape and pigmentation were mostly obtained from open databases Ecotaxonomy and GBIF. The presence of chewing type of mouthparts was found for all examined species, regardless the importance of fungi in their diet. That indicates the absence of a specific type of mouthparts for fungivorous microarthropods. It is shown that the body size of Oribatida does not correlate with the contribution of fungi to their diet, while among Collembola this resource has a greater contribution to the diet of species, characterized by small size and cylindrical body shape.

Changes in ground-dwelling carabid communities and their interactions with the microbiota of selected soil compartments along an Alpine elevational gradient

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Global warming is affecting Alpine habitats through an increase in temperature above the global average. Such rapid environmental change may affect biotic interactions and thus ecosystem stability and functionality; however, these processes in mountain soils are not well understood. We used an elevation gradient ranging from 1000 to 2500 m a.s.l. as a proxy for climate change to investigate the diversity of ground-dwelling carabid beetle species and selected body traits. We also analysed the microbiota of the beetles and other soil-associated compartments to understand the complex interactions and co-occurrences of microbial communities in alpine soils.

On 12 grazed pastures (3 replicate sites every 500 m of altitude), we set up pitfall traps for an entire growing season and emptied them every two weeks. Nearly 6000 individuals were captured and morphologically identified to species, with body length, wing development and sex recorded. In addition, 182 carabid beetles were collected by hand, and used for microbial community analysis by next-generation sequencing. For comparison, microbiota analyses were also performed on soil, rhizosphere, nematode, collembola, earthworm and vertebrate faecal samples.

Community composition and diversity of carabids changed significantly with elevation, but not in a linear pattern. Especially the prokaryotic communities in carabid beetles showed trophic related patterns. Compared to the other soil-associated compartments, bacterial and fungal alpha and beta diversity in carabids was very low and few taxa were shared. Our data confirm ecological patterns along elevation and provide a first insight into the complex interactions between soil, faunal and microbial players.

Tree species mediated effects of microbes and earthworms on carbon storage under the monoculture forests in Denmark

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Past research illustrated that different tree species affect carbon stocks and shape microbial and earthworm communities. Meanwhile, the roles of microbes and earthworms in carbon transformation have been disclosed in lab or field manipulation experiments. However, litter-mediated effects of tree species on soil biota specifically associated with soil carbon remain poorly understood. We used a common garden experiment with six tree species which differed in leaf litter quality to investigate tree species mediated effects of microbial and earthworm communities on soil carbon (divided into forest floor C and mineral soil C). Foliar decomposition in litterbags and soil respiration in the lab indicated the forest floor C and mineral soil C turnover, respectively.

Our results showed strong tree species mediated effects of microbial community and earthworms (only endogeic and anecic) on forest floor C but weak effects on mineral soil C. The tree species producing higher quality leaf litter (lower C/N, higher N & Ca) supported bacterial active communities that drove a higher decomposition rate and stored less C in the forest floor. Under those tree species, the microbial communities comprised a lower Gram+ to Gram- ratio and a higher fungal to bacterial biomass ratio. The microbial biomass and activity had a weak effect on mineral soil C. Only the fungal to bacterial biomass ratio strongly and negatively correlated with mineral soil C in 0-5cm. Lower biomass of endogeic and anecic earthworms was sampled under the tree species producing lower quality leaf litter and negatively correlated with the forest floor C. Overall, our study stresses the importance of considering the effects of tree species on soil community and their ecosystem functions, particularly for forest floor C storage; Microbial community composition, e.g. biomass ratios of Gram+ to Gram- and fungi to bacteria, are potential indicators for C stocks, presumably, both forest floor C and mineral soil C.

Mycorrhizal associations determine diversity–productivity relationships across tree-diversity experiments

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Global environmental changes are affecting the diversity, composition, and functioning of ecosystems, invoking research to evaluate the relationship between biodiversity and ecosystem functioning (BEF). It remains unclear about the generality of and mechanisms behind BEF relationships, especially for forest ecosystems, where most tree species are associating with either arbuscular mycorrhizal (AM) or ectomycorrhizal (ECM) fungi. Using 11 tree-diversity experiments across the globe, we found that tree species diversity can generally promote community productivity via complementarity effects, the strength and significance of which, however, are contingent on the composition of tree mycorrhizal associations. In particular, tree communities containing only ECM trees and mixed communities containing both ECM and AM trees showed the strongest relationships between tree species diversity and productivity, with mixed communities showing the highest proportion of significantly positive diversity–productivity relationships across experiments. Moreover, there were considerable variation in belowground fungal communities as affected by tree species diversity and mycorrhizal associations. Our study indicates that tree-mycorrhiza interactions are critical in determining biodiversity effects and the functioning of forest ecosystems. Our study also suggests that the impact of environmental changes on BEF relationships would depend on the composition of mycorrhizal associations.

Plant roots fuel tropical soil animal communities

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Belowground life relies on plant litter, while its linkage to living roots had long been understudied, and remains unknown in the tropics. Here, we analysed the response of 30 soil animal groups to root trenching and litter removal in rainforest and plantations in Sumatra, and found that roots are similarly important to soil fauna as litter. Trenching effects were stronger in soil than in litter, with an overall decrease in animal abundance in rainforest by 42% and in plantations by 30%. Litter removal little affected animals in soil, but decreased the total abundance by 60% in rainforest and rubber plantations but not in oil palm plantations. Litter and root effects on animal group abundances were explained by body size or vertical distribution. Our study quantifies principle carbon pathways in soil food webs under tropical land use, providing the basis for mechanistic modelling and ecosystem-friendly management of tropical soils.

Temporal trends and drivers of earthworm abundance and biomass in German soils over the past 30 years

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Soil biodiversity is crucial for the functioning of terrestrial ecosystems, but it is threatened by human activities and climate change. Despite its importance, our understanding of soil biodiversity changes and their drivers is still limited. Long-term data analysis is necessary to address this gap, but has hardly taken place so far, since existing data are scarce or lack harmonization. Here, we present the most comprehensive temporal trend and drivers analysis of earthworm abundance and biomass in Germany, to date. The underlying data represent the longest time series of soil biodiversity for Germany, covering over 30 years of monitoring.

Data on biological, physical, and chemical soil properties have been collected on about 800 sites throughout Germany, with varying sampling intervals and procedures among sites. The sites, first ones set up in 1985, comprise the three main land-use types found in Germany, i.e., arable land, grassland, and forest. We compiled and harmonized these data, and statistically analyzed them using time-series and meta-analytical tools.

We show how earthworm abundance and biomass have changed over the last few decades in Germany in total and among the three land-use types. Further, we link the resulting trends to selected soil properties like pH, soil nutrients, and heavy metal concentrations.

Overall, we present the first temporal trend and drivers analysis for earthworm diversity in Germany and thus contribute to the understanding of the current state and recent developments of soil biodiversity. In addition, our results can be used for improving existing soil monitoring programs as well as policies to protect soil biodiversity.

Plant pathogen resistance is mediated by recruitment of specific rhizosphere fungi

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Beneficial interactions between plants and rhizosphere microorganisms are key determinants of plant health with the potential to enhance the sustainability of agricultural practices. However, pinpointing the mechanisms that determine plant disease protection is often difficult due to the complexity of microbial and plant-microbe interactions and their links with the plant's own defense systems. Here, we found that the resistance level of different banana varieties was correlated with the plant's ability to stimulate specific fungal taxa in the rhizosphere that are able to inhibit the *Foc* TR4 pathogen. These fungal taxa included members of the genera *Trichoderma* and *Penicillium*, and their growth was stimulated by plant exudates such as shikimic acid, D-(-)-ribofuranose, and propylene glycol. Furthermore, amending soils with these metabolites enhanced the resistance of a susceptible variety to *Foc* TR4, with no effect observed for the resistant variety. In total, our findings suggest that the ability to recruit pathogen-suppressive fungal taxa may be an important component in determining the level of pathogen resistance exhibited by plant varieties. This perspective opens up new avenues for improving plant health, in which both plant and associated microbial properties are considered.

The effect of climate change on soil microbial community composition associated with different vegetation along the Shei-Shan elevation in Taiwan.

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Shei-Shan lies in Shei-Pa National Park, is the second highest mountain (ca. 3886 m) after Yu-Shan (ca. 3952 m) in central Taiwan range. The specific alpine ecosystem harbors diverse plant species under changeable climates has formed a variety of forest types along the elevations. The representative forest types including (i) Alpine vegetation (higher than 3600 m), (ii) Abies zone (3100~3600 m), (iii) Tsuga-Picea zone (2500~3100 m) and (iv) Upper Quercus zone (1800~2500 m). Alpine or high mountain ecosystems are considered to be the most vulnerable to climate changes. A broad-scale of survey in numerous aspects including vegetation, macro- and microfauna and fish in order to monitor the dynamic change of biodiversity response to climate change. However, it seems that the tiny creatures have been ignored, microorganisms including fungi and bacteria are both vital important in nutrient cycling. Soil was collected in August 2018, 2020 and 2021 to analyze the microbial community structure and soil physicochemical properties. A total of 603,596 high-quality fungal sequences were obtained by Pacbio platform; a total of 2,296,169 high-quality bacterial sequences were obtained using Mi-seq platform. After the taxonomic assignment, a total of 12 phyla, 38 classes, 87 orders, 166 families, 284 genera and 498 species were obtained for fungi; 28 phyla, 79 classes, 177 orders, 282 families, 507 genera and 587 ASVs were obtained for bacteria. The forest types harbored significantly different soil fungal and bacterial assemblages ($P < 0.001$), specifically soil fungi were more tree species centric. Overall, there was no significant difference in soil properties during the three years; there was no significant difference in the diversity index of fungi and bacteria, but the community composition changed significantly, especially the symbiotic fungal community composition of Tsuga and Abies showed to gradually become similar from that of the Juniperus tree soil before the main peak. Long-term monitoring is needed to further confirm whether the annual increase in the ambient temperature causes the Tsuga and Abies to gradually move to higher altitudes.

Key to common earthworms in agriculture in Germany

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Involving society in scientific issues plays an important role and the instrument of citizen science has proven its worth in many projects. Volunteer researchers are increasingly involved in measuring biological indicators. This also concerns the sampling of earthworms as important soil organisms in agriculture. Identifying earthworms is very complex and requires some practice. However, many farmers (and gardeners) want to improve their soils in order to maintain their soil fertility in the long term, but have no way of measuring the condition of their soils or quantifying the success of measures already implemented. At the Centre for Biodiversity and Sustainable Land Use, we develop concepts to promote soil organisms, especially earthworms. Increasing soil biodiversity in agriculture contributes to improved erosion control, leads to a reduction of pesticides and long-term adapted tillage. In England, a key to identify earthworms (Key to common British earthworms by Jones &Lowe) was already developed some time ago and used in a Citizen Science project. Although it cannot replace the expertise of scientists, this earthworm key offers a good opportunity for lay people to deepen their knowledge. Investigating earthworm species on an agricultural field can give an indication of the soils status. Similar to the British earthworm key, we have developed an earthworm identification key with the most common German earthworm species on grassland and arable land. An initial test phase with farmers has already shown great success.

Quantification of energy channels in soil food webs – A systematic review and meta-analysis

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Interactions in soil food webs drive stabilization and decomposition of organic matter – the largest pool of carbon on Earth. These interactions involve different pools of detritus, living plants, and microbes (basal resources), and their consumers – mainly soil invertebrates. Since soil food webs are very complex, multiple trophic connections among soil organisms are commonly clustered in 'energy channels', originating from different basal resources, such as bacteria, fungi, or plants. In the present study, we perform a novel review and quantitative summary on different energy channels in soil food webs across animal taxa and ecosystem types.

Utilizing a systematic review of published literature on the use of different basal resources in soil food webs, we want to focus on the channeling of root carbon through mycorrhizal, fungal and bacterial energy channels to soil meso- and macrofauna. The inclusion of applied methods allowing for in situ quantification of consumption of different basal resources (13C/15N-labeling, CSIA-AA, FA-analyses), allows us to synthesize knowledge with quantitative information about the key players in each energy channel.

Preliminary results suggest high omnivory across most of the investigated soil invertebrate taxa, while algae appear to be more relevant to meso-, rather than macrofauna. Also, fungal-feeding was lowest in Collembola, despite being assumed to be fungivores. The presence of root carbon resulted in distinct responses by the community abundance, but not biomass, which could point to body size changes. Despite this, root carbon showed to be of importance for all studied organisms. Still, 13C enrichment varied depending on the soil invertebrate group.

Here, we expand on our first results and show how resource consumption is affected by distinct ecosystems, mycorrhizal types, and environmental parameters. Such an approach will allow the more realistic reconstruction of soil food webs and get a more comprehensive and mechanistic understanding of carbon re-allocations and transformations in soil.

Dynamic feedbacks among tree species traits, termites and an endangered mammal via deadwood turnover

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Biodiversity losses may impact ecosystem processes via food-webs. We hypothesized that time can modulate feedbacks among plant functional diversity, resource quality, prey and predator populations and litter turnover. Thereto we incubated coarse deadwood of 34 woody species, with and without (wood-feeding) termite access, in Chinese subtropical forests with and without (termite-feeding) pangolins. The results supported our hypothesis: in the first 12 months, termites amplified the positive linear relationship between % wood mass loss and initial wood quality (along a wood economics spectrum, WES). In contrast, between 12 and 18 months, termite-mediated consumption, and associated wood mass loss, showed a humpback relation with the initial WES. This shift in termite preference of deadwood species along the WES indicated complementary food availability to termites through time, thereby promoting both termites and endangered pangolins. Thus, plant functional diversity through time can help to sustain keystone consumers, predators and their effects on carbon turnover.

Multidimensional stoichiometry mismatches as drivers of changes in density of detritivores along an altitude gradient

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The core of ecological stoichiometry is the relationship between the supply and demand of elements between the environment and living organisms. Organisms must obtain sufficient amounts of elements to maintain their own elemental homeostasis. Therefore, changes in the content of environmental elements may become the primary limiting factor affecting the growth and development of organisms. Here, we study typical detritivores (millipedes) taxa in eight altitudes primary forests in the Changbai Mountains of Northeast China. Based on various ecological stoichiometric assumptions, we tested the content of 11 elements in 5 millipede species and their litter resources and quantified their nutrient element mass ratios. We analyzed multidimensional stoichiometric mismatches and examined how they affected the biomass of five millipede species in the context of an altitude gradient. The results showed that while the elevation gradient changed the litter stoichiometry, the elemental content in millipedes remained stable. These 5 millipede species exhibited different patterns of multidimensional stoichiometric niche (MSN) and trophic stoichiometric mismatch (TSR) along the altitudinal gradient, which resulted in a decrease in their population density. Elemental calcium (Ca) is closely related to the population density of millipedes. In other words, detritivores reduce their population density in order to keep their body stoichiometry stable. Thus, our study may provide new insights into the adaptation strategies of species to their environments.

Decoding Soil Metagenomes: Global Insights into Organic Matter Decomposition Across Grasslands and Forests

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Soil organic matter (SOM) decomposition and nutrient cycling are among the most important functions of soil ecosystems, particularly in grasslands and forests, which cover about 70% of the Earth's land surface. We lack a systematic understanding of how these cycles are influenced by local and interregional variations. The International Soil Biogeography Consortium (iSBio) links microbial genomic diversity with soil functional analyses across environmental gradients. Here, decomposition data from the Tea Composition Project at more than 350 sites and soil metagenomics data were sampled and analyzed using a standard protocol. A total of 314 metagenome assemblies were annotated with gene functions potentially involved in SOM degradation, such as carbohydrate-active enzymes. Our analysis revealed a unimodal distribution of microbial functional diversity along a latitudinal gradient, with peak diversity shifting towards the poles and decreasing towards the equator ($R2=0.02$, $p<0.05$). Grassland metagenomes had a significantly higher richness of SOM degradation genes than forest metagenomes ($F=8.151$, $p<0.005$). Interestingly, despite lower gene richness, forest soils exhibited higher litter mass loss, indicating that gene richness does not always reflect metabolic activity in situ. Furthermore, the functional gene composition differed significantly between grassland and forest soil communities ($R2=0.05$; $F=13.30$; $P<0.001$). These differences were mainly contributed by genes involved in cellulose and lignin degradation. Future analyses will incorporate metagenome-assembled genome-centric analyses to link gene functions to abundant taxa and assess their occurrence along environmental gradients. The integration of metagenomics and more extensive amplicon sequencing based measures of taxonomic and phylogenetic diversity of bacteria, archaea, fungi and protists will further contribute to a better understanding of microbial taxa and soil function relationships.

Ecosystem-relevant traits of the microbial community are shaped by agricultural practices

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The type and the amount of fertilizer applied in agriculture have a vast impact on transformation processes of soil organic matter mediated by soil microorganisms resulting either in C sequestration or loss. Based on the Static Fertilization Experiment (Bad Lauchstädt, UFZ), we studied how contrasting long-term fertilization strategies (no fertilization, PK, N, NPK, farmyard manure as well as combinations of organic and mineral fertilizers) and agricultural practices (legume planting, liming) influenced a range of microbial functional traits related to respiration, growth and enzymatic activity.

As compared to N, PK and unfertilized control, the soil organic carbon (SOC) and total nitrogen (TN) content essentially increased after NPK ‹ manure ‹ NPK + manure application. However, fertilization strategies did not affect soil C:N stoichiometric ratios. Surprisingly, the microbial C:N ratios were much higher under mineral (20.1) versus organic (13.1) fertilization indicating the conditions of N deficiency in the former. Liming strongly increased the SOC, dissolved organic carbon (DOC), dissolved organic nitrogen (DON) and microbial N content, but not the microbial C. Consequently, the microbial C:N ratio was particularly low (10.3) under liming application. Legume planting resulted in a lower MBC and MBN, delayed microbial growth but did not have any significant impact on soil C and N content. This suggests that the effects of legumes may be limited to the microbial community rather than the overall soil properties. Nutrient availability and agricultural practices also affected soil hydrolytic enzymes involved in C, N and P cycling as well as basal respiration and kinetic parameters of unlimited microbial growth. Our results demonstrated the vast impact of the agricultural practices on microbial traits and related ecosystem functions crucial for maintaining ecosystem services and developing sustainable land-use strategies.

Optimising High-throughput sequencing data analysis, from gene database selection to the analysis of compositional data: A case study on tropical soil nematodes

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HTS provides an efficient and cost-effective way to generate large amounts of sequence data, being a very powerful tool to characterize biodiversity of soil organisms. However, marker-based methods and the resulting datasets come with a range of challenges and disputes, including incomplete reference databases, controversial sequence similarity thresholds for delineating taxa, and downstream compositional data analysis. Here, we use HTS data from a soil nematode biodiversity experiment to address the following questions: (1) how the choice of reference database affects HTS data analysis, (2) whether the same ecological patterns are detected with ASV (100%) versus classical OTU (97%), and (3) how different data normalization methods affect the recovery of beta diversity patterns and identification of differentially abundant taxa. At this time, the SILVA database performed better than PR2, assigning more reads to family level and providing higher phylogenetic resolution. ASV- and OTU-based alpha and beta diversity of nematodes correlated closely, indicating that OTU-based studies represent useful reference points. Further, our results indicate that rarefaction-based methods are more vulnerable to missed findings, while clr-transformation based methods may overestimate tested effects. ANCOM-BC retains all data and accounts for uneven sampling fractions for each sample, suggesting that this is currently the optimal method to analyze compositional data. Overall, our study highlights the importance of comparing and selecting taxonomic reference databases before data analyses, and provides solid evidence for the similarity and comparability between OTU- and ASV-based nematode studies. Further, the results highlight the potential weakness of rarefaction-based and clr-transformation based methods. We recommend future studies use ASV and that both the taxonomic reference databases and normalization strategies are carefully tested and selected before analyzing the data.

Afforesting with microbes: the biotic vs abiotic soil effects on *A.glutinosa* during the early stages of afforestation.

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In recent years, human activity such as deforestation, mining and arable farming have been replacing forested areas with intensively managed fields. This has resulted not only in a loss of natural habitat for many species but also in a decline of the soil microbial diversity. In an effort to combat this, considerable effort and resources are being allocated to afforestation and restoration projects. Often times, these projects focus on planting trees under the assumption that their associated microbial communities will passively colonize with them. However, due to various dispersal limitations, this is often not the case. By transferring soil from a mature forest ecosystem, we might be able to overcome these dispersal limitations. We set up two experiments, one where we planted *Alnus glutinosa* seedlings in live and sterile forest soil of three different forest ages (10-25 years since planting) to test the combined biotic and abiotic effects on tree performance and one where we inoculated sterile poor quality soil with soil from the same forests. Early results show that inoculating sterile soil leads to higher aboveground biomass and root nodule density in 15 year old forests. Sterilizing the soil eliminated root nodules from the trees and led to a reduction in the percentage of fine roots suggesting a potential for microbes to affect the percentage of fine roots depending on age. In both cases, lower root nodule density was observed in trees growing in/inoculated with 25 year old forest soil which also reflected in lower leaf nitrogen and lower herbivory rates.

SESSION 62:

Phenology Across Organisms and Scales

Using citizen-science photos to track the phenology of invasive species

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Phenology explores the timing of recurring biological events (such as bud burs flowering, and fruiting), their causes, and the relation among phases within an between species. When species are introduced to new regions, they are confronted with new environmental conditions. Phenology may be key for understanding what makes species invasive, as a range of factors driving species interactions competition for resources are tied to their timing. For plants, the capability to reach key phenological stages under differing climates can be considered a prerequisite to persist across geographical ranges and strongly shapes interactions with native communities. For example, the timing of resource acquisition is tied to the beginning (budburst) and the end (senescence) of a species' phenological cycle, the timing of flowering influences the availability of pollinators, and the timing of fruiting determines competitiion for potential dispersal vectors. Furthermore, the timing of effective IAS management is often linked to a species' phenology. Despite their importance, phenological studies on invasive species are still rare, in particular for herbaceous plants. The recent upsurge in publicly available photos collected by citizen scientists is a valuable source of phenological data for many species. Using citizen-science photos, we investigate the timing of phenological events of several widespread IAS across Europe. To this end, we explore the spatio-temporal patterns of flowering and fruiting and analyze climatic drivers of phenological events. We show how citizen-science photos can complement existing phenological studies on IAS and present future prospects of the approach.

Pflanze KlimaKultur!: Using citizen science to investigate the effects of urbanization on herbaceous plant phenology

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Urban areas are perfect test beds to assess the effect of urban heat islands on plant phenology. The citizen science project Pflanze KlimaKultur! (www.pflanzeklimakultur.de), coordinated by botanical gardens in the four cities Berlin, Halle, Jena, and Leipzig, studies these effects on the phenology of eleven herbaceous species together with almost 200 citizen participant sites located across the urban gradient (private gardens, allotments, and parks). Participants planted a set of our model species in their garden following a plant scheme and were asked to make weekly phenological observations over two years. Paired with local data for soil, surface, and air temperature monitored with climate loggers as well as satellite-based Sentinel-2 imagery land cover data, we assess the indicator potential of plant phenology to identify influences of the urban heat island effect using a citizen science approach.

Overall, results from 2022 demonstrate a negative correlation between the onset of flowering in some species with air temperature, i.e., earlier flowering at warmer temperatures. No association was found, however, with the surrounding land cover (green space, built-up area, or water) in a 500m radius and flowering data, despite present correlations between land cover and temperature. Analyses of data from 2023 should deepen our understanding of these correlations. This will provide insight into the complex factors underlying urban plant phenology.

In parallel, we offer botanical gardens as dialogue platforms to discuss with citizens ideas and visions for biodiverse, healthy, and climate-resilient cities using participatory mapping approaches. Interestingly, management for biodiversity, climate, and mobility seem highly linked in citizens' views. We aim to strengthen citizen science as a community capacity building approach for botanical gardens in order to enhance their science-society interface and offer opportunities for creating joint knowledge and understanding.

Growing degree days reliability to explain phenological events in herbaceous species depends on the species' functional traits and strategies

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The concept of "growing degree days" (GDDs), where daily mean temperatures are added up, is commonly used to accurately predict the day of the year (DOY) for the onset of phenological events in crops and trees. This approach has only rarely been applied for the phenology of wild herbaceous species, although it could be crucial to study how species-climate interactions may change in ecosystems under future warming.

In this study we combined phenological records of leaf unfolding and flowering onset of 48 herbaceous species with daily temperature data from nearby weather stations. The records were gathered by the members of the PhenObs network in six botanical gardens between 2019 and 2022. We then attempted to explain the variation of these two phenological events using GDDs calculated from 1st of January with either a temperature base of 0°C or 5°C and compared them to the null model, which would predict these events on the same date every year.

Overall, we found that including temperature sums does not always increase the proportion of variance explained, especially for flowering onset, which is in contrast to findings on crops and trees. The reasons for this could be a high genetic differentiation between the studied populations of herbaceous species, the high variability of local micro-environmental conditions, and stronger photoperiodic or plant internal factors over temperature. However, we found that GDDs can explain more variance in the onset of leaf-unfolding and flowering in early-flowering and small-growing species than in late flowering and taller plants.

This study provides first insight into the use of the GDDs concept in herbaceous species, its links to plant traits and, ultimately the potential to better predict species-specific responses in phenology to changes in climate based on their traits.

The role of plant traits in climate warming responsiveness of tree species

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Climate warming is mostly advancing the onset date of spring phenology, yet milder winters with higher temperatures may in fact delay this date, as chilling requirements of species are not fully met in time. The spring phenology of trees and forests is interconnected with ecosystem functions and services, thus the responses of single species to climate warming may have significant implications at the economic and ecological levels. Despite the numerous studies which have been conducted during the past decade on the responses of plant spring phenology to climate warming, the relative importance of various factors, such as phylogeny, floristic status, climate of the native range, life strategy and plant traits, is still not well understood. In this study, twigs from 55 different tree species with two different natural-chilling treatments were forced in climate chambers at 20°C/day and 15°C/night until budburst, and the onset of budburst was monitored 3 times per week. The probability of budburst was linked to phylogeny, life strategy, climate of their native range (oceanic to continental), floristic status (native or invasive) and seven important plant traits from the TRY database. The aim of our study is to answer the following questions: (1) Are species chilling and forcing requirements conserved at the genus level? (2) Are pioneer species more responsive to warming compared to later successional stages? (3) Is the climate of the native range and floristic status of species related to the responsiveness to forcing? (4) Can plant traits indicate species' phenological responses to climate warming? This information will contribute to an improved assessment and extrapolation of multiple species' spring phenology in a changing climate.

Late season coarse root growth: is winter growth an opportunity or requirement in temperature deciduous tree species?

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Temperate forests are productive with high carbon sequestration capacity. In late autumn, the debate about whether carbon sink limitation governs the end of the growing season is extremely vivid. Coarse roots (diameter › 2 mm) account for ~25% of the tree biomass in angiosperm temperate forests and act as an active carbon sink. Studying coarse roots' wood growth might contribute greatly to disentangling the sink/source processes. In wood xylem, new cells first enlarge (increase in size) before maturing (increase in density), the last stage sequestering most of the carbon. We hypothesize that coarse roots continue to grow in autumn (after aboveground nutrient remobilization) and in winter as a possible competitive advantage for soil resource acquisition. We studied, in Belgium, mature and sapling trees of common angiosperm deciduous forest species: European beech, silver birch, pedunculate oak and common aspen. In addition, we studied saplings of birch and beech in northern Spain and southern Norway to cover the whole range of the temperate maritime region of Europe. For all experiments, the root sampling started in mid-August and continue until December and in some cases until next year spring, resulting in a unique dataset of 1050 root samples. For all roots of mature trees and saplings of the four species and three countries, enlargement of cells occurs until late autumn which represents ~1-2 cells out of the ~10-15 cells usually present in the annual ring. Similarly, the maturation in late autumn occurs in ~2-5 cells in the annual ring and is species-specific. In addition, throughout the winter and until next year's spring, ~1 -2 cells are maturing, without species specificity. These results highlight that a large part of the coarse root annual ring is produced in autumn. Winter root growth seems to be generalized across species and countries reinforcing the importance of belowground organs in the whole tree carbon balance.

Spring phenology under continued climate change - Insides from an extreme warming experiment.

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Ongoing climate warming has led to a clear advancement in spring phenology of trees. However, this advancement is slowing down despite continuous climate warming, because reduced chilling during winter delays spring phenology. How will this end up if climate warming goes on? Will the advancing effect of warming be compensated by the delaying effect of reduced chilling? Or even overcompensated?

We experimentally investigated the impact of extreme warming from September till flushing on two common European tree species. The control temperature was 3°C above the long term mean, and the elevated temperature was ca. 4°C above the control. Both species still unfolded their leaves earlier under elevated temperature. But no all buds were able to flush. While normally all buds of those species flush, under the extreme warming bud survival reduced to 80% in Fagus sylvatica and to 90% in Betula pendula.

To reveal the underlying mechanism, we tracked the development of dormancy depth over the whole period in a forcing chamber. Under elevated temperature, dormancy induction in autumn was delayed. The peak of dormancy was lower. From January onwards, dormancy release rate was almost similar under both temperature regimes. Only in the last weeks before leaf out, dormancy release and leaf flushing was accelerated by warm temperatures. The percentage of buds being able to flush constantly increased over the dormant period.

The short nongrowing season that resulted from our extreme warm temperature apparently caused an incomplete dormancy cycle as reflected by its shallow dormancy depth at its peak, which lead to irregular flushing and reduced bud survival.

Determinants of interspecific variation in season length of perennial herbs

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Perennial plants in temperate climate need to optimize their carbon balance by adjusting their active season length to avoid risks of tissue loss by frost or drought. As the season length is determined by both spring growth and senescence, it is likely to respond to several potentially contrasting selective forces. Here we present data that disentangle the cascade of ecological determinants of interspecific differences in season length.

We measured size trajectories in 231 species in a botanical garden. We examined the correlations between their spring and autumn size and their contributions to the season length. By employing structural equation models (SEMs) we were able to determine how niche parameters and species traits combine in their effect on species-specific season length.

The interspecific differences in season length were primarily driven by senescence, while spring growth exhibited a high level of synchronization across species. Structural equation models revealed that niche parameters such as light and moisture had stronger, and often trait-independent, effects compared to species traits. Several niche (light) and trait variables (plant height, clonal spreading) had opposing effects on spring growth and senescence.

The findings suggest that growth and senescence are influenced by different drivers and potential risks. The prominent role of niche-based predictors implies that shifts in season length due to global change are likely vary across habitats and will not be uniform across the whole flora.

Overwintering buds as an important driver of plant phenology of temperate perennial herbs

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Overwintering buds of perennial herbs in temperate regions are the key plant component ensuring spring renewal and also maintaining the perennial life strategy. The available studies, mostly of trees and shrubs, also show that overwintering buds play an important role in the timing of phenological events. However, in herbs, except for a few studies mainly focussing on flower preformation and its strong impact on flower phenology, we know very little, how also other bud traits are related to whole spring growth.

Here, we examined different bud traits (bud size and depth in the soil, bud coverage and bud development – e.g., leaf and flower preformation) in the middle of the winter season in a large phylogenetically representative set of temperate non-woody perennials. Leaf preformation was defined as the number of leaf primordia already initiated in the stage of a bud in winter, while flower preformation (an ordinal variable) denoted the degree of generative meristem development. We linked all these bud traits to plant architectural traits, belowground organ size and plant phenology.

We found that different bud traits drove different spring phenological events. Day of peak growth and first flowering were negatively correlated with the leaf preformation and positively with plant height indicating earlier growth of smaller species with fully preformed leaves. In addition, flower preformation was the most important driver of early flowering. In contrast, the growth rate was positively driven by a degree of bud protection traits showing that well-protected buds grow faster in comparison to species with unprotected buds.

These findings show the functional relevance of the (great) variety of traits of overwintering buds. They are indispensable for the functional understanding of the phenological variability of temperate perennials.

Plant growth phenology - from destructive to non-destructive measurements.

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Plant phenology has been recognised as a useful climate change indicator. Non-destructive measurement of plant growth phenology (size) allows easy tracking of a particular individual's growth throughout the season. The modelling of spring growth trajectories is usually based on the dynamics of biomass accumulation and is thus described by exponential or logistic functions. Unfortunately, the relationship between plant size and biomass is not clear. Moreover, different ways how to measure plant size (e.g. plant height, foliage volume) are used in different studies. Results of plant growth phenology studies are thus not comparable. Therefore, we measured non-destructive (plant size in several different ways) and destructive (fresh and dry biomass and leaf area) parameters for twenty different plant species during their spring growth in the botanical garden. We investigated which non-destructive plant size parameters are the best predictors of plant biomass and leaf areas across species and developmental stages. Our work can help us better understand the results of plant growth phenology measurement and, thus, the processes determining the species' coexistence under changing climate conditions.

Plant Species Richness Buffers Climate Induced Responses of Plant Phenology in a Semi-dry Grassland – The Role of Functional Traits

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AIM

Many studies have shown changes in plant phenology in response to variations in climatic conditions. In a previous study, we found that plant species richness has the potential to buffer climate-induced phenological changes at the community level. Now, we aim at identifying the role of plant traits and ask:

How do plant traits change along a species richness gradient?

How are phenological stages linked to species richness, traits, and habitat conditions?

Do traits determine the differences in phenology among herbaceous species?

METHODS

We established five semi-dry grassland sites in central Germany, representing five diversity levels. We performed weekly phenological observations from March to November in 2019 and 2020 to detect leaf and flowering phenology of all flowering species co-occurring at these sites. Additionally, we carried out vegetation relevés, measured plant traits in 2019, and abiotic habitat parameters in 2020.

RESULTS

Our results indicate that traits are related to phenology, particularly for stages of senescence. We found trait-specific patterns along a gradient of species richness, reflecting conditions of a semi-dry grassland. We also found species-specific responses in phenology and traits to increasing species richness, although trends among species were more similar for late phenological stages, such as leaf senescence.

CONCLUSIONS

We conclude that a higher plant diversity clearly affects phenology in a species-specific manner, as higher plant diversity reveals a species community with a particular trait combination that may be related to explicit phenological patterns.

Non-additive Interactive Effects of Global Change Drivers on the Phenology of Mountain Grassland

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Rapid increases of atmospheric CO2 concentrations and other greenhouse gases are accelerating global warming and the occurrence of extreme climatic events such as droughts. Mountain ecosystems, including the European Alps, have been exposed to significantly higher warming rates compared to the global average, with consequences for their functioning and their phenology. While the individual effects of warming, drought and elevated CO2 on phenology have been comparatively well studied, there is a lack of understanding of their interactive effects. Using a multifactorial experimental setup in a managed mountain grassland we investigated the individual and interactive effects of elevated CO2 (C; +300ppm), elevated temperature (T; +3^0 C) and drought (D) on phenology. From times series of phenocam images we derived canopy-level phenological transition dates from green chromatic coordinates (GCC) and in field-based surveys we monitored species-level phenological responses. At canopy level, our results revealed that temperature was the key driver advancing spring phenology. The combination of elevated CO2, warming and drought (CTD) accelerated senescence more strongly compared with ambient conditions and indicated potential drought legacy effects during spring, advancing the upturn date. At the species level, we observed larger phenological shifts both under T and CT treatments compared to ambient conditions especially, the effects being more pronounced for the forbs than the grasses. CTD advanced senescence among all the species. Overall, our findings reveal distinct, non-additive effects of interacting global change drivers on the phenology of mountain grassland, and show that phenological shifts are pivotal indicators of global change, which may have strong repercussions for biogeochemical cycles.

Shifts in phenological reaction norms: applying a macroecological approach to detect signs of adaptation in bird egg laying times

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Biodiversity is threatened by a multitude of anthropogenic factors, including climate change. Phenotypic plasticity can allow species to respond rapidly and adaptively to changes in the environment. Therefore, it has often been viewed as the main strategy for species to respond to rapid climate change. Even assuming that phenotypic plasticity is adaptive, plasticity may not be sufficient to track shifts in optimum timing and populations may be placed under selection to evolve. Evolution in response to climate change have been shown to act even over short time spans for individual species. Nevertheless, studies on how different species rely on phenotypic plasticity versus evolutionary adaptation under ongoing climate change remain scarce, and this undermines our capacity to predict species responses and future population trajectories. Using nest card data for 66 bird species across Finland from which egg-laying dates can be discerned, we define climatic windows under spring to estimate response norms over 5-year and 60-year periods and compare them by extending the within-subject centering approach to evaluate changes in the slopes and intercepts of the phenological response over a temporal gradient. We postulate that evolutionary adaptation in egg-laying time should be discernible though a steeper long-term than short-term response and show this using simulated data. When applied on the Finnish nest card data, we observe only rare cases pointing towards an evolutionary response in egg-laying phenology with no differences across the latitudinal belts across Finland. Thus, we conclude that bird species in Finland are mainly adjusting their reproductive phenology through plasticity.

Changes in spring migration phenology of bird species in central Germany over the last 180 years

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Current and future global change will have significant effects on species, of which birds, especially migratory birds, are considered to keep pace to those effects by changes in migration phenology. However, many studies that investigate such changes often consider only a limited time frame or only a set of few species. Here we analysed probably one of the earliest and most comprehensive datasets on avian spring phenology for central Germany, recorded between 1842 and 1865 for 62 species. Based on that data, we compared the historic phenological spring observations with the current period of the latest 20-yr time frame for the same area (Kassel, Hesse). We investigated long-term changes in species' spring arrival between periods, analysed trends within periods and differences among species' guilds. Out of 62 species, 48 species showed a significant advance in spring arrival, while only one species showed a significantly delayed arrival. Historically, only one species tended to advance its spring arrival, whereas 14 species showed to be observed later over the period. In contrast, during the current period only one species showed a trend to delay its spring arrival and 11 species were observed significantly earlier. When looking at species' guilds, for example, short-distance migrants showed a much stronger advance compared to long-distance migrants. Our results confirm similarly investigated changes in spring arrivals of bird species, but we highlight that for many species, advances are even more pronounced than in other studies due to their much shorter period of comparison. Therefore, so far, the true extent of changes in spring migration for some species may have been underestimated by now. We conclude that climate change strongly affects bird migration patterns and emphasise the value of historic bird observations in old written documents and of citizen science data as recent data source for such studies.

Comparing diapause termination in wild bees with dormancy release in flowering plants.

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Flowering onset and wild bee emergence in the spring are key phenological events which shape pollination timing and the potential of a plant-insect phenological mismatch. Studying factors affecting dormancy release in flowering plants and diapause termination in insects are crucial to be able to project spring phenology, yet simultaneous tracking of dormancy and diapause changes in plants and insects is lacking. I quantified diapause termination in two wild bee species (Osmia cornuta and Osmia bicornis) and dormancy release in several adult fruit tree and perennial flowering plants. Wild bee cocoons were kept in under ambient winter conditions in a rain-out shelter close to the sampled trees and potted flowering plants. From January to May I exposed overwintering wild bee cocoons, tree twig cuttings and potted perennials by transferring the cocoons and plant material to warm and long-day conditions in a climate chamber. The thermal time required for bee emergence and flowering onset in each month for each species was recorded. Species-specific changes in the diapause termination and dormancy release curves were found, which explained insect and plant phenology under ambient conditions in the spring. Chilling time was more influential that chilling temperature and photoperiod with respect to diapause termination and dormancy release. The novel yet simple experimental set up thus allows to estimate future species order in terms of plant flowering and insect emergence phenology.

Unapparent trees: escaping enemies in time by being discreet, unpredictable and inaccessible

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For half a century, biologists considered trees as being particularly apparent to their enemies. But why then do some trees escape enemies in time and burst buds too early or too late for their herbivores, i.e. phenological mismatch? We hypothesize that herbivore phenologies mismatch on trees whose buds burst discreetly, unpredictably and inaccessible to matching herbivores, i.e. slowly, inconsistently across years, and surrounded by spatially or phylogenetically distant neighbours. Studying the entire caterpillar community on oaks for three years we find that, across species, caterpillar size (in the field) and pupation date (in the lab) overall matched leaf phenology in the field. Mismatch occurred in trees that bursted buds slowly and either inconsistently or isolated from neighbours. Phenology mismatch decreased herbivory. We suggest that matching of caterpillars to present tree phenology is achieved by sorting of matching species into communities over years – except in trees that are unapparent in time.

Quantitative morphology of modern and fossil larvae reveals a loss of diversity in lacewings

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Comparing biodiversity, also in deep time, is crucial in the modern biodiversity crisis. Only by involving fossil data and extinction rates in the past, it becomes possible to evaluate how fast (and possibly exceptional) current extinction rates are. Yet, establishing comparative frames that allow to effectively compare modern and fossil diversity is not so simple, leaving common comparisons between the two in a vague state. Even more complicated is including larvae into such quantitative comparisons. However, a considerable part of the lifetime is spent in the larval phase, especially in the group Holometabola (including beetles, bees, butterflies and other groups), and most individuals will not make it into adulthood as they get eaten by other organisms. Hence, ecological interactions are in fact concentrated on larvae, and larvae should be considered in diversity assessments. We used quantitative morphology of head and mouthparts to compare the shape diversity of lacewing larvae over that last 100 million years. The group of lacewings, Neuroptera, is generally understood as having declined significantly since the Cretaceous, but this decline remains challenging to demonstrate quantitatively. Using Elliptic Fourier Transformation in combination with Principal Component Analysis, we can demonstrate that indeed lacewing larvae in the Cretaceous had a much larger morphological diversity than their modern counterparts. Another advantage of using morphological diversity, instead of taxonomic diversity, to assess ecological diversity is the tight fit between the two due to functional coupling. Our findings therefore clearly indicate that specific ecological functions performed by these larvae back in the Cretaceous are no longer represented in the modern fauna.

Identifying the proximate abiotic cues controlling the phenology of tropical rainforest tree species

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Clarifying phenological patterns of tree species is essential to understand the impact of climate change on forests and on the interaction partners that rely on resources produced by trees. Even though seasonal changes in temperature, day length, and rainfall are far less pronounced in tropical rainforests compared to temperate regions, many tree species still show high levels of synchronicity in their phenology. This suggests that they rely on abiotic cues such as light or rainfall for the timing of phenological transitions. However, our knowledge about the phenology of tropical tree species and the abiotic cues they rely on is still scarce.

Here, we investigate the timing and synchronicity of phenological transitions of characteristic tree species of a Cloud Forest in Southern Ecuador. Specifically, two deciduous species and two evergreen species are monitored continuously for three years. We access tree canopies of 8 individuals per species through tree-climbing techniques every 2 – 3 weeks to collect precise phenological observations. In addition, time-lapse cameras were installed on nearby trees to monitor the target trees.

Using Circular Statistics, we will identify the timing and synchronicity of leaf, flower, and fruit phenology. Extracting RGB values from the pictures obtained from the time-lapse cameras will allow us to create time series using Green Chromatic Coordinates (Gcc) and thus, to identify phenological transitions. With GLM models based on phenological and environmental data, we seek to identify the proximate abiotic cues controlling the phenology of the four species.

Thus, our study will provide in-depth knowledge of the phenological patterns of relevant rainforest tree species. The information about the abiotic cues will allow us to better assess the potential impact of climate change on flowering and leafing times. Moreover, the results will also inform practitioners about the time of seed collection for the creation of reforestation nurseries.

Effects of climate, stand structure, soil characteristics and topography on leaf phenology in Switzerland

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Leaf phenology of trees is influenced by a wide range of environmental factors, such as climate, stand structure, soil and topography. While temperature is a major driver, other environmental factors also play a role. However, there are only few studies that have investigated the compound effect of multiple environmental factors that may affect the phenological timing of leaf unfolding and leaf colouring. Especially the influence of soil characteristics, such as water-holding capacity and the resulting soil water balance, on the phenological timing of adult trees is largely unexplored.

This study aims to understand how interactions between multiple environmental factors, including climate, stand structure, soil, and topography, influence the phenological timing of *Fagus sylvatica*, *Picea abies*, *Larix decidua*, *Tilia cordata*, *Castanea sativa*, and *Robinia pseudoacacia*. To understand the effects of these factors, field data on soil characteristics (depth, texture, bulk density and organic carbon), topography (elevation, relief type, slope aspect and slope inclination) and stand structure (land cover type and competition) were collected at long-term observation sites from a homogeneous phenological network across all biogeographic regions of Switzerland. The data are currently being analysed using mixed-effects models. Preliminary results indicate that elevation, slope aspect, and competition have a species-specific influence on the phenological timing.

Our study will contribute to a better understanding of how rarely investigated environmental factors affect the phenological timing of the investigated species across a wide range of environmental conditions and how they are affected by climate change.

Phenology of growth and plant coexistence

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Niche differentiation along the temporal axis has often been suggested as a potential mechanism of species coexistence. Species may co-occur by shifting growth timing to avoid competition for seasonally available resources, namely light. However, due to the lack of data on growth phenology of a large set of species, we do not know whether the phenologies of coexisting species are indicative of either niche differentiation or resource competition.

We recorded phenology of growth of a large set of perennial herbaceous species in a botanical garden. We used the measurements to derive the day of peak growth and two types of growth rates. For the same set of species, we determined flower preformation in overwintering buds as a proxy of growth flexibility during the vegetation season. We then used co-occurrence data of these species from the Czech National Phytosociological Database and examined whether co-occurring species show non-random patterns of these parameters in major habitat types.

We found large differences both in phenology and proportion of preforming species among these habitat types, with grasslands, shore and anthropogenic habitats showing least phenological differentiation, and forests understory showing highest phenological differentiation. These differences are likely to be due to differences in habitat productivity. In productive habitats with high competition for light (such as grasslands or shore habitats), there is only one possible strategy to survive in competition, namely fast and flexible growth. Consequently species there tend to be synchronized in their growth phenology; they attain growth flexibility by not preforming their organs. In contrast, unproductive habitats with weak competition for light are associated with asynchronous growth phenologies and preformed buds. The prime driver of differences in growth phenology and of organ preformation should thus be sought in light competition among species of similar sizes.

Do floral traits explain phenological patterns in herbaceous plants?

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Plant functional traits have been shown to explain phenological variation, but so far mainly vegetative traits such as plant height or leaf area have been considered. Floral traits are often neglected in trait-based studies as protocols are far less developed compared to vegetative traits. However, they may be strongly associated to the flowering phenology of plants as there are known trade-offs between vegetative and reproductive traits. Floral traits were recently shown to be an independent dimension within the plant economic spectrum and might thus differently relate to phenology than vegetative traits.

In this study, we tested the hypotheses that, (i) floral traits are more important to explain variation in flowering phenology (e.g. flowering start) and that (ii) vegetative traits are more closely linked to vegetative phenology (e.g. leaf out timing). We monitored the year-round phenology (8 phenological stages) of 65 herbaceous plant species in three Botanical Gardens in Germany (Halle, Jena, Berlin) as part of the PhenObs network and measured 16 generative traits (eight floral, four nectar and four pollen traits) and three vegetative traits for the same populations. Using Boosted Regression Trees, we investigated the relative impact of floral traits compared to vegetative traits to explain variations in plant phenology. The data shows that vegetative traits such as plant height, specific leaf area (SLA) and leaf dry matter content (LDMC) are most important in explaining phenological patterns regardless of whether flowering or vegetative phenology is considered. Floral traits, especially pollen traits that were assessed by multispectral imaging flow cytometry using a recently developed protocol, additionally contributed to explain phenological patterns.

In this contribution, we discuss the importance of floral traits in studies of phenology-trait relationships, increasing our knowledge of often neglected floral traits in phenology studies.

Morphological diversity of adephagan beetle larvae through time

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The expression "Big Four" refers to four groups of holometabolan insects with enormous species richness, including Diptera (flies), Lepidoptera (butterflies), Coleoptera (beetles) and Hymenoptera (wasps in the wide sense). Each of these ingroups includes more than 100,000 species, with Coleoptera being most species-rich (›380,000 species). The fossil record of Coleoptera reaches back to at least to the Permian (about 265 million years ago). Coleoptera includes several different ingroups, the most species-rich being Polyphaga (›320,000 species), accounting for about 84% of all beetle species. However, Polyphaga is a relatively young group, while the coleopteran group Adephaga has diversified much earlier. Adephaga comprises about 40,000 species in the modern fauna. As in general for beetles adaphagans spend quite some time of their life as larvae, which likely also have the greater impact on the ecosystem. Adephagan larvae have various ecological roles also including terrestrial and aquatic predators with forward-protruding mandibles, but also herbivorous forms. As Adaphaga diversified quite early representatives of the group likely also had ecological roles that are nowadays fulfilled by representatives of Polyphaga. In order to explore this idea. We compared the morphological diversity of adephagan larvae through time, including fossil representatives. For this purpose, we compared different body parts from different larval specimens of Adephaga via an Elliptic Fourier Transformation and a Principal Component Analysis. With this method, we evaluate the morphological diversity since the late Palaeozoic and the potential influence of the diversification of Polyphaga.

SESSION 63:

Land-Use Changes in the Tropics

Restoring a selectively logged East African rain forest

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Tropical forests are increasingly degraded by human activities. Restoration is recognized as a way to reverse degradation and enhance biodiversity and ecosystem services. Necessary for effective restoration is a profound understanding of the species regeneration ecology as well as of the patterns and processes of recovery of these ecosystems. We aim to contribute to better our knowledge of the regeneration ecology of selected tree species and to provide knowledge of the patterns and the processes of structural and functional forest recovery. Thereby, we aim to support the development of effective restoration strategies. Using forest inventory data collected in 204 (1000 m^2) plots, we identified the most relevant site factors influencing the occurrence and abundance of tree regeneration in Budongo Forest. Requirements for reproduction at the individual tree level were investigated using an 11-year fruit production data of 64 African mahogany trees. Regeneration was primarily determined by availability of seed sources and soil pH. The two most important requirements for seed production are tree size and low competition. In the next step, we investigate the patterns and processes of recovery of logged tropical forests by studying the structural and compositional dynamics along a recovery gradient in Budongo Forest Reserve Uganda. Such information is essential for effective restoration planning of selectively logged tropical forests. Against this background, we will present early results on the structural and compositional recovery based on detailed forest inventories and 3D terrestrial laser scanning data and close our presentation with concrete recommendation for active forest restoration.

Rainforest transformation reallocates energy from green to brown food webs

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Functional and energetic consequences of land-use change above- and belowground and across trophic levels in megadiverse tropical ecosystems remain largely unknown. To fill this gap, we assessed changes in energy fluxes across 'green' aboveground (canopy arthropods and birds) and 'brown' belowground (soil arthropods and earthworms) animal food webs in tropical rainforests and plantations in Sumatra, Indonesia. In contrast to the misleading perception of tropical ecosystems as a 'green world', our results indicate that most of the energy in rainforests is channelled to the belowground animal web. Plantations had similar, or in the case of rubber agroforest, higher total animal energy fluxes compared to rainforest, but the key energetic nodes were distinctly different: in rainforest ›90% of the total animal energy flux was channelled by arthropods in soil and canopy, while in plantations ›50% of the energy was allocated to annelids (earthworms). Plantation food webs relied more on resources with fast turnover (living plants and bacteria) and in most cases had a reduced energy flux to higher trophic levels (down to -18% aboveground and to -90% belowground) in comparison to rainforest. Our study shows that tropical land-use change drives consistent decline of multitrophic energy flux aboveground, and intensification of soil organic matter consumption joint with nearly complete elimination of energy flux to predators belowground, which coincide with previously reported soil carbon stocks depletion. We highlight the pervasive role of land-use choices on multitrophic and multistrata functioning of tropical ecosystems and call for managing their energy for sustainable land use.

Ecological intensification in macadamia orchards – how to sustainably increase pollination and biocontrol services

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More sustainable and environmentally-friendly agricultural practices are needed to reduce biodiversity loss and environmental degradation. We evaluated the potential of ecological intensification through the enhancement of pollination services in an intensively managed crop, Macadamia integrifolia. We compared the effects and importance of agronomic practices that include agronomic input (i.e. irrigation and managed honeybees), orchard design requiring no external inputs (i.e. spatial orchard structure) and landscape factors in ten South African macadamia orchards. Additionally, we examined the role of natural habitat at landscape scale (1km radius) for predator abundance and crop damage. Flower visitation rates increased with the cover of natural habitats, outperforming the effect of managed honeybee colonies, as agronomic practice. A perpendicular orientation of the planted macadamia rows towards the natural habitats increased initial nut set more than threefold compared to parallel row orientation. In contrast, agronomic practices, such as irrigation, did not increase initial nut set. When trees were accessible to predators (bats and birds) compared to their exclusion, insect damage was reduced by 40%, while natural habitat increased bird abundance and indirectly reduced the insect damage.

Pollination and biocontrol services complementary increased yields and nut quality of macadamia and can be improved without further agronomic input. Especially, the orchard design, i.e. spatial arrangement of tree rows and natural habitats at local and landscape scales, was more important to boost insect pollination and the initial development of macadamia nuts than agronomic practices. Considering the urgency to reduce the environmental impacts of agricultural production, we highlight the high potential of ecological intensification by a smart orchard design and the restoration and conservation of natural habitats in the orchards and their surrounding landscape

Effects of local and landscape factors on the specialization of hummingbird-plant interactions in human-altered landscapes of the Tropical Andes

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The degree of species specialization influences network stability and associated ecosystem functions, and it can vary along anthropogenic disturbance gradients. However, the effects of anthropogenic disturbance on specialization could depend on the mobility of the organisms involved in interactions. In the case of hummingbird-pollination networks, hummingbirds are highly mobile and could respond to anthropogenic disturbance according to the composition and configuration of the landscape. In contrast, plant individuals have a fixed spatial position, and their levels of specialization should respond to local ecological conditions.Here, we used independent measures of hummingbird abundance, flowers, and plant-hummingbird interactions to examine changes in the specialization of hummingbird-plant networks at both the local and landscape scales in the southern Andes of Ecuador. In total, 17 hummingbird species and 76 plant species were involved in pollination networks across different habitats. The specialization of hummingbirds was exclusively associated with landscape-scale variables, indicating that their specialization increased in landscapes with higher edge density. On the other hand, in the case of plants, their specialization was associated with local habitat characteristics, showing a decrease in specialization in shrubs compared to forests. Overall, our results indicate that the specialization of species can be modified by anthropogenic habitat disturbance, but the responses will depend on the trophic guild of the interacting species.

Land use and fragmentation affects bird communities and the ecoservices they provide in Papua New Guinea

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Tropical forests worldwide are being fragmented, logged and turned into plantations or slash-and-burn gardens at a rapid rate, causing a tremendous loss of biodiversity. Determining the impacts of forest disturbance on tropical biotas, and the food-webs in which they are involved, is therefore a central goal of conservation biology. We focused on bird communities and their ecology in the interior of forest fragments (300, 600, 1200 ha), in the secondary forests surrounding them and in the continuous primary forests (>10,000 ha) in the lowlands of Papua New Guinea. We surveyed bird communities, measured habitat and climatic characteristics at each site. We also surveyed arthropod communities and obtained diet samples from birds to examine food availability vs. food preferences. Finally, we studied predation pressure the insectivores express on the arthropods and plants in selected forest types. We recorded significantly fewer birds in secondary forests and in 300 ha forest fragment that in other study sites. Specifically, large frugivores and insectivores had lower species richness in secondary forest, than in forest fragments, and in continuous forest. The insectivorous birds were limited more by microclimate characteristics than by resources, and they expressed much stronger impact on arthropods in primary than in disturbed forests.

Natural regeneration of neotropical rainforests and their species interactions

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Natural recovery of rainforests in the neotropics can be surprisingly fast, particularly in landscapes with larger intact forests in the surrounding where seed dispersal by animals is pronounced. We currently examine such regeneration and underlying processes in detail within the Research Unit "Reassembly" (reassembly.de). We are studying the role of various taxa and ecosystem components in the reassembly of trees, animal communities and species interaction networks. Our research takes place in a lowland forest reserve in North-Western Ecuador (Reserva Canandé, protected by Fundación Jocotoco). Our research includes a chronosequence of 62 plots including active cacao plantations and pastures, secondary forests of different ages and old-growth forests.

In more degraded landscapes with small forest fragments, recovery is expected to be much slower, which will be studied in a second reserve in the South of Ecuador (Reserva Buenaventura). Here, active regeneration involves planting native trees and facilitates forest recovery. Both projects are open for international collaborators interested to use our research framework and facilities.

Tree islands enhance biodiversity and ecosystem functioning in oil palm landscapes

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In the United Nations Decade on Ecosystem Restoration, large knowledge gaps persist on how to increase biodiversity and ecosystem functioning in cash crop-dominated tropical landscapes. Here, we present findings from a large-scale, 5-year ecosystem restoration experiment in an oil palm landscape enriched with 52 tree islands in Sumatra, Indonesia (EFForTS-BEE), encompassing assessments of ten indicators of biodiversity and 19 indicators of ecosystem functioning. Overall, indicators of biodiversity and ecosystem functioning, as well as multidiversity and ecosystem multifunctionality, were higher in tree islands compared to conventionally managed oil palm. Larger tree islands led to larger gains in multidiversity through changes in vegetation structure. Further, enriching cash crop-dominated tropical landscapes with dissimilar tree islands promotes biodiversity at the landscape level and did not decrease landscape-scale oil palm yield. Our results demonstrate that enriching oil palm-dominated landscapes with tree islands is a promising ecological restoration strategy, yet should not replace the protection of remaining forests.

Tropical landscape design modulates trade-offs among ecological and socio-economic functions at different spatial and temporal scales

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Land use changes have dramatically transformed many tropical landscapes from forest to agriculturally dominated landscapes. Agricultural land uses, such as rubber and oil palm plantations, increase the socio-economic benefit at the cost of reduced ecological functioning, so called trade-offs. Questions arise on how different landscape designs in terms of fragmentation and connectivity of land cover types as well as different dynamic market prices for rubber and palm oil affect these trade-offs at different spatial (farm- vs landscape-level) and temporal scales (short- vs long-term).

To tackle these knowledge gaps, we developed the integrated ecological-economic land-use change model EFForTS-ABM that follows a combined agent- and grid-based approach. The model simulates the impact of land use change decisions made by smallholder farmers on the economic outcomes from oil palm and rubber plantations as well as ecological functions such as carbon sequestration. EFForTS-ABM is based on socio-economic and ecological field data from the Jambi province in Sumatra (Indonesia). Using EFForTS-ABM we ran model scenarios on different landscape designs (i.e., different landscape fragmentations) and different dynamic crop price scenarios (i.e., constant vs different fluctuations of prices for rubber and palm oil). We then assessed farm-level and landscape-level ecological and socio-economic functions as well as trade-offs among them over the simulation time.

Here, we will demonstrate the challenges in developing EFForTS-ABM and the usefulness of the model to assess the effect of different landscape design and price scenarios on socio-economic and ecological functions as well as trade-offs among them. We expect individual ecological functions to be affected differently by changes in landscape fragmentation, leading to different trade-offs with socio-economic functions. In addition, trade-offs among functions found at the farm-level might be less severe at the landscape-level. Temporal changes of land use and plantation ages driven by crop prices might change trade-offs over time. The results will be an important basis for identifying landscape designs that minimize losses in ecological functions while still allowing for economic benefits.

Improving inclusion in ecology and conservation through Global South leadership

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Strengthening participation of Global South researchers in tropical ecology and conservation is a target of our scientific community, but strat- egies for fostering increased engagement are mostlydirecteda tGlobal Northinstitutions and researchers. Whereas such approaches are cru- cial, there are unique challenges to addressingdi- versity, equityand inclusion (DEI)withintheGlobal South given its socio-economic, cultural and scientific contexts. Sustainable solutions pro- tecting biodiversity in t h etropics depend on the leader- ship of Global Southcommunities, and therefore DEI improvements in the Global South are paramount in our field. Here, we propose ten key actionstowards equitable international collab- orations in tropical ecology, which, led by Global South researchers, may improve DEI at institu- tional, national and interna- tional levels. At an institutional level, we recommend (1) becoming rolemodels for DEI, (2)co-developing researchwith local stakeholders, and (3) promoting transparent funding management favouringlocal sci- entists. At a national level, we encourage (4)engagement in political actions protecting scientists and their research in tropical countries, (5) participation in improving biodiversity research policies,and (6) devising research that r e a c h e ssociety. At an international level, we encourage Global South researchers in international collaborations to (7) lead and direct funding applications,(8) ensureequitable workloads and (9)procure equal benefits amongnational and foreign collabora- tors. Finally, (10) we propose that Global South leadership in DEI efforts has the most potential for worldwide improvements, supporting posi- tive long-lastingchanges in our entire scientific community.

From sugarcane to macadamia: How crop conversion influences bat abundance and diversity in agricultural landscapes of South Africa.

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The homogenization of agricultural landscapes through the establishment of large monocultures negatively affects species diversity and ecosystem services such as pest control by bats. Although much research has been conducted on the effects of local conditions, such as crop identity or field size, there is still a gap in our understanding of how entire agricultural landscapes influence biodiversity and ecosystem functions.

Between October and December 2022, we conducted a landscape-wide survey of bats across 16 study sites in eastern South Africa. The region historically was dominated by forest, grassland, and sugar cane plantations, but in recent years farmers have been converting sugar cane to macadamia plantations. To assess bat communities, we deployed 16 acoustic recorders in each landscape for a total of four nights, resulting in 1536 hours of audio recordings. We automatically filtered for recordings with bat calls, which were then semi-automatically analysed and identified. Overall, we detected › 80,000 bat passes, which we classified into three ecologically and behaviourally distinct feeding guilds, and assigned to eight different sonotypes.

Our results shed light on the bat communities present in these agricultural landscapes and allow us to infer how land-use type, conversion, and complementarity of land uses at the landscape scale affect bat diversity and foraging. We found that the conversion of sugar cane to macadamia plantations increased bat activity and diversity. Structural landscape elements as well as the amount of natural grassland also promoted the foraging activity of insectivorous bats.

Our findings have important implications for the conservation of bat populations in agricultural landscapes, particularly in regions where land-use types are drastically changing. By promoting crop diversity, farmers and land managers can create landscapes that are more hospitable to bat populations and provide valuable ecosystem services such as pest control.

Parallel changes in multidimensional biodiversity of canopy springtail and spider communities

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In recent decades, much of the existing lowland rainforest in southeast Asia has been converted into rubber and oil palm plantations, resulting in a decline in biodiversity and in changes in species composition. However, it remains unclear whether the direction of change in species composition *per se* can be predicted, and whether changes in one taxonomic group can be predicted by another of different trophic level. Springtails are considered to be typical detritivores in the canopy of trees, while spiders are mainly predators that at least in part to feed on springtails. These two taxa thus provide a model system to study the effects of trophic interactions on community assembly processes of each other. We applied trait-based and phylogenetic approaches to investigate the responses of canopy arthropod communities to the transformation of tropical rainforests. Using data from a long-term integrative project investigating ecological and socioeconomic consequences of the conversion of rainforest into plantation systems in Southeast Asia (EFForTS), we tested for trait and phylogenetic associations between springtails and spiders and report changes in their functional and phylogenetic diversity with changes in land-use. We also investigate which traits or phylogenetic groups of each taxonomic group are most responsive to land-use change. The results will contribute to a better understanding of the impact of land-use change on trophic interactions and ecosystem functioning in canopy food webs.

Recovery of tree-seedling-herbivore interactions along a tropical chronosequence

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Tropical rainforests are highly threatened by deforestation, yet they have the potential to regrow naturally on abandoned land. To promote natural recruitment, it is essential to explore the complex interplay of traits within the community assembly of recovering forests. Here, we monitored tree seedling recruitment and seedling-herbivore interactions across a gradient of tropical rainforest recovery. We collected information on seedling functional traits such as leaf thickness, leaf toughness, specific leaf area, as well as invertebrate-inflicted leaf area loss, and diversity of leaf damage types. Our results show that with forest recovery, the species diversity of tree seedlings increases, reaching a peak at 25 years, while the functional trait diversity does not show a pattern with forest age. Seedling species composition also becomes more similar to the old growth forest with regeneration age. Leaf area loss due to invertebrate herbivory does not change along the chronosequence but the diversity of herbivory damage types decreases along the chronosequence. Although leaf area loss is not affected by forest age, it is negatively related with leaf toughness and thickness, and positively with specific leaf area of seedling species. Our results provide first insights into the complex interplay of traits and interactions with the community assembly of recovering tropical forests that may foster natural growth on deforested land.

Biodiversity enrichment using tree islands in Oil palm plantations influences fine-root morphology and dynamics in response to belowground competition.

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The conversion of Indonesian natural rainforests to oil palm plantations has resulted in a vast decline in biodiversity and ecological functionality. Biodiversity enrichment strategies, such as the creation of agroforestry zones as tree islands, have been proposed to promote ecological sustainability while maintaining the productivity of oil palm plantations. Three native multi-purpose tree species were planted in an oil palm plantation at various diversity levels and plot sizes in agroforestry zones as part of an experiment to test this theory. The study was conducted in a region with dominated oil palm cultivation. Our study mainly focuses on the root interaction within the three native species and oil palm and their influence on the oil palm yield. Our study aims at, 1. Investigating potential shifts in conservative and acquisitive root strategies with biomass enrichment. 2. Whether tree diversity influences the morphology and dynamics of oil palms.

This study used a combination of fine root inventory, species-specific root excavation as well as the ingrowth core approach to investigate morphological and functional differences in fine roots and to estimate fine root biomass and production. Fine root biomass was estimated by extracting the roots, sorting, and weighing them. Ingrowth core involved marking soil region with cylindrical mesh and measuring the root regrowth after a year. Additionally, intact, distal strands of fine root from each tree were collected to study the species-specific root traits.

From our study, we expect that oil palm co-exists with the introduced tree species and has a positive influence on oil palm root growth and yield. We also anticipate the oil palm root system gradually transition from an acquisitive to a conservative root strategy with increasing species diversity. Furthermore, we also expect the multi-species island with the highest diversity will yield the best results for oil palm growth. Overall, this research aims at providing a thorough understanding of the fine root competition and interaction between the oil palm and other trees on the biodiversity-rich tree islands, highlighting the impacts of agroforestry zones on plantation landscapes.

Linking forest stand structure to multi-taxa diversity and ecosystem functions in northeastern Madagascar.

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Biodiversity of Madagascar, characterized by its large prevalence of endemic species, is highly threatened due to a pervasive transformation of forests into agricultural lands. A further understanding of how changes in habitat structure affect biodiversity and ecosystem functioning is needed for sustainable management and restoration of these ecosystems. This study aims to assess responses of biodiversity and ecosystem functions to vegetation structure in northeastern Madagascar. Response variables include species richness of 6 taxa (ant, butterfly, bird, amphibian, reptile and herbaceous plant), as well as multidiversity (overall species richness), and ecosystem functions (soil organic carbon, predation rate, acoustic diversity index) at plot level.

58 plots were inventoried across five different land-use types: old-growth forest, forest fragment, woody fallow and vanilla agroforests, the latter derived from forest or from fallow land. To analyze dependency between biodiversity and stand structure, linear mixed effect models were performed, with basal area, canopy closure, leaf area index, diameter diversity and tree species diversity as predictor variables.

The results revealed that species richness of different taxonomic groups responded differently to stand structure. The relationship was particularly strong for endemic species. Basal area, tree species diversity, diameter diversity and leaf area index were significant predictors. Concerning ecosystem functioning, the analyses demonstrated that soil organic carbon was positively related to basal area, while predation was increased by canopy closure.

The findings highlight the importance of stand structure for maintenance and promotion of biodiversity especially endemic species, and ecosystem functioning. The results can inform sustainable land-use management options and ecosystem restoration activities in the study region and provide guidance for the choice of stand structure metrics as biodiversity indicators.

Land-use change drives of below-canopy surface temperature in lowland, Sumatra

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Global change affects life in tropical landscapes by increasing temperatures. Therein, surface temperaturesare highly relevant. They are relatively well-documented for exposed surfaces using space- or airborne approaches. However, many organisms including humans live sheltered below canopies. In lowland Sumatra, we assessed surface temperatures below canopies across different land-use types using a handheld thermal camera. The canopy leaf area index decreased from forest over shrubland to oil palm and rubber plantations. For given mean radiation, predicted noon surface temperatures below the canopy increased from forest to rubber plantations by 3.8°C. A unit decrease in canopy leaf area index increased below-canopy surface temperature by 1.5 °C. Thermoregulation by reduced surface to air temperature was widespread but was absent at high temperatures, which were recorded below canopy gaps, for non-transpiring as well as dark surfaces. Very high temperatures were partly also measured on hijab or cap surfaces, which people often wear e.g. when working in the plantations. Thus, in addition to climate change also land-use change significantly drives experienced temperatures in human-modified tropical landscapes. Mitigating such adverse temperature effects will include closed canopies with high leaf areas.

Patterns of flower functional trait distribution across a disturbance gradient give insight into assembly mechanisms in a tropical Andean landscape

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Patterns of trait convergence and divergence in flower communities pollinated by animals can provide insight into the mechanisms (i.e competition or facilitation) influencing the assembly of communities. Hummingbird pollinated plants in the tropical Andes have diverse floral functional traits related to attracting pollinators; however, little is known about the structure and variation of these traits along disturbance gradients. We analyzed the structure of floral functional traits related to pollination across a disturbance gradient (forest, shrub and natural hedgerow) in montane ecosystems of the southern Andes of Ecuador. We collected abundance information on 36 hummingbird-pollinated plant species in nine periods from December 2017 to March 2020. For each plant species we obtained data on eleven floral traits grouped into three functional categories: visibility (traits related to how attractive they are to pollinators), access (traits related to how accessible the flowers are to pollinators), and reproduction (traits related to the plant reproduction). We compared observed values of functional richness index (FRIC) and the quadratic entropy index (RAO) of functional traits against null models to assess convergence or divergence patterns. In addition, we used linear models to compare functional diversity among habitat types. We found 25 flower species in forests, 27 in hedgerows and 33 in shrubs. Visibility and access functional traits did not vary across habitat types. However, flower reproductive traits differed among habitat types, indicating trait divergence in forests and trait convergence in natural hedgerows. Reproductive traits may be more sensitive to disturbance because of their direct importance in plant reproduction and fitness. Our results also suggest disturbance could influence the process behind community assembly of plants, where competition for pollinators could result in trait divergence in less stressful habitats (i.e. forests), while facilitation interactions among plants could lead to trait convergence in more stressful habitats (i.e. hedgerows).

Keywords: facilitation, competition, trait convergence, trait divergence, stress gradient, forest, shrub, hedgerow

Effects of environmental conditions and human activity on nest site distribution of the Nigeria-Cameroon chimpanzee (*Pan troglodytes elliot*i) in Kom-Wum Forest Reserve, North-West Cameroon

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Environmental conditions and human activity influence the selection of nest sites by chimpanzees and may have serious conservation implications. We quantified the effects of seven environmental variables on chimpanzee nesting locations (N = 427) in Kom-Wum Forest Reserve, Cameroon (100 km^2). Chimpanzee nests and hunting signs, as indicators of activity, were georeferenced along 23 transects (each 2 km) and 17 km recces (92 km^2) between May and September 2018 for 131 survey days. Land cover maps were derived from Landsat 8. The elevation was obtained from a 30 meters resolution Digital Elevation Model Shuttle Radar Topography Mission. The distance to villages, bare land, water bodies, and primary and secondary forest was calculated using the Euclidean distance modelling technique in ArcGIS 10.6. A multiple linear regression model showed that the occurrence of chimpanzee nests was positively related to increasing elevation ($P < 0.001$) and slope ($P < 0.005$) and decreased with distance to primary forest ($P < 0.001$). In contrast, the number of nests increased with distance to secondary forest ($P < 0.001$), open land ($P < 0.001$), and villages ($P < 0.001$). Our findings suggest that chimpanzees prefer nesting in primary forest, at high elevations, and on steep slopes that are not easily accessible by humans. Primary forests at higher elevations are crucial for the conservation of the species and should be protected with high priority. Conservation efforts should focus on protecting primary forests at high elevations and steep slopes and reducing human impact.

Sapling survival one year after the implementation of a large-scale restoration project in the Brazilian Atlantic Forest

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The overexploitation of natural resources has resulted in a drastic reduction in tropical forest cover in the past decades, with negative effects to biodiversity and several ecosystem services. The Brazilian Atlantic Forest is a biodiversity hotspot and a priority area for forest restoration in SE Brazil. Given that most restoration initiatives in the Brazilian Atlantic Forest use only a few commercially available species of trees, the aim of this study was to evaluate seedling survival one year after planting within a biodiversity and ecosystem functioning experiment on abandoned pastures of an experimental farm. Saplings of 24 native trees were planted in 4 experimental blocks divided into 124 plots representing species richness gradients (1, 3, 6, 12, 24 species), with 48 saplings per plot (total 5952). After 7 and 12 months of implementation, overall survival was 74 and 67%, respectively. The species with highest survival was *Handroanthus chrysotrichus* (98%), and the lowest *Machaerium nictitans* (31%). Adverse weather conditions (i.e. lack of rain) and invasive plant species (i.e. *Brachiaria sp.*) reduced plant survival. *H. chrysotrichus* was most resistant to such effects, unlike *M. nictitans*, indicating that soil water availability was a decisive factor for survival. There was a slight negative correlation between survival and species richness, but this was probably a result of sampling effects due to the increased presence of low-surviving species in treatments with higher species number. Also, no direct interference was observed among saplings in the initial development stages of the restored communities. Finally, we argue that planting in the rainy season and its subsequent monitoring has positive technical and economic implications for such restoration projects. Thus, planting native saplings is an expensive but reliable restoration technique for areas of difficult natural regeneration in the Brazilian Atlantic Forest.

SESSION 64:

Green Infrastructure for Biodiverse and Healthy Cities

Urban green areas and biodiversity in cities. A structural typology and a multi-species approach.

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The last 30 years have seen a sharp increase in the rate of urbanization across the world, with more than half of the world's population living currently in urban areas.

The urbanization process has caused radical changes in the landscape within and surrounding the urban area, leading to several negative consequences for public health, global and local climate, and nature.

In this scenario, green areas within cities represent important elements for the urban environment, improving human well-being and acting as fundamental stepping stones for the local biodiversity. Species living inside cities suffer from the fragmentation of the landscape, and therefore rely on the habitats that the urban green areas can provide.

Urban green areas (UGA) are highly dynamic and heterogeneous at both spatial and temporal scales. They can differ in relation to their vertical complexity, size, shape, and to the characteristics of the surrounding impervious surfaces.

Within the "GreenCityNet" project a comprehensive structural typology of the UGA is being developed. The classification relies on standard land use data, enriched with high resolution environmental and structural vegetation data derived from remote sensing.

This typology of the UGA is evaluated in association with multi-species assessments derived from species distribution models of selected taxa. The approach is important for biological conservation and enhancement of urban biodiversity, as it helps to better understand how the spatially dynamic structure of the UGA is related to biodiversity within cities.

Trait-based approaches to understand social-ecological processes in cities

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Cities create new opportunities for unique biodiversity assemblages. There is an urgent need to understand the socio-ecological mechanisms underlying these new assemblages and how they affect ecosystem functions and benefit to humas in cities.

Functional traits of organisms (i.e., features related to individual fitness) are considered good candidates for predicting biodiversity and ecosystem changes across taxa, regions, and ecozones. Applied to an urban context, a functional traits approach would allow us to better understand and predict how changes in the environmental and socioeconomic structure of cities affect the distribution of biodiversity in turn impacting the distribution of ecological processes and human benefits within and across cities.

To advance in trait-based urban ecology, we need first to identify the main social-ecological filters and traits under selections, and then test their direct and indirect effects on measurable ecosystem functions and services.

In this talk, we will summarize the concepts and the results of studies that have investigated functional aspects of biodiversity in cities. We will illustrate which traits are filtered from the regional species pool to the urban species pool, how this latter is further shaped by the mosaic of urban green space types, and how the resulting species assemblage affects ecosystem functions and services. Finally, we will present future perspectives, such as the importance of intraspecific trait variation to investigate species adaptation to urban ecosystem and the potential role of trait-based approaches to bridge ecological and social sciences and improve conservation in the face of an urbanizing world.

A method to evaluate the barrier effect of urban elements: a case study with blackbirds in Munich

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Connectivity maps can aid city planners by identifying areas important for animal movement and thereby preserve urban biodiversity. Despite being rare, faunistic urban connectivity analyses primarily focus on landscape-scale dispersal processes between populations. However, animal movements mostly occur within the home range. The barrier effect of artificial landscape features within the home range can have a significant impact on resource accessibility, and thereby on home range formation and species distribution.

I will present a methodology for parametrizing urban connectivity models based on the home range scale using the blackbird in Munich as a case study. To (i) identify areas with sufficient resources for blackbird home ranges and (ii) evaluate the resistance of different urban elements, this study uses high-resolution land cover data and various sets of presence-absence data. The resistance of streets and buildings is evaluated using a connectivity approach based on graph and circuit theory. I will show the results of a model selection procedure for different resistance values of urban elements, isolation distances of resource patches, and connectivity metrics that was used for model parametrization.

From the case study, several conclusions can be drawn on the barrier effect of urban elements. Only a few combinations of isolation distances and resistance maps attain a high explanatory power for the movement of blackbirds. They all indicate that buildings and streets are more resistant to movement than vegetation and that higher buildings (over 13 m) have a stronger barrier effect than lower buildings or streets.

The presented methodology can be applied to other cities and birds to parametrize urban connectivity models that can depict urban connectivity based on the most frequent animal movements. The resulting connectivity analyses could aid city planners in transitioning to a city that supports free animal movement, promoting urban biodiversity.

The effect of urbanization on the genetic structure of *Trifolium pratense* populations

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Urban green spaces getting to be more appreciated for providing a variety of ecosystem services. Regeneration of plant populations is essential for maintaining these services in cities. However, the urban environment is specified with a high level of habitat fragmentation which strongly influence the maintenance of genetic diversity. In this study, we analysed the genetic structure of the red clover (Trifolium pratense L.) populations in Wroclaw City, Poland. T. pratense is not considered to be a valuable plant for urban grasslands and therefore, we assumed that its population structure mainly reflects spontaneous succession and survival. We hypothesized that the genetic structure of populations is shaped mostly by isolation in the cityscape. For this purpose, leaves from 16 populations of T. pratense (eight individuals per population) were collected from the city grasslands. The genomic DNA from plants was extracted. The PCR reactions were performed based on the reaction mixture and the amplification products were separated in 1% agarose gel with a DNA mass ruler and photographed. The isolation by resistance was analysed using the least cost patch approach focusing on gene flow via pollinators. The results indicated the existence of a great variation within and between Trifolium pratense populations within the city, with no discernible geographic pattern of genetic diversity. We have interrelated this result to a long history and land-use changes along with city development. The spatial analysis showed that the populations are significantly isolated by distance and resistance which means that the populations are threatened by genetic drift. Particularly, we did not find that Odra River with a width of ca. 100 m is a strong barrier for gene transfer. We did not find a correlation between the urban grassland patch area and the genetic diversity of the population settled in the patch. We also did not find any significant correlations between the genetic diversity of populations and the landscape connectivity of the settled patches. Since naturally regenerating plants are critical in sustaining both the ecological functions and the ecosystem services of urban green areas, the gene movement between populations should be increased by appropriate urban green areas management.

How much species traits matter in delivering ecosystem services in cities?

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Ongoing urbanization and global climate change have already altered our urban ecosystems leading to various disasters i.e., unbearable heat loads, greater and faster runoff and biodiversity losses. Urban greenspaces, in particular, urban trees have significant potentials to mitigate those problems. However, a detailed understanding on the mechanisms of different components of greenspaces on optimizing those benefits at local and city scale is still limited. In a global meta-analysis, we found that the tree canopy density is the most influential driver of both shading (ST) and transpiration air-cooling (AT). Surface temperature decreases almost linearly with the increase of leaf area index (LAI); however, the rate is significantly lower over transpiring grass surfaces. Transpiration of trees planted over grass was ten times higher (4.15 g m^{-2} min^{-1}) compared to a tree planted in paved cut-out pits (0.44 g m^{-2} min^{-1}). Moreover, diffuse porous wood anatomy and trees originating from temperate and resource-rich forests showed better cooling potentials. Among the leaf traits, dark green leaves, ‹ 0.15 mm of thickness showed higher AT and ST benefit. In another meta-analysis, we studied the influence of tree functional types on rainfall partitioning into uptake and runoff. The study showed that within functional types, conifers provided better protection on an annual scale through higher interception (I) and transpiration (T) but broadleaved species provided better infiltration (IR). Regarding tree traits, LAI again showed a positive influence for both I and T. For every unit of LAI increment, additional 5% rainfall partition through T (3%) and I (2%) can be predicted. Overall, runoff was significantly lower under mixed species stands. All together, these studies establish a more detailed understanding of the benefits of different urban tree species and the retrospective species characteristics to guide management decisions.

Growth of urban trees and their reaction to drought stress

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Frequent heat waves and drought events, in particular, within the last decades were observed in Germany and this trend is not expected to change in the future. The increasing stress caused by heat and drought in the cities further deteriorate the already challenging growth conditions of urban trees. To plan future resilient cities, it is necessary to understand which species show higher drought resistance. In this study, we focus on the tree growth and drought tolerance of the six common urban tree species Tilia cordata, Acer platanoides, Robinia pseudoacacia, Platanus x acerifolia, Fagus sylvatica and Quercus robur in temperate climate. The growth analyses include increment core data from 176 urban trees to assess the growth and link it to climate over a longer period (1980-2019), as well as dendrometer data of permanent tree laboratories in two German cities with different precipitation levels. Species-specific trends have been identified, as well as differences linked to growing location (urban/suburban) and analysed period of growth (1980-1999/2000-2019). First analyses for the city of Munich showed e.g., significantly better growth for A. platanoides and T. cordata in suburban areas. The overall tree growth in Munich was 28% lower in the period 2000-2019 compared to the previous years, indicating negative effect of recent climate change. Growth trends linked to drought and future climate conditions will be analysed by linear mixed models, considering two temporal resolutions. For long time spans, dendrochronology can analyse the impact of the recent climate changes in the last twenty years, while for shorter periods dendrometer data can give precise information about growth in several years but also within years, e.g., to link growth length with seasonal climate data. Investigating the species specific responses to drought events and the growth of trees under different urban conditions, can support planning decisions on tree species selection for urban areas.

Exploring the Effectiveness of Multilayered Urban Green Infrastructure in Alleviating Urban Heat Stress

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Cities are increasingly threatened by the Urban Heat Island (UHI) effect which is likely to be further intensified by climate change. Consequently, climate simulations project a significant increase in the number, duration, and intensity of heat stress events in German cities which poses a serious health hazard to urban residents. Therefore, enhancing the regulation of local climate and cooling effect provided by Urban Green Infrastructure (UGI) is becoming even more important for human health and wellbeing in urban environments.

While the benefits of urban trees on outdoor thermal comfort have been extensively studied, the effects of other vegetation types (such as grass and shrubs) as well their combined interactions on cooling effects require further research. Moreover, the contributions of each plant type and any potential synergies or tradeoffs in terms of human thermal comfort need further investigation. At the same time, the ecosystem services offered by multilayered vegetation depend heavily on their responses to the highly heterogeneous urban surroundings. Therefore, this research aims to develop a holistic understanding of the interactions and feedbacks between the microclimate and UGI to improve the cooling effect provided by UGI and reduce urban heat stress.

Ground-based observations and field measurements were taken at multiple public squares in Munich, which featured different surface combinations. The data collected included measurements of bio-meteorological variables, vegetation structure and physiology, and soil conditions. Growth rate and thermal comfort indices were calculated to provide a comprehensive picture of the microclimate-UGI interactions. Preliminary findings reveal notable variations in the cooling impact of distinct plant types, with shrubs having almost one third the latent heat exchange compared to trees of similar crown volume and species. Furthermore, public squares with the presence of multilayered vegetation, especially where tree canopy covered over 50% of the area, exhibited the lowest mean radiant temperatures, which were 9K cooler than those of fully sealed sites. The study's results can guide urban planners and designers to develop sustainable urban landscapes, mitigating UHI effects and enhancing UGI ecological benefits.

Biodiversity façade: development of a green façade system for people, plants and pollinators.

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With this talk, we will present the overall concept development of an innovative green façade system developed to promote biodiversity. We will show the first findings on the biodiversity potential of green façades, the role of hands-on experiences of gardening practitioners and overarching target species for developing green infrastructures. We used a three-steps approach to develop a façade system supporting both a heterogeneous plant composition with changing and high flowering occurrence, and vertical, high-quality habitats for selected plant and animal species. Firstly, we investigated the microclimate, the gardening and maintenance concepts and the biodiversity potential of already existing facades in and around Stuttgart. From these findings, we identified key factors or "drivers" for promoting biodiversity on green façades. Secondly, we determined, with the help of target plant and animal species, which combinations in plant traits and structures could improve the existing systems for a more holistic greening approach. Hereby, we expect that a targeted use of specific cultivated and native plants in vertical urban space can improve accompanying ecosystem services such as microclimatic regulation or habitat function. Finally, we planned two innovative green façade systems from this interaction of scientific findings and from the practical experience of HELIX Pflanzensysteme GmbH. The systems are now installed on a facade area of about 250 m² and a suitable green maintenance and control concept will be developed.

"Stadtnatur" and "urban nature" - development and meaning of these terms for perception, research and implementation of urban biodiversity in the past and present

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The terms "Stadtnatur" and "urban nature" or the objects, which are described by these terms, have important functions in the perception, recording and development of biological diversity in urban areas. Furthermore, these terms can play an important role in transformation processes of cities towards sustainability and resilience, especially, because these terms have been and are used by nature and social scientists and became adapted by politicians, not only on the local level.

Therefore, it is interesting to analyse the history, use and importance of these terms in research and implementation. Funded by the Federal Ministry of Education and Research, the history, perception, meaning, and implementation in planning processes of these both terms were studied and analysed. For the research several workshops with nature and social scientists were organized and online researches, literature analyses, expert interviews, and the analysis of urban transformation processes were conducted. The focus of the investigation was mainly on the situation in Germany and the term "Stadtnatur".

The results of this research will be presented in the session of URBIO.

Greenspaces for all seasons and all people: Winter nature interaction in urban parks

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Greenspaces like urban parks can support and enhance biodiversity in cities. However, urban parks should be designed and managed to support both nature and people, especially since cities are the primary location of day-to-day nature interaction for many people. Nature interaction is associated with numerous physical, social, and mental health benefits. However, many people, especially urban residents, are interacting less with their natural surroundings. This has negative implications regarding nature-derived well-being benefits and the development of nature-connectedness and nature-positive attitudes and behaviors. Despite this, there is little insight into how people interact with nature in public greenspaces throughout the year, with which natural elements they interact, and if certain visitation behaviors or landscape patterns influence the odds of interaction. We therefore conducted a non-participatory study in three urban parks in Stuttgart, Germany (N=13,474) to better understand these aspects specifically in winter—a season often neglected in socio-ecological research. Results indicate that high-engagement winter-nature interaction (e.g. active observation, photographing, touching or collecting natural elements) was low, and certain park visitation behaviors like technology use were associated with a reduced odds of high-engagement nature interaction. However, we found that certain natural elements within parks like small ponds may encourage nature interaction. Such context-specific research can strengthen the social-oriented design of urban greenspaces to support nature interaction and associated nature-derived benefits for park users year-round. Furthermore, because many winter nature experiences (e.g. skiing) are often expensive, it is crucial to understand how nature interaction can be supported in publically accessible (and fairly distributed) greenspaces so that all people have equal opportunity for nature interaction and its associated benefits.

Effects of the COVID-19 pandemic on the use of urban green spaces: A systematic review

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The COVID-19 pandemic has caused major disruptions to peoples' daily lives and has challenged urban resilience. Many localized studies have been published on the changed use of urban green spaces (UGS) since the COVID outbreak, yet there is no consensus in the literature on the direction of changes and how they relate to governance regimes and economic conditions. Combining global evidence of such changes provides an unprecedented indication of availability and accessibility of UGS. We systematically searched published studies, following systematic review methodology, screening ›3000 sources from academic literature databases and Google Scholar in Chinese, English, French, German, and Spanish. Based on inclusion criteria, we identified 175 studies from which we extracted information on 248 locations in 55 countries. We conducted a critical appraisal of methods to re-analyse results weighed by study quality score. We find that during the first lockdowns the world was divided in places with increased and decreased use of UGS. Locations with decreases had significantly stricter COVID policies and the GDP per capita was significantly lower than where use increased. Decreased UGS use was mostly reported for public parks (77 %), whereas private gardens, UGS near peoples' homes, and forests showed more cases of increased uses (100%, 72%, 63% respectively). After lockdowns, many locations (68%) showed increased UGS use, but less so in the Global South. Overall, evidence from the Global South is limited, thus allowing only a geographically biased insight. Our results indicate that economic wealth strongly influences access to UGS, which was exacerbated during COVID-19. We highlight that UGS is a crucial precondition for urban resilience, especially in times of crisis. UGS planning needs to extend beyond public parks by additionally restoring natural areas within and near cities to make them accessible to people for their well-being.

Dynamics of Street Tree Populations in Urban Areas: Understanding Mortality Rates and Associations with Age and Size Classes

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Urban green spaces are important for mitigating climate change challenges by regulating air quality, increasing shade, cooling, and air humidity, enhancing biodiversity, and offering erosion control. Trees are a vital component of these spaces and provide significant benefits to urban ecosystems.

Our study focused on understanding the dynamics of street tree populations in urban areas, built through planting, growth, death, removal, and replacement cycles. In this study, we used the cadaster dataset of 12 cities in Germany with 5-10 years of street tree monitoring. Our research objectives were to a) calculate annual mortality rates for the most common urban tree species; b) analyze the association between mortality rate, age and Diameter at breast height (DBH) size classes with multivariable logistic regression models.

We hypothesized that the mortality rate varies across species. Furthermore, the mortality rate is associated with age and DBH size classes, with a high mortality rate for young and small classes and a low mortality rate for middle, large age and DBH size classes. Annual tree counts and mortality observations were used to calculate the elements of the street tree demographic modified balancing equations, and to determine annual mortality rate and population growth. Since demographic concepts like survivorship and mortality curves are useful to analyze urban tree mortality rates. In the next phase of our study, we will assess the size and age-based shape of the street tree mortality curve to identify factors that contribute to high mortality rates and how they change as trees age and grow.

Our study provides a framework for future urban tree mortality research and may fill the knowledge gap on mortality rates of urban trees, aiding in the design of effective urban forestry strategies. It can be replicated in other cities with similar climates for further comparisons.

Using terrestrial laserscanning for deriving and updating allometric equations for urban trees

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Allometric equastions are the prerequisite for estimating many ecosystem services provided by urban trees, including carbon storage. Recent advances in terrestrial laserscanning (TLS) have improved our ability to estimate allometric equations for trees. In the past, such equations were derived by destructive sampling of trees, a process that is laborious but also not feasible in cities where it is usually not possible and desirable to fell a large number of trees from different age groups. Therefore, many studies that have estimated carbon storage used forest-based equations, even though urban trees grow under atypical conditions and consequently differ in their morphology and biomass development. In addition, allometric equations usually only exist for common and commercially interesting tree species.

TLS can help to overcome these problems, because it allows estimating the volume of trees in a non-invasive way. Here, we present allometric equations for common urban trees (*Quercus robur* "Fastigiata," *Tilia cordata* and *Acer pseudoplatanus*) and for less common species that are increasingly planted in order to adapt the urban forest to climate change (*Liquidambar styraciflua, Ostrya carpinifolia, Quercus cerris, Tilia tomentosa, Corylus colurna and Ginkgo biloba*). They were derived using the Riegl VX400i TLS for measuring point clouds and Quantitative Structure Models for estimating volumes. The raw point clouds will be uploaded to a data repository so that they can be combined with additional scans from other cities in the future, in order to improve the quality and diameter range of the equations.

Tools for urban tree health observation – How can we optimize stress identification in urban trees?

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Tree vitality is decreasing around the world. Especially, urban trees are exposed to extreme climatic conditions, affecting their health. Urban trees fulfil several ecosystem services like shading and cooling, but need to be vital to provide these services. Therefore, detecting stress at an early stage is essential to secure the longevity of tree health. However, controlling and maintaining tree vitality, require resources, manual labor and trained staff. All of which are often limited in municipalities. Methods are needed to identify trees and species, which have a higher probability of withstanding urban climatic conditions. In this contribution, methods of stress detection (for instance through the measurement of leaf water potential, chlorophyll fluorescence and chlorophyll content) are discussed and conclusions are drawn regarding the potential of these technologies for future large-scale applications (based on their informative value, their applicability for arborist and municipalities) in tree health observations.

Prototyping Integrated Façade Systems for Multi-Species Habitation

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Urbanization is an important cause of local biodiversity decline, inducing an increasing disconnection between people and nature. The negative effect of the urban environment on biodiversity largely arises from the smooth, flat, and impermeable surfaces that constitute most buildings. Vertical building surfaces in cities appear as promising zones for interventions to support biodiversity, as they represent vast surface areas, are mostly inaccessible to people, and can be modified to offer food and shelter resources to various animal and plant species. Research into the ecological potential of man-made walls points at specific geometric formations, such as cracks, fissures, ledges, and micro-textures, that can contribute to making cities more biodiversity-rich. Architects' current computational design tools enable the modelling of geometrical features that could be used to design integrated species-riche facades for spontaneous biodiversity. Designing such a façade for a given building needs to integrate information on local ecological conditions to evaluate the biodiversity outcomes. Here I present first results of a project connecting architectural and ecological modelling, to explore design solutions for biodiversity-rich façades. The modelling approach involves bringing ecological modelling into the software environment Rhino used for architectural modelling, to model the ecological consequences in terms of animal occupation as a function of architectural design.

On the way to developing biodiverse sustainable urban drainage systems

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Urbanization has increased during the past decades and is continuing. This leads to the sealing of even more surfaces, fragmentation and loss of habitats, and altered microclimates. Due to those developments, problems arise for urban biodiversity and stormwater management alike, which are only amplified by the effects of climate change.

Infiltration swales are a type of sustainable urban drainage system that pose great potential to aid in stormwater management while simultaneously increasing biodiversity. To realize this potential, plants must be able to cope with difficult conditions such as pollution with heavy metals, particulate substances and trace organic compounds and fluctuating water conditions, reaching from very dry to submerged for multiple days.

A greenhouse experiment was designed to study plant trait differences between and within species in reaction to flooding and pollution stress and to different soil types. A substrate mixture similar to current practice using topsoil and sand proved equally suited for plants as a mixture where sand was replaced by brick sand. This opens opportunities for circular economy in the form of using urban construction waste in the construction of infiltration swales. Furthermore, we expected differences in the survival rate of plants of the Poaceae family originating from sites with fluctuating water availability, ranging from primarily dry to wet conditions. We found differences in the variability of traits like specific root length (SRL) and specific leaf area between grass species that survived stress treatment (*Deschampsia cespitosa, Festuca arundinacea*) and species that showed poor resilience to stress (*Festuca amethystina, Festuca rubra*). Survival rates beyond germination phase and variability of SRL were higher in species originating from habitats with higher soil moisture, while heavy metal pollution had no effect on survival in concentrations similar to road runoff that were used here.

Fresh hay and seed incidentally collected during mowing yielded grassland quality comparable to commercial seed mixtures

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Urban grasslands (UG) are among the most common types of urban green areas and provide numerous ecosystem services. They are usually species-poor, and spontaneous plant migration which can increase biodiversity is limited. Different seed mixtures have been applied for the establishment and restoration of UG. Unfortunately, mixtures with high taxonomical diversity and high quality are expensive and available in small amounts. On the other side, inexpensive commercial mixtures could have low quality and might lead to poor restoration outcomes. Instead, transferring plant material in the form of fresh hay or seeds harvested by brush can result in higher species richness, however, these methods have not been well studied in UG restoration. In this study, we evaluate the efficiency of different seed sources to create high-quality urban grasslands in two parks in the city of Wroclaw in Poland. For this purpose, we established two experiments using different seed mixtures including commercial flower meadow with plants dedicated for pollinators (FM), semi-natural meadow mixture with known seed origin (SM), seeds collected accidentally from mower (MO), mixture with grass species with known seed origin (G), and spreading of fresh hay (FH). We would like to answer the question: which method of seed introduction ensures the highest biodiversity and highest overall quality during two years from recultivation? We also hypothesized that the seeds collected accidentally from the mower, and fresh hay can contain unwanted species (i.e. invasive species, weeds). Our results showed that all seed addition methods increased the species richness of restored grasslands. The outcome of seed addition was satisfactory regardless of differences in residual vegetation species composition and soil properties between the sites. The alternative seed sources including fresh hay and seed incidentally collected during mowing yielded grassland quality that was comparable to that of plots that received commercial seed mixtures.

The importance of specificity: correlates of attitudes towards 32 animals among the population of Munich, Germany

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With the ongoing efforts to construct greener and more biodiverse cities, it becomes necessary to make cities better available for animals and to consider which animals are or are not welcome in them. Cities are the prime meeting ground between humans and animals, and human attitudes towards their urban wildlife can strongly affect the success of attempts at furthering biodiverse cities. We investigated Munich inhabitants' attitudes towards 32 animals to examine these attitudes.

We conducted a survey in Munich where we asked participants how much they liked 32 different animals and related these to demographic information such as gender and age, as well as questions relating to their habits and relationships with animals and nature.

Attitudes towards the different animals were variable within the surveyed population. Some animals (e.g., fireflies, squirrels, and owls) were well-liked, while others (e.g., cockroaches, rats, city pigeons and slugs) were severely disliked. Not all asked predictors significantly affected attitudes towards the animals. Age and gender, for example, did not unidirectionally influence attitudes towards the animals but did significantly influence them in varying directions depending on the animal. Additionally, people with a garden liked the animals less than people without one, while having a balcony or community garden did not significantly influence attitudes. When asked which animals they wanted more in their neighbourhoods, different kinds of birds, insects, and mammals were among the most commonly mentioned; some people did, however, explicitly mention animals they would rather not want in their neighbourhood, even if not prompted.

Knowing which animals people in cities like and dislike can aid in the design of biodiverse cities and help avoid the worst human-animal conflicts. Understanding why they like the animals more or less can help tailor biodiverse urban design for human acceptance.

SESSION 65:

Creating urban green spaces for nature and people / Grünflächengestaltung in der Stadt für Natur und Mensch

Eignet sich das eDNA-Metabarcoding für ein bürgergestütztes Insektenmonitoring im urbanen Raum?

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Die rund 17 Mio. Privatgärten nehmen knapp 2 Prozent der Gesamtfläche Deutschlands ein, und haben aufgrund ihrer Heterogenität und Verteilung ein großes Potenzial zum Schutz und zur Förderung der Biodiversität beizutragen. Besonders Insekten sind dabei häufig in diesen Teillebensräumen zu finden. Gleichzeitig wirken sich hier kleinräumige Veränderungen und Stressoren, wie etwa der Einsatz von Pestiziden in privaten Gärten, erheblich auf ihr Vorkommen aus. Um das Wissen über die Insektendiversität in der Stadt zu verbessern, sowie die Effekte von Nutzungspraktiken zu verstehen, sind Monitoringerhebungen erforderlich. Allerdings sind klassische Erfassungen von Insekten aufgrund ihrer geringen Körpergröße und ihrer durch spezifische Habitatansprüche bedingten lokalen Verbreitung sehr zeit- und kostenintensiv. Hier birgt die Einbeziehung von Bürgerwissenschaftler*innen in die Datenerhebung für ein solches Monitoring großes Potenzial. Durch diese Zusammenarbeit wird nicht nur der Zugang zu den Insektengemeinschaften in Gärten ermöglicht, sondern es kann auch eine Vielzahl an Flächen über einen ausgedehnten Zeitraum erfasst werden. Bisher wird in dem Bereich häufig auf die Verwendung von Fotobelegen zurückgegriffen. Allerdings lassen sich nur wenige Insektengruppen anhand von Belegfotos eindeutig bestimmen. Eine vielversprechende Alternative stellt die nichtinvasive Methode des Metabarcodings von Umwelt-DNA (eDNA) für die Erfassung der Biodiversität dar. Diese relativ junge Methode vereint die Vorteile, dass hierfür keine Tiere entnommen werden müssen bei gleichzeitiger hoher taxonomischer Genauigkeit. In dem hier vorgestellten Projekt wurden neue wissenschaftliche Methoden des Monitorings von Insekten im urbanen Raum evaluiert, etabliert und der Einfluss von Alltagspraktiken auf die Insektenvielfalt untersucht. Ferner wurde ermittelt, inwieweit sich das eDNA-Metabarcoding für ein großflächiges Monitoring der Insektendiversität eignet.

Präferenzen und Hemmnisse für die Gestaltung artenreicher Privatgärten - Einblicke in das Projekt gARTENreich

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Privatgärten haben ein großes Potenzial zum Schutz und zur Förderung der biologischen Vielfalt. Rund 17 Millionen Privatgärten nehmen knapp zwei Prozent der Gesamtfläche Deutschlands ein. Die biologische Vielfalt in Privatgärten nimmt jedoch durch einen stetigen Rückgang der Strukturvielfalt und eine Zunahme der Versiegelung ab. Gründe dafür sind u.a. mangelndes Wissen über die richtige Pflege und Gestaltung von Gärten, ästhetische Vorlieben, gesellschaftlicher Druck oder mangelndes Interesse der Gartenbesitzer*innen. Aufgrund ihres hohen Potenzials zur Förderung der biologischen Vielfalt rücken Privatgärten zunehmend in den Fokus von Politik und Verwaltung.

gARTENreich untersucht in einem inter- und transdisziplinären Forschungsdesign, wie Privatgärten zum Schutz und zur Förderung der Biodiversität beitragen (können). Mit Hilfe verschiedener Indizes wird die Struktur- und Artenvielfalt in Privatgärten ermittelt und analysiert, wie diese auf andere räumliche Skalen übertragen werden können. In Reallaboren in den Partnerkommunen Gütersloh und Aumühle wird in einer Reihe von Workshops mit Gartenbesitzer*innen diskutiert, welche Faktoren die Gartengestaltung beeinflussen und wie die Biodiversität gefördert werden kann fördern. Gemeinsam werden sogenannt „Biodiversitätsbausteine" entwickelt: kleine Maßnahmen, mit denen Gärtnerinnen und Gärtner die biologische Vielfalt in ihren privaten Gärten fördern können und die unter verschiedenen Rahmen- und Standortbedingungen umgesetzt werden können. Zusätzlich wird mit Hilfe von Online-Communities und einer bundesweiten Befragung von Gartenbesitzern analysiert, welche sozialen, ökonomischen oder gestalterischen Faktoren mehr Vielfalt in Privatgärten fördern oder hemmen und welche Anreizinstrumente Gartenbesitzer*innen zu einer vielfältigeren Gestaltung ihrer Gärten motivieren können. Darauf aufbauend werden Strategien für mehr Vielfalt in Privatgärten sowie Informationen und Instrumente zur Kommunikation entwickelt und den Kommunen zur Verfügung gestellt.

Ein Blick aus der Praxis: Das Verbundprojekt *VielFalterGarten*

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Vorstellung des Verbundprojekts VielFalterGarten. Schwerpunkt des Vortrags ist der praktische Blick auf die Zusammenarbeit zwischen Stadtverwaltung, Wissenschaft und Umweltverband mit den Fragen: Wie erreichen und motivieren wir die Menschen naturnah zu gärtnern bzw. sich für naturnahe Grünflächen einzusetzen? Wo liegen Stolpersteine?

VielFalterGarten ist ein Kommunikations- und Bildungsprojekt, das modellhaft aufzeigen möchte, wie es gelingen kann, urbane Räume so zu gestalten, dass die Vielfalt der Tagfalter gefördert wird. Ziel ist es, die Vielfalt der Schmetterlinge erfahrbar zu machen und Arten durch gezielte Maßnahmen im privaten und städtischen Grün zu unterstützen. Projektpartner sind das Department Ökosystemleistungen des Helmholtz-Zentrums für Umweltforschung (UFZ), das Deutsche Zentrum für integrative Biodiversitätsforschung (iDiv), der BUND Leipzig und die Stadt Leipzig. Das Projekt wird gefördert im Bundesprogramm Biologische Vielfalt vom Bundesamt für Naturschutz mit Mitteln des Bundesministeriums für Umwelt, Naturschutz, nukleare Sicherheit und Verbraucherschutz.

Konzeptentwicklung für ein nachhaltiges Grünflächenmanagement (Fallbeispiel: Grünflächen der Justus-Liebig-Universität Gießen, JLU)

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Städtische Grünflächen tragen zu nachhaltigeren und klimaresilienteren Städten bei. Da immer mehr Menschen in Städten leben, spielen Grünflächen für eine nachhaltige Raumplanung eine zentrale Rolle. Grünflächen tragen unter anderem zu Nachhaltigkeitsziel (SDG) 11 (Nachhaltige Städte und Gemeinden), SDG 13 (Maßnahmen zum Klimaschutz) und SDG 3 (Gesundheit und Wohlbefinden) bei, indem sie einen sicheren Zugang zu Grünflächen bieten, positiv auf das körperliche und geistige Wohlbefinden der Stadtbevölkerung wirken und das Stadtklima verbessern. Städtische Grünflächen bieten aber auch wichtige Lebensräume für Pflanzen und Tiere. Was jedoch häufig fehlt, ist ein fundiertes Konzept, das dabei hilft, die Bewirtschaftung von Grünflächen nachhaltig auszurichten und Maßnahmen systematisch umzusetzen. Aufgrund der vorhandenen Kapazitäten wie wissenschaftliches und technisches Personal, motivierte Studierende, Gartengeräte und Grünflächen zur Erprobung nachhaltiger Ansätze haben Universitäten gute Voraussetzungen, einen wissenschaftlichen Rahmen für die nachhaltige Bewirtschaftung von Grünflächen bereitzustellen. Die JLU Gießen nutzt diese Gelegenheit, um ein nachhaltiges Bewirtschaftungskonzept für ihre Grünflächen zu entwickeln. Die hat zum Ziel, die Artenvielfalt und die Kohlenstoff- und Wasserspeicherkapazität des Bodens zu erhöhen, das Stadtklima zu verbessern, Grünflächen für Erholung bereitzustellen und Nachhaltigkeitsaspekte stärker in die Lehre zu integrieren. Basierend auf digitalen Orthofotos und detaillierter Felderhebungen haben wir die Vegetationsbedeckung in Gehölzbestände, Solitärbäume, einzelne Büsche, Hecken, Kletterpflanzen, Wildblumenwiesen, Vielschnittrasen, Zierpflanzen sowie Gewässer, Gebäude, Dachbegrünung, Wege und andere versiegelte Flächen klassifiziert. Diese Karte diente als Grundlage für die Messung von Ökosystemeigenschaften wie Biodiversität und physikalischen und chemischen Bodeneigenschaften einschließlich des Kohlenstoffvorrats. Diese Daten fließen in einen konzeptionellen Rahmen eines quantitativen und qualitativen Nachhaltigkeitsmodells für städtische Grünflächen ein.

Schlagworte: Städtische Grünflächen, multifunktional, nachhaltiges Management, Justus-Liebig-Universität Gießen

Auf dem Weg zu einem insektenfreundlichen Campus

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Der Rückgang der Insektenvielfalt ist ein großes Problem unserer Zeit, auf das die Bundesregierung mit dem Aktionsprogramm Insektenschutz reagiert hat. An die Bundeseinrichtungen wurde damit der Auftrag erteilt, die Lebensbedingungen für Insekten auf Bundesliegenschaften zu verbessern. Am Thünen-Institut für Biodiversität wurde das LInCa-Projekt (**L**ebenswerter **In**sekten-**Ca**mpus) gegründet. LInCa hat zum Ziel, den Thünen-BVL-Campus in Braunschweig langfristig so zu gestalten, dass Insekten gefördert werden und die Nutzerschaft sich hier wohlfühlt. Der Campus ist nicht nur ein Arbeitsplatz, sondern z.B. auch Wohnsitz, Standort für einen Sportverein und eine Kita. Eine erfolgreiche Umsetzung des Projektes ist nur möglich, wenn die Interessen aller Betroffenen berücksichtigt werden. Dafür wurde die Nutzerschaft aktiv in die Planung einbezogen. Mit einer Umfrage wurden Wünsche und Bedenken der Menschen herausgestellt, auf denen die Planung für Maßnahmen aufbaut. Die Umfrage ergab, dass das allgemeine Interesse an einer Förderung von Insekten auf dem Campus hoch ist. Wichtig ist der Nutzerschaft, dass Sicherheit und Gesundheit der Menschen durch Maßnahmen nicht eingeschränkt werden. Zudem werden diese eher akzeptiert, wenn sie einen ästhetischen, materiellen oder emotionalen Nutzen für den Menschen erfüllen. Es stellte sich heraus, dass Wissen über die Wirkung der Maßnahmen, sowie persönliche Erfahrungen die Akzeptanz für diese steigern. Auf Grundlage dieser Erkenntnisse wurden bereits Maßnahmen umgesetzt. Dabei handelt es sich unter anderem um eine angepasste Mahd zur Schonung der Insekten, Aushagerung des Bodens zur Schaffung natürlicher Blühflächen, sowie teilweise auch Aussaat von Wildblumenwiesen. Obstbäume, von deren Früchten auch die Menschen profitieren, steigern zusätzlich die Pflanzenvielfalt. Regelmäßige Newsletter, die über den ökologischen Nutzen der Maßnahmen informieren, sollen die erfolgreiche Optimierung des Campus im Sinne des Insektenschutzes fördern.

Grünflächenumgestaltung in Riedstadt Ziele, Maßnahmen, Monitoring

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Die Büchnerstadt Riedstadt hat im Jahr 2009 mit einer weit gehenden Umgestaltung innerstädtischer Grünflächen begonnen. Bis dahin mit nicht einheimischen Ziersträuchern (Symphoricarpus, Lonicera, Cotoneaster, Mahonia etc. in Arten und Sorten) bepflanzte Flächen des Straßenbegleitgrüns wurden nach Entnahme des Vorbewuchses und tiefgründigem Bodenaustausch mittels Einsaat eigens zusammengestellter Saatgutmischungen aus Regiosaatgut in artenreiche Blühflächen umgewandelt. Die zunächst in einem Riedstädter Stadtteil als Pilotprojekt gestartete Umgestaltung wurde in der Folgezeit auf alle fünf Riedstädter Stadtteile ausgeweitet. Neuanlagen von städtischen Grünflächen (z.B. im Zuge von Baugebietsneuerschließungen oder Straßensanierungen) erfolgen mittlerweile grundsätzlich mit artenreichen Ansaaten. Die Pflege wurde entsprechend angepasst – die umgestalteten und neuen Grünflächen werden in der Regel zweimal jährlich gemäht, wobei der erste Schnitt ab Mitte Juni eines Jahres erfolgt. Bei diesem Schnitt wird das Mahdgut vollständig abgeräumt und abgefahren. Der zweite Schnitt, der meist erst kurz vor Beginn der neuen Vegetationsperiode Mitte bis Ende Februar durchgeführt wird, erfolgt als Mulchschnitt. Diese Pflegestaffelung stellt einen Kompromiss im Hinblick auf die Ziele „Erhaltung der Artenvielfalt“ und „Pflegekostensenkung“ dar. Bisher hat sich gezeigt, dass dies auch im Hinblick auf beide Aspekte gelingt (insbesondere im Vergleich mit dem Vorzustand). Beim ersten Schnitt werden grundsätzlich 5-10 % der Fläche als „Altgrasstreifen“ zur Förderung auch der faunistischen Vielfalt stehengelassen.

Die Maßnahmen wurden von Anfang an intensiv wissenschaftlich begleitet und haben sich im Hinblick auf das Ziel einer Erhöhung der biologischen Vielfalt als erfolgreich erwiesen, siehe z.B. Mody et al. (2020): https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0234327

Weitere Informationen unter www.riedstadt.de/gruenflaechen.

Rietzschke-Aue Sellerhausen Leipzig Park, Retention, Renaturierung

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Neben der Quartiersschule Ihmelsstraße entsteht ein neuer Park für den Leipziger Osten. Auf einer Fläche von ca. 18.000 Quadratmetern entsteht eine neue öffentliche Freifläche, die den Freizeit- und Aufenthaltswert im Quartier erhöht und gleichzeitig bei starken Regenereignissen in der Lage sein wird, Regenwasser aufzunehmen. Auf dem Flurstück der ehemaligen Kleingartenanlage wird der Entwässerungsgraben Sellerhausen offengelegt und als natürlich erlebbarer Bachlauf gestaltet. Weite Teile der neuen Grünfläche werden als natürliche Blühwiesen zur Förderung der Insekten- und Artenvielfalt angelegt. Neben neuen Wegeverbindungen in die angrenzenden Wohngebiete werden auch neue Spiel- und Sportangebote geschaffen.

Fachliche Unterstützung für naturnahe Gestaltung und naturfreundliches Grünflächenmanagement in Kommunen im Rahmen des Projekts N.A.T.U.R. des Bündnisses „Kommunen für biologische Vielfalt“

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Das Bündnis „Kommunen für biologische Vielfalt“ (Kommbio) ist ein Zusammenschluss von inzwischen 363 Kommunen und Landkreisen aus ganz Deutschland. Gemeinsam setzen wir uns für die Biodiversität im Siedlungsbereich und in der freien Landschaft ein. Das Bündnis dient den Kommunen zum Informationsaustausch und zur Wissensvermittlung und unterstützt sie bei der Öffentlichkeitsarbeit. Vom Bündnis werden aktuell verschiedene Projekte umgesetzt. Das Projekt N.A.T.U.R. (Nachhaltiger Artenschutz durch Theorie und Umsetzung im besiedelten Raum) hat zum Ziel, speziell die biologische Vielfalt im Siedlungsbereich zu fördern. Kommunen werden im Rahmen dieses Projekts fachlich bei der Gestaltung naturnaher Grünflächen und beim naturfreundlichen Grünflächenmanagement unterstützt. Dazu bieten wir unter anderem praxisorientierte Fortbildungen und Webinare zu den fünf Themen-Modulen „Stauden“, „Wiesen und Rasen“, „Bäume und Sträucher“, „Planung und Strategie“ sowie „Artenschutz und Monitoring“ an. Im Vortrag werden beispielhaft Einblicke in die Inhalte der Module „Wiesen und Rasen“ und „Bäume und Sträucher“ gegeben. Beim Modul „Wiesen und Rasen“ geht es schwerpunktmäßig darum, wie artenreiche Wiesen und Rasen gepflegt, entwickelt oder neu angelegt werden und welche Mäh- und Abräumtechnik für den jeweiligen Einsatzbereich geeignet ist. Im Modul „Bäume und Sträucher“ gehen wir unter anderem auf mögliche Beispiele für bestäuberfreundliche und klimawandelangepasste Stadtbäume ein und zeigen, wie naturnahe Hecken gepflegt und angelegt werden, wie mit Schnittgut, stehendem und liegendem Totholz umgegangen werden kann und dass Baumtorsi eine biodiversitätsfördernde Alternative zu vollständigen Fällungen in Grünanlagen sein können.

SESSION 66:

Biodiversity of Gardens / Biodiversität in Gärten

Home Sweet Home: Evaluation of native versus exotic plants as resources for insects in urban green spaces

Home Sweet Home: Evaluation von heimischen versus exotischen Pflanzen als Nahrungsquelle für Insekten in städtischen Grünräumen

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English:

Insect decline and loss of biodiversity are terms one is regularly confronted with nowadays. It is undisputed that a greater supply of flowers in urban green spaces can provide insects with more food and habitat. However, controversy still surrounds the question of whether native wild plants, or non-native ornamental plants and varieties are the right choice? The aim of our study was to investigate the number of insects interacting with the plants on the basis of a selection of ornamental and wild perennials. In this context, not only the number of flower visitors was recorded, but also the feeding damage caused by insects herbivores on the leaves and stems. We planted 18 plant species in ten independent study plots in the city of Darmstadt, Germany. The plants were six native wild plant species, six ornamental plant species related to the wild plants, and six exotic ornamental plant species not closely related to the wild plants. During the main flowering of each species, all flower visitors were recorded during 10-minute observation periods. Native insects that feed on pollen and nectar, including wild bees and “non-bees” such as beetles, flies and wasps, visited wild perennials significantly more often than ornamental and exotic plants. A total of 67% of these visits occurred on the wild perennials, compared to 24% on ornamental perennials and 9% on exotics. In contrast, honey bees (Apis mellifera) showed no preferences to any of the three target plant groups and interacted with other plant species than the non-bees and most wild bees.

The assessment of leaf damage caused by insect herbivores on the individual plants again showed a significant difference between the wild, the ornamental and the exotic plants. On average, 2.3% of leaves of wild plants, 0.8% of leaves of ornamental plants and 0.1% of leaves of exotic plants were consumed by the herbivores. Our study shows that in urban green spaces, both flower-visiting and leaf-feeding insects are more likely to use native wild plants as a food source than closely related and exotic ornamental plants.

Deutsch:

Insektensterben und Biodiversitätsverlust sind mittlerweile Begriffe, mit denen wir täglich konfrontiert werden. Dass ein höheres Blütenangebot in öffentlichen Grünflächen den Insekten mehr Nahrung und Lebensraum bieten kann, ist unumstritten. Kontrovers wird allerdings noch die Frage diskutiert, ob heimische Wildpflanzen oder die seit jeher angepflanzten nicht heimischen Zierpflanzen und Sorten die richtige Wahl sind? Ziel unserer Arbeit war es, anhand einer Auswahl von Zier- und Wildstauden die Anzahl der mit den Pflanzen in Wechselbeziehung befindlichen Insekten zu untersuchen. Hierbei erfolgte nicht nur die Erfassung der Blütenbesucher, sondern auch der an den Blättern und Stängeln lebenden Insekten. Im Stadtgebiet Darmstadt wurden auf zehn Flächen mit einer Größe von je neun Quadratmetern 18 Pflanzenarten angepflanzt. Sie repräsentierten sechs heimische Wildpflanzenarten, sechs mit den Wildpflanzen verwandte Zierpflanzenarten und sechs exotische Zierpflanzenarten. Während der Hauptblüte der einzelnen Arten erfolgte in einem 10-minütigen Beobachtungszeitraum die Erfassung sämtlicher

Blütenbesucher. Heimische Insekten, die sich nur von Pollen und Nektar ernähren, besuchten signifikant häufiger die Wildstauden. Diese Besuche erfolgten mit einem Anteil von 67 % auf den Wildstauden gegenüber 24 % auf Zierstauden und 9 % auf Exoten. Die Honigbiene (Apis mellifera) zeigte hingegen keine Präferenzen für eine der drei Pflanzengruppen und interagierte mit anderen Pflanzenarten als die Gruppe der „non-bees" und die meisten Wildbienen.

Die Auswertung des Blattschadens von je fünf Blättern pro Pflanze und Fläche ergab erneut einen signifikanten Unterschied zwischen den Wildstauden, den Zierstauden und den Exoten. Im Schnitt wurden die Wildpflanzenblätter zu 2,3 % angefressen, die Blätter der Zierstauden zu 0,8 % und die Exotenblätter zu 0,1 %.

Die Studie weist darauf hin, dass heimische Wildpflanzen auf städtischen Grünflächen stärker als Nahrungsressource für blütenbesuchende und blattfressende Insekten genutzt werden als nah verwandte und exotische Zierpflanzen.

Thousands of gardens - Thousands of species: Wild plants, the new superstars for garden markets, gardens, parks and balconies

Tausende Gärten - Tausende Arten: Heimische Wildpflanzen als neue Superstars in Deutschlands Gartenmärkten und Gärten

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English:

Thousands of gardens - Thousands of species: Wild plants, the new superstars for garden markets, gardens, parks and balconies. Native wild plants make a valuable contribution to biodiversity, are robust and attract wild bees, beetles, birds and many other animals. Near-naturally designed gardens can also be aesthetically beautiful and oases of well-being for people. The Thousands of Gardens - Thousands of Species campaign aims to generate enthusiasm for gardening with wild plants and motivate citizens as well as initiatives, associations and municipalities to join in. This also requires nurseries that produce and market native wild plants. Here, the German Horticultural Society is building a network for nurseries as a central element. The aim is to bring wild plants into gardens, balconies and parks, as wild plants are still scarce. Why it is important to use native wild plants, what our plant teams look like, what potential wild plants offer and what opportunities there are to join in are revealed in this session.

Thousands of Gardens - Thousands of Species is funded by the German Federal Agency for Nature Conservation as part of the Federal Program on Biological Diversity with funds from the German Federal Ministry for the Environment. Project partners are: Deutsche Gartenbau-Gesellschaft 1822 e.V., Wissenschaftsladen Bonn (WILA) and the agency for sustainable communication tippingpoints. Cooperation partners are NaturGarten e.V., the Association of German Wild Seed and Wild Plant Producers (VWW) and the Heinz Sielmann Foundation.

Deutsch:

Heimische Wildpflanzen leisten einen wertvollen Beitrag für die biologische Vielfalt, sind robust und locken Wildbienen, Käfer, Vögel und viele weitere Tiere an. Naturnah gestaltete Gärten können zudem ästhetisch schön und Wohlfühloasen für Menschen sein. Die Kampagne Tausende Gärten - Tausende Arten möchte Begeisterung für das Gärtnern mit Wildpflanzen wecken und Bürgerinnen und Bürger sowie Initiativen, Vereine und Kommunen motivieren, mitzumachen. Dafür braucht es auch Gärtnereien, die heimische Wildpflanzen produzieren und vermarkten. Hier baut die Deutsche Gartenbau-Gesellschaft als zentrales Element ein Netzwerk für Gärtnereien auf, damit Wildpflanzen in die Gärten, Balkons und Parks kommen, denn Wildpflanzen sind bislang noch Mangelware. Warum es wichtig ist heimische Wildpflanzen zu verwenden, wie unsere Pflanzenteams aussehen, welche Potentiale Wildpflanzen bieten und welche Mitmachmöglichkeiten es gibt, wird in dieser Session verraten.

„Tausende Gärten – Tausende Arten“ wird im Bundesprogramm Biologische Vielfalt durch das Bundesamt für Naturschutz mit Mitteln des Bundesumweltministeriums gefördert. Projektpartner sind: Deutsche Gartenbau-Gesellschaft 1822 e.V., Wissenschaftsladen Bonn (WILA) und die Agentur für nachhaltige kommunikation tippingpoints. Kooperationspartner sind der NaturGarten e.V., der Verband Deutscher Wildsamen- und Wildpflanzenproduzenten (VWW) und die Heinz Sielmann Stiftung.

Nothing else matters: habitat features that promote arthropod diversity in urban gardens

Vielfalt in urbanen Gärten: Welche Habitatmerkmale fördern die Arthropodendiversität?

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English:
Urbanization can have various impacts on arthropod diversity, depending on the habitat types within cities and the habitat requirements of specific arthropod taxa. Yet, little is known about the precise features that support arthropod diversity within urban ecosystems. Urban community gardens can be structurally complex habitats that harbour a diverse range of nesting and food resources for arthropods. Our aim in this study was (1) to show which features of urban community gardens affect the diversity, richness and abundance of flower visiting arthropods; and (2) to determine the effect of urbanization on flower visitor communities in general and on certain groups of arthropods in particular. We will present results from two years of research, in which we observed flower visiting arthropods in 31 urban community gardens in two German cities (Munich and Berlin). To measure the effect of specific garden structures on arthropod taxa, we assessed biotic and abiotic habitat features within the gardens (i.e. plant diversity, flower abundance, ground cover, availability of deadwood, stone structures, water resources and environmental parameters) and the urbanization gradient surrounding the gardens (i.e. impervious surfaces). Understanding the interplay between habitat factors and arthropod communities may support the development of evidence-based recommendations for the conservation of arthropods. These findings may be adapted in private gardens and other green spaces to actively promote arthropod diversity in cities.

Deutsch:
Urbanisierung kann unterschiedliche Auswirkungen auf die Arthropodenvielfalt haben, abhängig von den vorhandenen Habitaten innerhalb von Städten und den Lebensraumanforderungen bestimmter Arthropodentaxa. Wenig ist jedoch über die konkreten Faktoren bekannt, die die Arthropoden-Vielfalt in städtischen Ökosystemen fördern. Urbane Gemeinschaftsgärten können strukturell komplexe Lebensräume sein, die ein breites Spektrum an Nist- und Nahrungsressourcen für Arthropoden bieten. Unser Ziel in dieser Studie war es, (1) zu zeigen, welche Merkmale urbaner Gemeinschaftsgärten die Diversität und die Abundanz von blütenbesuchenden Arthropoden beeinflussen, und (2) die Auswirkungen von Urbanisierung auf blütenbesuchende Arthropoden im Allgemeinen und auf bestimmte Taxa zu ermitteln. Wir präsentieren Ergebnisse aus zwei Jahren Forschung, in denen wir blütenbesuchende Arthropoden in 31 urbanen Gemeinschaftsgärten in zwei deutschen Städten (München und Berlin) untersucht haben. Um die Auswirkungen spezifischer Gartenstrukturen auf Arthropodentaxa zu messen, haben wir biotische und abiotische Habitatmerkmale innerhalb der Gärten (d.h. Pflanzendiversität, Blütenabundanz, Bodenbedeckung, Verfügbarkeit von Totholz, Steinstrukturen, Wasserressourcen und Umweltparameter) sowie den Urbanisierungsgradienten um die Gärten (d.h. versiegelte Flächen) erfasst.
Zu verstehen, wie Habitatmerkmale und Arthropodengemeinschaften zusammenspielen, kann die Entwicklung von evidenzbasierten Empfehlungen für den Erhalt von Arthropoden unterstützen. Diese Erkenntnisse können auf private Gärten und andere Grünflächen übertragen werden, um die Arthropodenvielfalt in Städten aktiv zu fördern.

Pollinator diversity, pollination services and citizen science in urban community gardens: insights on opportunities and challenges

Bestäubervielfalt, Bestäubungsleistung und Bürgerwissenschaft in städtischen Gemeinschaftsgärten: Einblicke in Chancen und Herausforderungen

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English:

Current research shows that urban gardens serve as important refuges for wild bees and other insects in the city. As such, biodiversity patterns in gardens may differ in comparison to negative trends in urbanization-driven insect biodiversity loss. At the same time, gardens are important places for urban residents to experience and interact with nature. Gardens are therefore important social-ecological systems that support both biodiversity conservation and various ecosystem services such as pollination-mediated food production. In this system, the gardeners act as habitat managers through their gardening practices - but often without being aware of their role. Our citizen science research project Forschen für Wildbienen aims to further investigate this relationship between garden environmental features, pollinator diversity and pollination service as a collaborative effort between urban gardeners and scientists.

In 2020 and 2021, 74 gardeners of 24 community gardens in Berlin and Munich, Germany, observed the pollination of their common crops over the course of the growing season. Here, they documented the number of buds, flowers and fruits every 3 to 7 days. At the same time, a team of scientists visited the gardens three to four times over the summer season and collected data on pollinator diversity as well as on garden environmental features like climate conditions, vegetation diversity, canopy cover or the degree of urbanization around the gardens.

Through this collaboration and the joint collection of data, we have obtained a unique data set on diversity in community gardens and its influence on pollination under real gardening conditions, and we have established a very close cooperation with the community gardeners. In this talk, we will present the first results, highlight the opportunities and the difficulties of a citizen science approach in pollination research and share our experiences with engaging urban gardeners in insect conservation.

Deutsch:

Aktuelle Forschungsergebnisse zeigen, dass städtische Gärten als wichtige Rückzugsgebiete für Wildbienen und andere Insekten in der Stadt dienen. Daher können sich in Gärten die Muster der biologischen Vielfalt von den negativen Trends des durch die Urbanisierung bedingten Biodiversitätsverlusts bei Insekten unterscheiden. Gleichzeitig sind Gärten wichtige Orte für die Stadtbewohner:innen, um Natur zu erleben und mit ihr zu interagieren. Gärten sind daher wichtige sozial-ökologische Systeme, die sowohl den Erhalt der biologischen Vielfalt als auch verschiedene Ökosystemleistungen wie die durch Bestäubung vermittelte Nahrungsmittelproduktion unterstützen. In diesem System fungieren die Gärtner:innen durch ihre Gartenpraktiken als Habitatmanager:innen - oft jedoch ohne sich ihrer Rolle bewusst zu sein. Unser Citizen-Science-Ansatz im Projekt Forschen für Wildbienen zielt darauf ab, diese Beziehung zwischen Gartenumweltmerkmalen, Bestäubervielfalt und Bestäubungsleistung im

Rahmen einer Zusammenarbeit zwischen städtischen Gärtner:innen und Wissenschaftler:innen zu untersuchen.

In den Jahren 2020 und 2021 beobachteten 74 Gärtner:innen aus 24 Gemeinschaftsgärten in Berlin und München die Bestäubung ihrer Nutzpflanzen im Laufe der Vegetationsperiode. Dabei dokumentierten sie alle 3 bis 7 Tage die Anzahl der Knospen, Blüten und Früchte. Gleichzeitig besuchte ein Team von Wissenschaftler:innen die Gärten drei- bis viermal während der Sommersaison und sammelte Daten zur Bestäubervielfalt sowie zu den Umweltmerkmalen der Gärten wie Klima, Vegetationsvielfalt, Baumkronenbedeckung oder dem Urbanisierungsgrad in der Umgebung der Gärten.

Durch diese Zusammenarbeit und die gemeinsame Datenerhebung konnten wir einen einzigartigen Datensatz über die Vielfalt in Gemeinschaftsgärten und ihren Einfluss auf die Bestäubung unter realen gärtnerischen Bedingungen gewinnen und haben eine sehr enge Zusammenarbeit mit den Gemeinschaftsgärtner:innen aufgebaut. In diesem Vortrag werden wir erste Ergebnisse vorstellen, die Chancen und Herausforderungen eines bürgerwissenschaftlichen Ansatzes in der Bestäubungsforschung aufzeigen und unsere Erfahrungen mit der Einbindung von Gärtner:innen in den Insektenschutz in der Stadt teilen.

ID: 66-05

MikroSafari: The effect of urbanisation on soil arthropod communities in three German cities

MikroSafari: Auswirkungen der Urbanisierung auf Gemeinschaften von Bodenarthropoden in drei deutschen Städten

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English:

It is widely known that arthropod populations suffer greatly from anthropogenic pressures like climate change. In cities, those climatic pressures are even stronger due to the urban heat island effect, which results in temperature differences of up to 10 °C between urban areas and their rural counterparts. Yet, how whole arthropod communities are affected by these changes is little explored. Here, we aim to gain more understanding thereof by disentangling the effects of climate change from additional urban stressors like high proportions of impervious surfaces and habitat fragmentation. With this approach, we can use cities as space-for-time laboratories of our climatic and environmental future.

Based on a citizen science approach, school children in Halle, Leipzig and Berlin in Germany have carried out over 200 standardised pitfall trap experiments in private gardens to measure soil arthropod species richness, abundance and biomass along with microclimate conditions. Combining their findings with remote sensing data on impervious surface and habitat fragmentation we show how arthropod communities are responding to the environmental pressure of increasing temperatures and habitat change across three cities of varying size, identifying winners and losers. We furthermore show how a citizen science approach can be effectively used to analyse a high number of sites in urban areas – in this case gardens – that would otherwise not be accessible. Those outcomes will provide advanced insights for the understanding and mitigation of future ecological and societal impacts of climate change and increasing urbanisation.

Deutsch:

Es ist allgemein bekannt, dass Arthropodenpopulationen stark unter anthropogenen Einflüssen wie dem Klimawandel leiden. In Städten sind diese klimatischen Belastungen aufgrund des städtischen Wärmeinseleffekts besonders stark. Dieser kann zu Temperaturunterschieden von bis zu 10 °C zwischen städtischen Gebieten und dem ländlichen Umland führen. Wie sich diese Veränderungen auf ganze Gemeinschaften von Arthropoden auswirken, ist jedoch noch wenig erforscht.

Mit unserer Untersuchung wollen wir mehr über die entsprechenden Zusammenhänge erfahren, indem wir die Auswirkungen des Klimawandels gemeinsam mit zusätzlichen städtischen Stressfaktoren wie einem hohen Anteil an versiegelten Flächen und der Fragmentierung von Lebensräumen untersuchen. Durch diesen Ansatz können wir Städte als Raum-Zeit-Labore für unsere klimatische und ökologische Zukunft nutzen.

Im Rahmen eines Citizen-Science-Projektes haben Schüler:innen in Halle, Leipzig und Berlin über 200 standardisierte Fallenexperimente in privaten Gärten durchgeführt um das Artenreichtum, die Abundanz und die Biomasse von Bodenarthropoden zu untersuchen. Zudem

wurden mikroklimatischen Bedingungen gemessen. Durch die Kombination ihrer Ergebnisse mit Fernerkundungsdaten über versiegelte Flächen und die Fragmentierung von Lebensräumen zeigen wir, wie Arthropodengemeinschaften auf den Stress durch steigende Temperaturen und Lebensraumveränderungen reagieren und identifizieren Gewinner und Verlierer. Dabei können wir Ergebnisse aus drei Stäten unterschiedlicher Größe vergleichen. Weiterhin zeigen wir, wie ein bürgerwissenschaftlicher Ansatz effektiv genutzt werden kann, um eine große Anzahl von Orten in städtischen Gebieten - in diesem Fall Gärten - zu analysieren, die sonst nicht einfach zugänglich wären. Die Ergebnisse liefern neue Erkenntnisse für das Verständnis und die Entschärfung künftiger Auswirkungen des Klimawandels sowie der zunehmenden Urbanisierung.

The structural diversity of gardens – a classification based on LiDAR-data

Die Strukturvielfalt von Gärten – eine Laserscan-basierte Klassifikation

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English:

Gardens represent a large proportion of urban green space (UGS) and urban land, hence, when it comes to identifying priority conservation areas and establishing effective and resilient ecological networks across urbanized areas, addressing urban gardens is essential. Depending on their size, structure, and proximity to other UGS, gardens can provide habitat, function as stepping-stones, and as areas were humans and non-human animals coexist and interact. The role of gardens in supporting biodiversity and ecological connectivity, but also their capacity for climate adaptation of urban areas, however, has so far received insufficient attention. One reason is the lack of detailed spatial information.

To overcome this gap we have conducted a comprehensive assessment of UGS with a focus on gardens in Braunschweig, Germany. Using high resolution LiDAR data in combination with other remote-sensing and GIS data, we mapped 3D vegetation structure, impervious and bare soil surfaces, and water bodies. Based on these results, we will present a structure-based garden typology. Overcoming present knowledge gaps, and better integrating gardens into city-wide and regional green infrastructure planning, is key to achieving nature-inclusive cities that contribute to biodiversity conservation and mitigate the negative effects of climate change.

Deutsch:

Gärten machen einen großen Teil des städtischen Grüns aus, daher sollten sie für die Entwicklung von wirksamer urbaner grüner Infrastruktur nicht außeracht gelassen werden. Je nach Größe, Struktur und Nähe zu anderen Grünflächen können Gärten Lebensraum bieten, als Trittsteine fungieren und als Gebiete dienen, in denen Naturerfahrung im Alltag stattfinden kann. Die Rolle von Gärten für den Schutz der biologischen Vielfalt und des Biotopverbunds, aber auch ihre Fähigkeit zur Klimaanpassung in städtischen Gebieten, wurde bisher jedoch nur unzureichend untersucht. Ein Grund dafür ist der Mangel an detaillierten räumlichen Informationen.

Um diese Lücke zu schließen, haben wir eine umfassende Bewertung von Gärten in Braunschweig durchgeführt. Unter Verwendung von hochauflösenden Laserscandaten (LiDAR) in Kombination mit anderen Fernerkundungs- und GIS-Daten haben wir die 3D-Vegetationsstruktur, versiegelte Flächen, unbewachsene Böden und Gewässer kartiert. Auf der Grundlage dieser Ergebnisse wurde eine strukturbasierte Gartentypologie entwickelt. Das Schließen von Informationslücken zu Gärten und die bessere Integration von Gärten in die stadtweite und regionale Planung grüner Infrastruktur ist der Schlüssel zum besseren Schutz der biologischen Vielfalt in Städten und zur Abmilderung der negativen Auswirkungen des Klimawandels.

Increasing biodiversity in gardens: motives and obstacles for garden owners as well as communication strategies and possibilities for action in communities and beyond

Erhöhung der biologischen Vielfalt in Privatgärten: Motive und Hemmnisse der Gartengestaltung sowie Kommunikationsstrategien und politische Handlungsempfehlungen

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English:

The project gARTENreich is dedicated to the question of how biodiversity in gardens can be increased in harmony with the needs of private garden owners. Thus, gARTENreich analyses motives and barriers to gardening practices that enhance biodiversity and develops recommendations for municipal and community stakeholders as well as garden owners.

Initial results show that the preservation of biodiversity does not yet play a major role in the perception of gardens by society as a whole and that awareness of the need for action is still low.

There are also deficits in knowledge and misconceptions of what should and should not be done in the garden to promote biodiversity. For a biodiversity governance strategy that aims to target private gardens it is therefore vital to increase awareness of this topic. As the style of gardening people choose is influenced by a complex array of motives and external factors, it is also important to offer inspiration and support to gardeners in a way that considers these factors.

Local governments play a vital role in influencing private garden owners. Not only are they generally well placed to further awareness and knowledge, but they can also regulate and financially support important aspects of garden design. gARTENreich aims to evaluate different political approaches to promoting biodiverse gardening styles and will offer strategic advice to local governments on how to approach gardeners.

In our presentation we will provide insights into our preliminary results regarding motives and barriers of garden owners as well as communication strategies and recommendations for public policy measures.

Deutsch:

Das Projekt gARTENreich widmet sich der Frage, wie die Biodiversität in Gärten im Einklang mit den Bedürfnissen privater Gartenbesitzer*innen erhöht werden kann. Dazu analysiert gARTENreich die Motive und Hemmnisse einer biodiversitätsfördernden Gartengestaltung und entwickelt Handlungsempfehlungen für kommunale Akteure sowie für Gartenbesitzer*innen. Erste Ergebnisse zeigen, dass der Erhalt der biologischen Vielfalt in der gesellschaftlichen Wahrnehmung von Gärten noch keine große Rolle spielt und das Bewusstsein für den Handlungsbedarf noch gering ist. Auch gibt es Wissensdefizite und unklare Vorstellungen darüber, was im Garten zur Förderung der biologischen Vielfalt getan werden sollte und was nicht. Für eine Strategie zur Erhöhung der biologischen Vielfalt, die auf Privatgärten abzielt, ist es daher unerlässlich, das Bewusstsein für dieses Thema zu schärfen. Da die individuelle Gartengestaltung von einer Vielzahl unterschiedlicher Motive und anderer Determinanten beeinflusst wird, ist es auch wichtig, den Gärtnerinnen und Gärtnern Anregungen und Unterstützung zu bieten, die

diese Faktoren berücksichtigen. Lokale und kommunale Behörden spielen hier eine wichtige Rolle. Sie sind in der Regel nicht nur in der Lage, Bewusstsein und Wissen zu fördern, sondern können auch wichtige Aspekte der Gartengestaltung regulieren und finanziell unterstützen. gARTENreich will verschiedene politische Ansätze zur Förderung biodiversitätsfördernder Gartengestaltung evaluieren und den Kommunen strategische Ratschläge geben, wie sie auf Gärtner zugehen können. In unserer Präsentation werden wir Einblicke in unsere vorläufigen Ergebnisse zu Motiven und Hemmnissen von Gartenbesitzer*innen sowie Kommunikationsstrategien und Empfehlungen für politische Maßnahmen geben.

SESSION 67:

People and Nature

What we think of wildlife: Investigating citizen's perceptions and stakeholders focus of wild mammals in Germany

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Human's perception of wildlife is linked with the acceptance of their management. Some see non-native mammals as charismatic and oppose hunting while simultaneous returned keystone species are seen by some as nuisance. Particularly as natural habitat declines and new habitats are found in settled areas, there is a need to understand human-wildlife relationships in urban areas. We investigate responses from an online survey (n = 2.997) circulated in German settlements in late 2020 regarding i) people's preferences for seeing wild certain mammals (beavers, squirrels, hedgehogs, foxes, marten, rats, hares, coypus, rabbits, deer, and wild boar) in settlement areas as well as their emotions towards them. We ii) explored how socio-economic variables gender, age, education and rurality as well as if participants had young children, garden access, a car and pets influence these perceptions and emotions. Further expert interviews (n=36) shed light on which mammals are focused in management by decision-makers from conservation, administration, and hunting. In general, experts focussed on wild boar, marten, beaver, fox and raccoons while citizens listed hedgehogs and squirrels as most mammals. Our results showed that while the smaller mammals were preferred and taller as well as non-native mammals were undesired, the actual encounters with wildlife were rather positive. The most negatively perceived mammals were also least encountered compared to those felt positive about. While gender, pet ownership and age showed the most significant results, having young children or a higher level of education showed the least significant influences. With the knowledge gained management for wildlife can be adjusted where animals are seen as unwelcomed and further wildlife being recognized as positive can be installed as ambassadors for biodiversity stewardship.

Mining crowdsourced text to capture hikers' perceptions associated with landscape features and outdoor physical activities

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Outdoor recreation provides vital interactions between humans and ecological systems with a range of mental and physical benefits for people. Despite the increased number of studies using social media data to assess how people interact with the landscape during recreational activities, the focus remains largely on mapping the spatial distribution of visitors or analyzing the content of shared images and little work has been done to quantify the perceptions and emotions people assign to the landscape. In this study, we used crowdsourced textual data from an outdoor activity-sharing platform (Wikiloc), and applied Natural Language Processing (NLP) methods and correlation analysis to capture hikers' perceptions associated with landscape features and physical outdoor activities. Our results indicate eight clusters based on the semantic similarity between words ranging from four clusters describing landscape features ("ecosystems, animals & plants", "geodiversity", "climate & weather", and "built cultural heritage"), to one cluster describing the range of physical outdoor activities and three clusters indicating hikers' perceptions and emotions ("aesthetics", "joy & restoration" and "physical effort sensation"). The association analysis revealed that the cluster "ecosystems, animals & plants" is likely to stimulate all three identified perceptions, suggesting that these natural features are important for hikers during their outdoor experience. Moreover, hikers strongly associate the cluster "outdoor physical activities" with both "joy & restoration" and "physical effort sensation" perceptions, highlighting the health and well-being benefits of physical activities in natural landscapes. Our study shows how textual data can provide significant advances in understanding peoples' preferences and perceptions while recreating. These findings can help inform outdoor recreation planners in the study region by focusing on the elements of the landscape that peoples perceive to be important (i.e. "ecosystems, animals & plants").

Impact of water-based recreation on aquatic and riparian biodiversity of small lakes

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Lakes offer important recreational sites for humans. However, water-based recreation might also conflict with conservation objectives. The objective of our work was to examine the impact of recreational use of small stagnant water bodies (‹ 20 ha) on several aquatic and riparian biodiversity indicators (species richness, Simpson index and number of endangered species) across multiple taxa (waterfowl, songbirds, damselflies, dragonflies, amphibians, fishes, submerged macrophytes, riparian herbs and trees). Samples were generated from 39 gravel pit lakes located in Lower Saxony (Germany). Recreational use intensity was quantified using a stratified roving creel survey design. Recreational use exhibited minor correlations with the different biodiversity indicators. Most of the variance in biodiversity was explained by non-recreation related environmental and land use variables. The most consistent negative relationships of recreation and biodiversity were revealed for dog walking in relation to species richness of songbirds, fish, macrophytes and riparian herbs. Some recreational impacts were positive. For example, increased human use intensity correlated positively with the species richness of fishes and riparian herbs. Moreover, lakes used exclusively by anglers showed higher fish species but reduced amphibian richness. These effects were likely caused by the establishment of fish via introductory stocking in gravel pit lakes and associated predation impacts. We conclude that dog presence maybe more influential in terms of recreation-related impact than human presence per se, perhaps because dogs will be perceived as a threat stimulus by wildlife, while habituation to non-threatening human presence may minimize human impacts on wildlife. More experimental work is needed to substantiate the correlative evidence presented in our study, but recreational impacts by humans on freshwater ecosystems might be less than often assumed.

Does tree species richness in forest affect mental health, stress reduction and attention restoration? An EEG study.

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Nature provides beneficial effects for mental health and well-being. Studies point for example towards improvements of mental health as a function of both direct and indirect exposure to natural environments through e.g. looking at nature photographs. There are, however, substantial knowledge gaps which particular properties of natural environments serve as drivers for mental health gains. Here, we use physiological assessments of psychological processes to better understand the underlying mechanisms of nature-health relationships. In a controlled laboratory experiment using electroencephalography (EEG) to monitor neurophysiological responses, we study the role of forest diversity by means of tree species richness on mental health and well-being. A special emphasis is put on stress reduction and attention restoration as potential mechanistic pathways linking forest diversity to mental health.

Overall, 52 participants looked at forest photographs depicting different tree species richness or perceptual controls in the form of phase-scrambled versions of the same photographs. Participants' mental health and well-being, as well as perceived stress and attention were assessed before and after each condition with questionnaires. In addition, an auditory oddball task was applied to objectively measure directed attention after looking at each set of photographs. EEG was recorded continuously to further assess neurophysiological correlates of stress reduction (via power spectral density analysis) and attention restoration (via event related potentials).

We present how actual and perceived forest diversity are linked to mental health and well-being using subjective questionnaires, objective behavioural data from an attention test and neurophysiological indicators.

Considerations of justice in achieving goals and targets for biodiversity and climate – the example of biomass production and consumption systems.

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We are currently in the middle of an interlinked twin crisis: climate change and the alarming decrease in biodiversity globally. Numerous ambitious goals and targets for nature, climate and people have been set out globally and at the European level to tackle this dual crisis and achieve a more sustainable future, for example, in the Kunming-Montreal Global Biodiversity Framework or the European Green Deal. However, to successfully meet these goals and targets, questions of justice, such as in the share of benefits and burdens, must be considered. The production and consumption of biomass influence both the climate and the state of nature and biodiversity. For example, agricultural production contributes to changes in biodiversity via land use change and intensification. Thus, transforming biomass production and consumption systems towards more sustainable patterns is essential. Here, we will (1) present a review and synthesis of goals and targets from important global and European policy and scientific frameworks, specifically focusing on goals and targets relevant to the interlinked biomass production and consumption system. We will then (2) introduce examples for relevant justice considerations and (3) illustrate how some of the goals and targets can be downscaled to explore such justice principles.

SESSION 69:

Miscellaneous

Symbio(s)cene: Arts & sciences collaboration for an era beyond the Anthropocene

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The biodiversity and climate crises make global, profound and transformative change urgently necessary. A new way of thinking, rooted in a renewed humans-nature relationship, could be a very strong lever to promote this change. This new way of thinking would require a renewed awareness of nature, an openness to and appreciation of other living things, and a new aesthetic that appreciates the beneficial character of natural materials and structures.

Symbio(s)cene is a non-profit initiative with a vision to contribute to shaping such a new mindset that promotes thinking beyond the Anthropocene. With the Symbio(s)cene initiative, we want to show examples that demonstrate that a future worth living in is already within reach, and we want to contribute with projects that accelerate the emergence of a new mentality that embraces a positive human-nature relationship. The distinctive proposition of our initiative is a holistic approach that interconnects sciences and arts – giving space to both cognitive and emotional dimensions of knowledge.

A core activity of Symbio(s)cene is the organization of exhibitions with integrated scientific discussions, bringing together artists and scientists and offering artists a platform to discuss their motivation and underlying reasoning. These exhibitions are e.g. featuring pieces of art that play with the idea of renewed human-nature relationships, or artefacts that demonstrate and represent novel approaches for regenerative design. On the website symbioscene.com, video documentations of the exhibitions and related talk events are available.

The poster will present our motivation, our vision of a 'Symbiocene' and our goals, and will provide more examples for current and future activities.

The gills of Lake Victoria cichlids: theatre for parasite interspecific relationships and niche segregation

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Hosts often harbour multiple parasite species, that may interact and thus modify each other's effects on host fitness. These interspecific interactions between parasites may result in parasites occupying different niches within hosts (niche segregation). The within-host distribution of different parasite taxa may constitute an important axis of infection variation among host populations and species.

We investigated the microhabitat distributions and species interactions of gill parasites infecting 14 sympatric Lake Victoria cichlid species. We found that the two most abundant parasite taxa (the monogenean *Cichlidogyrus* spp. and the copepod *L. monodi*) had non-random microhabitat distributions on gills, which also differed between host species. This may indicate microhabitat selection by the parasites and cryptic differences in the host-parasite interaction among host species.

Relationships among parasite of different genera were synergistic: the abundances of *Cichlidogyrus* spp. and the copepods *L. monodi* and *E. lamellifer* tended to be positively correlated. In contrast, relationships among congeners (members of *Cichlidogyrus* belonging to different species) were antagonistic. Together with niche overlap, this suggests competition among species of *Cichlidogyrus*.

These findings may indicate host species-specificity in parasite niche selection and consequently in the host-parasite relationship. Microhabitat distribution of parasites over gills may represent an important axis of infection variation, therefore we suggest to include the location of parasites on the host in future studies, alongside with canonical measures of infection (i.e. parasite abundance).

Deep-water hypoxia in Lake Lunz:

Effects of oxygen depletion on phosphorus cycling and vertical distribution of zooplankton in Lake Lunz

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In the last decades, oxygen depletion has become an increasingly important phenomenon in freshwater ecosystems due to increasing water temperatures and longer stratification periods, with effects on the development of zooplankton, community structure and vertical distribution, as well as nutrient cycling. In the light of climate change, increased nutrient inflow from the catchment and the release of phosphorus from the sediment to the water column has been observed. Increased primary production due to the fertilizing effect of high phosphorus values in the water column may lead to additional oxygen depletion due to the decomposition of organic matter.

Zooplankton was obtained at Lake Lunz in the eastern Austrian alps on four different occasions throughout Autumn 2022. Samples of 12 liters were taken in eight depths with a Schindler sampler and were then filtered and analyzed morphologically under a microscope. Dissolved oxygen (DO) and chlorophyll a data was obtained via a multiparameter probe. Total phosphorus (TP) and soluble reactive phosphorus (SRP) were measured monthly over the whole water column over the years 2021 and 2022.

In total, four crustacean species and ten rotifer species were found. The crustacea community was dominated by *Eudiaptomus gracilis*, while the rotifera community was strongly dominated by *Keratella cochlearis*. All crustacean and most rotifer species showed a strong positive correlation with dissolved oxygen levels, while *Keratella quadrata* was the only species with a clear negative correlation between vertical distribution and dissolved oxygen content. This could indicate that most species prefer higher oxygen levels. However, tolerance for lower oxygen levels seems high. As for phosphorus values, we found that in both 2021 and 2022 total phosphorus and soluble reactive phosphorus over the whole water column correlated negatively with DO and that TP values are evenly distributed horizontally across Lake Lunz.

Morphological diversity in crabs is incongruent with taxonomic diversity especially when considering larval stages

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Brachyura and Anomala (or Anomura), true and false crabs, are prominent crustacean ingroups, with ca. 7,000 and ca. 3,000 described species respectively. They express a large biological diversity with their representatives being adapted to marine, limnic and terrestrial habitats. Reasons for the evolutionary success of these groups may be the process of carcinization (attaining a crab-like shape) or the megalopa phase (a specialised larva), both unique features of the group Meiura, to which both true and false crabs belong. Carcinization describes the process of gradually acquiring crab-like features, such as a flattened and widened body. Development of true and false crabs consists of an often planktic zoea phase, followed by the megalopa phase, which is a transition phase, to the benthic lifestyle of the adults. Although both groups possess these features that promote diversity, true crabs have more than twice as many species described as false crabs. Yet, false crabs still express a large range of morphological diversity. Taxonomical diversity, therefore, seems to be ineffective in grasping diversity. Therefore, to investigate the biological diversity of these two groups, we analyse the morphological diversity of the two groups. To this end, we reconstructed more than 1600 shield outlines of different developmental stages (zoea, megalopa, juveniles, adults) of true and false crabs, including representatives of Nephropidae, i.e., lobsters, as an outgroup. Using elliptic Fourier analysis, we quantified the morphological diversity of the shield, representing a proxy for morphological and ecological diversity. We find that both, true and false crabs, have diverse morphologies in their zoea and adult phases, but both groups have less diverse megalopa phases. The megalopae of both groups are also strongly overlapping within the morphospace, therefore seeming to be a phylotypic stage. Although the difference in species numbers, we see no large difference in morphological diversity between true and false crabs. However, we find that adults of true crabs are more diverse than adults of false crabs, while it is the other way around when looking at the zoea stage. Morphological diversity is therefore contradicting taxonomic diversity.

Identifying hydrogeomorphological and ecological filters for seed dispersal and riparian vegetation composition in a boreal river system

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Riparian vegetation and seedbanks are particularly sensitive to the riverscape's hydrogeomorphology. We assessed the respective roles that the process domain concept (PDC), the serial discontinuity concept (SDC) and the river collector thesis (RCT) played along 40 km of a tributary to the river Klarälven in boreal Sweden. The RCT assumes an important role for hydrochory and suggests higher species richness towards downstream. According to the PDC, composition in river process domains (RPDs) of the same type should be more similar to each other than to other parts of the system. Of these RPDs, we expected lakes to receive more propagules and to have more species-rich seedbanks than slow-flowing and rapid reaches, and to have more species-rich vegetation. Based on the SDC, we also expected lakes to function as a reset of any increasing species richness towards downstream. Because of their low flow velocity, we expected relatively more species with long-floating propagules in lakes than in slow-flowing or rapid reaches. We inventoried vegetation composition and analysed the seedbank in 20 riparian sites and found that species richness towards downstream increased in neither. Seedbanks were not particularly similar to their upstream locations in any of the RPDs. Vegetation showed higher resemblance, although proximity might be a better predictor for similarity than RPD type. Lakes did not hold richer seedbanks, more propagules or richer vegetation than the other RPDs. Plant species with long-floating propagules made up most of the vegetation (50 - 91.7% of the species) and seedbanks (66.7 - 100% of the species) at all sites, and more so at slow-flowing reaches and lakes. Although none of the above processes showed very clear patterns, local hydrogeomorphology, following the PDC, seemed to be a somewhat more important determinant of vegetation and seedbank composition than regional processes such as hydrochory.

The impact of wildfire on beetle communities in an unmanaged heathland

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Wildfires alter the composition of insect communities due to fire-induced mortality. The altered post-fire vegetation and soil conditions further affect the initial re-colonization and subsequent local emergence of adult beetles from soils. In eastern Germany, large areas of open landscapes with sandy soils were formerly used as military training sites and deforestation and mechanical soil disturbance resulted in rapid heathland succession and a high local diversity. Ammunition remnants in the soil cause problems for fire management and prevention. Our study area (Lieberoser Heide) was one of the largest military training sites in Germany and is now a nature reserve managed as a "wilderness" area without human intervention. We studied locally emerging beetle communities in the area that was affected by a severe wildfire in 2017 using replicated triplets of the habitat locations unburnt forest, burnt forest and burnt bog. In total, 3037 beetles from 25 families emerged from soils and the overall abundance and family richness were highest in the burnt forest. In a second experiment, we then focused on the response of a generally understudied group to wildfires, the carrion-associated beetle species, by adding wild boar carcasses to the burnt and unburnt forest plots. Scavenging beetle species colonized carcasses in burnt plots to the same extent as in unburnt plots, but the post-fire conditions favored species with very specialized habitat preferences. A few rare species of conservation concern almost exclusively occurred in the burnt area with the presence of a carcass, such as *Onthophagus semicornis* and *Trox hispidus*. These results highlight the importance of wildfires for species conservation in beetle communities of heathland areas and further emphasize the relevance of larger mammal carcasses for beetle diversity in nature reserves.

Does high functional trait similarity to a neighbor force grassland species to change their own traits?

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Plants have the ability to modify their functional traits in response to a change in soil conditions, but also to biotic interactions with neighboring species. The presence and the identity of the neighbor may affect the trait values and how much they change within one species (intraspecific trait variability) and whether they become more similar or dissimilar to each other in term of their traits. In our study, two different soils, one representing soil from undisturbed species-rich grasslands and the other its counterpart from grassland restored on arable land 20 years ago, were used to test species interactions in variable environmental conditions. To observe how species change their functional traits in presence of either similar or dissimilar species and with the presence/absence of a competitor, we conducted a pot experiment with 8 common grassland species and put together 4 most similar and 4 most dissimilar pairs of species with the addition of a competitor. We found that having any heterospecific neighbor is highly important for seedling establishment, however growing together with a dissimilar neighbor results in higher establishment. Maximum plant height is not affected by similarity of the neighbor, but the presence of a competitor suppresses the growth in terms of both height and leaf area. Leaf nitrogen content however is higher for the species pairs which are dissimilar. Leaf traits are mostly affected by soil, plants in the restored soil had higher SLA and lower LDMC and leaf biomass. Our results demonstrate that irrespectively to soil type, neighbor functional similarity is highly important for seedling survival and their overall functional trait profile.

Negative plant-soil feedbacks disproportionally affect dominant plants, facilitating coexistence in plant communities

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Plant-soil feedbacks (PSFs) are believed to play a vital role in the coexistence of plant species and the success of exotic invasions in natural plant communities. It is widely believed that species exhibiting more favorable PSFs are likely to be more prevalent in these communities. However, most of the evidence supporting this hypothesis is based on mesocosm experiments involving single species, and the applicability of these findings to diverse plant communities remains uncertain and subject to debate. To address this gap, we conducted a comprehensive experiment that encompassed both monoculture and community settings. Our objective was twofold: (1) to assess whether PSFs observed in monocultures can accurately predict PSFs in plant communities, and (2) to investigate the role of PSFs in the success of invasive plant species. Our findings revealed the following key insights: (1) PSFs observed in monocultures poorly predict PSFs in plant communities, (2) the competitive strength of invasive species did not consistently rely on PSFs, and (3) larger competitive species experienced significantly more adverse PSFs compared to smaller species when grown in communities. Consequently, the predictive power of PSFs observed in monocultures for determining species abundance or invasibility in plant communities appears to be less significant than previously assumed. Nonetheless, PSFs, particularly negative ones, emerge as influential drivers of plant species coexistence, with a noteworthy species-specific pathogenic impact on dominant plants that facilitates the persistence of rare species.

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