Forests in the face of accelerating environmental change

Quantifying, monitoring and predicting climate change impacts

SFL Science Day

Friday, 14th February 2025

08:00 – 17:00

University of Basel
Hörsaal 118 (1st Floor)
Kollegienhaus
Petersplatz 1
4001 Basel

Keynote Speakers

Dr. Allan Buras
TU Munich

Dr. Alessandra Bottero
SLF Davos

Spotlight Speakers

Dr. Alex Grendelmeier
Swiss Ornithological Institute

SWISS FOREST LAB

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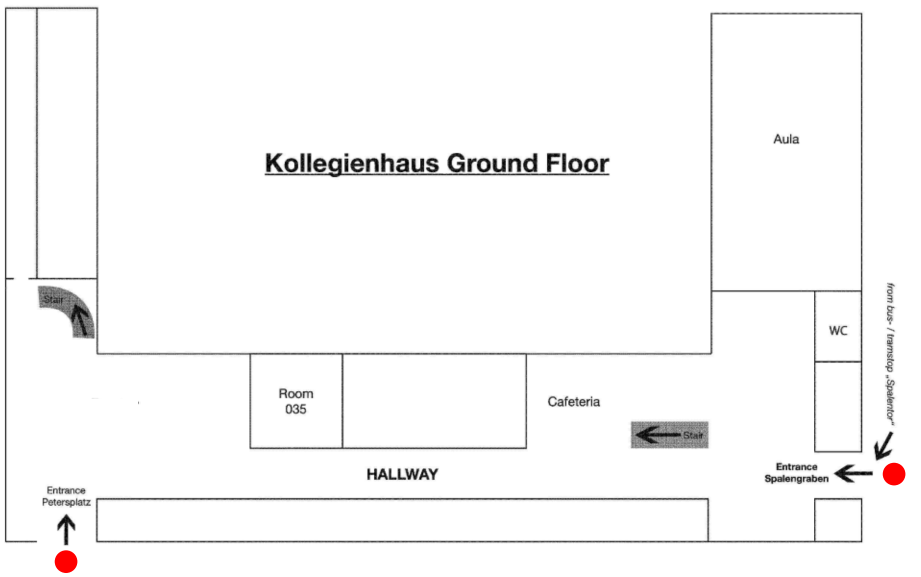
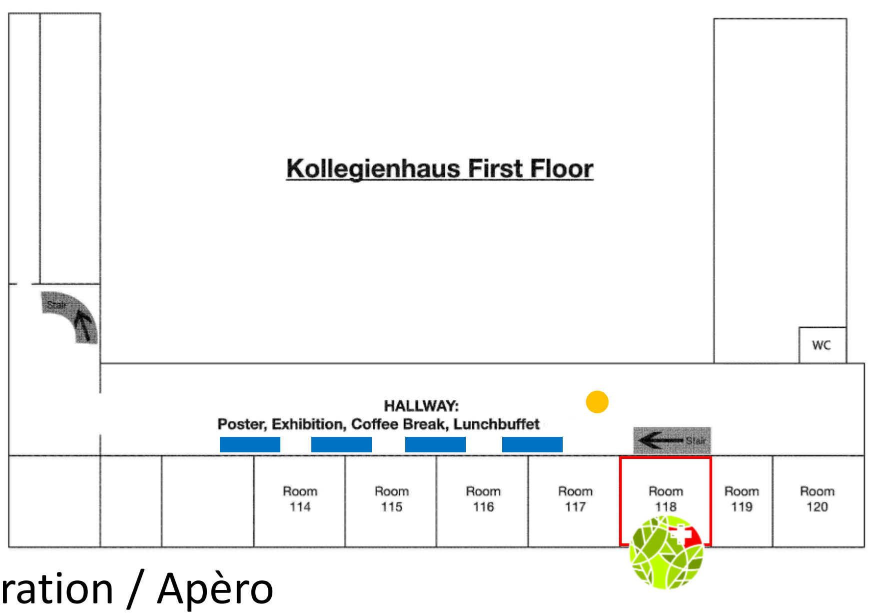
Content

University of Basel
Kollegienhaus
Petersplatz 1, 4051 Basel
Floor Plan





- Registration / Apèro
- Entrances
- Poster Sessions

Event Program

08:00 - 09:00	**Registration**		
09:00	**Welcome**		

Session 1 Chair: Hoch, Günter

09:00 - 09:30	1.0	Buras, Allan	**Keynote:** Studying the climate-change resilience of forest ecosystems in space and time
09:30 - 09:45	1.1	Floriancic, Marius G.	Revealing The Origin, Age And Seasonality Of Streamflow, Soil Waters And Transpiration
09:45 - 10:00	1.2	Steger, David N.	Drought Effects on Root Water Uptake Depth of Temperate Trees – Findings from a Two-year Rain Exclusion Experiment
10:00 - 10:15	1.3	Dups, Raphael	Drought Vulnerability in a Temperate Forest Stand: A Comparison of Conspecific Mature and Juvenile Trees
10:15 - 10:30	1.4	Schaub, Marcus	VPDrought – a Novel Approach to Disentangle Atmospheric and Soil Drought in a Natural Scots Pine Fores
10:30 - 11:00		**Coffee break**	
11:00 - 11:15	1.5	Zhorzel, Tobias	Relevance of Osmotic Adjustment During Drought in Mature Temperate Trees
11:15 - 11:30	1.6	Braun, Sabine	Recent Drought Effects on Beech, Oak and Spruce compared to four decades of Intercantonal Long-term Forest Observation
11:30 - 11:45	1.7	Marano, Gina	Simulating the recent drought- induced mortality of European beech (*Fagus sylvatica* L.) and Norway spruce (*Picea abies* L.) in German forests
11:45 - 12:00	1.8	Lukovic, Mirko	Virtual Trees
12:00 - 12:15	1.9	Beloiu Schwenke, Mirela	TreeAI: A High-resolution Global Dataset for Advancing AI-based Forest Monitoring
12:15 - 13:30		**Lunch Break and poster session** (posters of Session 1 & 2)	

Session 2 Chair: Vitasse, Yann

13:30 - 14:00	2.0	Grendelmeier, Alex	**Spotlight:** Impact of climate change and extreme events on Swiss (forest) birds
14:00 - 14:15	2.1	Kurath, Dave	Leaf Spectroscopy Reveals Drought Response Variation in *Fagus Sylvatica* Saplings from Across the Species' Range
14:15 - 14:30	2.2	Schneider, Pascal	Flush to Crush: The Paradox of Favourable Springs Leading to Tree Mortality
14:30 - 14:45	2.3	Luo, Yunpeng	The Underlying Physiological Reasons Cause Delayed Spring Photosynthesis Resumption
14:45 - 15:00	2.4	Deluigi, Janisse	Photosynthetic and Respiratory Acclimation Cannot Compensate Reduced Plant-level Carbon Uptake in Beech and Oak Saplings Under Prolonged Warming and Drought
15:00 - 15:30		**Coffee break**	
15:30 - 16:00	2.5	Bottero, Alessandra	**Keynote:** Mountain Forests in a Changing Climate: Challenges, Insights, and Adaptation Strategies
16:00 - 16:15	2.6	Hunziker, Stefan	Tree crown defoliation and tree mortality in Swiss forestry
16:15 - 16:30	2.7	Marande, Camille	Drought Resilience of 14 Native and Non-native Tree Species in the Long-term Experimental Plantation Copera, Based on Treering Analyses and Quantitative Wood Anatomy
16:30 - 16:45	2.8	de Boer, Maaike	Enhancing Resilience of Temperate European Forests by Promoting Rare Native Tree Species (RareSpec Project)
16:45 - 17:00	2.9	Heubel, Sina	Assessing Forest Dynamics Tools for Tackling Emerging Challenges in Forest Management
17:00 - 18:00		**Apéro and poster session** (posters of Session 1 & 2)	

Oral Presentations

Studying the climate-change resilience of forest ecosystems in space and time

Allan Buras[1)]

[1)] Land Surface-Atmosphere Interactions, Technical University of Munich, Freising, Germany

Understanding how forest ecosystems respond to and cope with climate-change is crucial in terms of a climate-smart forest management. In particular, the weather extremes of recent years related to e.g. hotter drought, floods, and late-spring frost have exemplified the multitude of challenges which forests and forest practitioners are facing.

In this regard, a (near) real-time monitoring of forest ecosystems can assist by indicating hot-spots of current tree stress related to various stressors. Moreover, studying tree growth and wood properties over the past decades may already provide insights on how forests already are reacting. Finally, such data may serve the purpose to train empiric and mechanistic models, which bear the potential of projecting tree growth as well as tree-species distributions under various climate-change scenarios.

In this keynote, I strive for an overview on how the combination of field-based measurements with remotely sensed observations and derived statistical models may identify hot-spots of recent forest decline, focal points of climate-change induced stress, as well as tree-species specific climate-change sensitivities. All of these investigations serve the overarching purpose to gather information that helps decision makers to increase forests climate-change resilience. Based on model projections for various scenarios, I moreover provide a glimpse on the possible future of Europe’s forests.

Revealing the origin, age and seasonality of streamflow, soil waters and transpiration

Marius Floriancic[1)], Scott Allen[2)], James Kirchner[1)]

[1)] Institute of Environmental Engineering, Department of Environmental Systems Science, ETH Zürich, Zurich, Switzerland

[2)] University of Nevada, Reno, USA

The forest water cycle is dominated by vegetation-mediated processes, such as interception, infiltration, and transpiration, that greatly impact the redistribution of waters between the atmosphere and subsurface. Based on a three-year time series of water stable isotope from precipitation, soils of various depths, groundwater, streams and xylem from the "WaldLab Forest Experimental Site" in Zurich, Switzerland we estimated seasonal signals and the fractions of more recent and older waters across the different compartments of the forest water cycle thereby generating new understanding of water transport across forested ecosystems.

Seasonal variation in streamflow isotopic signatures was small, indicating that annual streamflow was dominated by old waters draining from subsurface storages. Mobile and bulk soil waters all showed a distinct seasonal signature, albeit with the seasonal amplitude decreasing with depth and mobile soil waters varying less than bulk soil waters. Young water fractions and new water fractions in forest soils decreased with increasing depth, indicating different degrees of subsurface mixing with waters from previous events and seasons. The fractions of recent precipitation in soil waters were generally smaller in summer than in winter, revealing the effects of interception and evaporation. Xylem water signatures in beech and spruce trees largely matched the bulk soil water signatures. Small soil water refill in summer led to both species predominantly transpiring winter precipitation. Canopy interception did not substantially alter the isotopic signal of precipitation, but it is a factor that could bias interpretations of transit times and seasonal precipitation partitioning.

Drought effects on root water uptake depth of temperate trees – Findings from a two-year rain exclusion experiment

David N. Steger[1)], Richard L. Peters[1), 2)], Tobias Zhorzel[1)], Raphael Dups[1)], David Basler[1)], Günter Hoch[1)], Daniel Nelson[1)], Ansgar Kahmen[1)]

[1)] Physiological Plant Ecology, Department of Environmental Sciences, University of Basel, Basel, Switzerland

[2)] Tree Growth and Wood Physiology, Technical University of Munich, Munich, Germany

Temperate trees are increasingly challenged by limited water availability and rising atmospheric demand, leading to an intensifying trend in drought events. Root-water uptake depth (RWUD) is a key trait determining a species' drought performance. This study evaluates the capacity of mature temperate trees from different species to adjust RWUD during drought.

To simulate (soil) drought, we initiated an experiment at the Swiss Canopy Crane II site in Switzerland in 2023, reducing rainfall by 50% during the vegetation period (April-October). We analyzed δ^2H and $\delta^{18}O$ isotope data from xylem water of 10 co-occurring temperate tree species across two growing seasons (2023-2024). Bi-weekly water samples from precipitation and soil at various depths were collected, and the LWFBrook90.jl hydrological model was used to simulate soil water isotope transport. The exceptionally dry summer in 2023, further amplified by the drought treatment, resulted in one of the driest growing conditions the trees have ever experienced. In contrast, the summer of 2024 was wetter than average. This contrast allowed observation of RWUD dynamics under extreme drought and possible subsequent recovery.

Initial results show species-specific differences in the summer δ^2H and $\delta^{18}O$ isotopic signals indicating species-specific RWUD and possible adjustment of RWUD of certain species under drought conditions. The extreme 2023 conditions caused canopy dieback and mortality in individuals of Fagus sylvatica, Picea abies, and Abies alba in the drought treatment. Dying/damaged trees exhibited distinct isotopic signals in their xylem water.

These initial findings reveal different rooting strategies and resource partitioning within the rhizosphere as well as isotopic signaling of high levels of drought vulnerability in the xylem water of dying/damaged trees. 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 an altered hydrological regime.

Drought vulnerability in a temperate forest stand: A comparison of conspecific mature and juvenile trees

Raphael Dups[1], David Steger[1], Tobias Zhorzel[1], Richard Peters[1, 2], Ansgar Kahmen[1], Günter Hoch[1]

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[2] Tree Growth and Wood Physiology, Technical University of Munich, Munich, Germany

Climate change induced drought stress increasingly affects temperate forests. Although hydraulic models suggest that taller trees are more drought vulnerable, due to the increased flow resistance with tree height, more extensive rooting systems may mitigate drought stress by accessing deeper and more soil water. Understanding the differences in drought vulnerability between conspecific mature and juvenile trees is essential for predicting future forest structure and function.

We used the Swiss Canopy Crane II infrastructure to assess differences in key physiological parameters related to tree hydraulics between conspecific mature and juvenile trees of nine temperate species. To this end, we measured pre-dawn and midday leaf water potentials (Y_{leaf}), stomatal conductance and the isotopic composition of the xylem water to assess root water uptake depths. All these parameters were measured at least monthly during the growing season 2023, marked by an extended warm and dry period in late summer and autumn.

For both age classes pre-dawn and midday Y_{leaf} decreased significantly as the season progressed. Mature trees consistently experienced lower Y_{leaf} compared to conspecific juveniles, with some species reaching midday Y_{leaf} close or at the species-specific P_{12} threshold, while juveniles of all species operated at wider hydraulic safety margins. The differences in Y_{leaf} between the size classes were mostly explained by hydrostatic effects. Interestingly, with the continuous drought in autumn, in three species the differences in pre-dawn Y_{leaf} between mature and juvenile trees diverged from hydrostatic effects. Further, we found less sensitive stomatal regulation in mature broadleaved trees, compared to conspecific juveniles.

Overall, in accordance with hydraulic models, our findings indicate a trend towards higher drought vulnerability in mature trees, primarily due to hydrostatic effects and, in broadleaved trees, due to less sensitive stomatal regulation. However, we emphasize the need for an improved mechanistic understanding of the differences between the size classes.

VPDrought – a novel approach to disentangle atmospheric and soil drought in a natural scots pine forest

Marcus Schaub[1)], Charlotte Grossiord[2), 3)], Jonas Gisler[1)], Katrin Di Bella Meusburger[4)], Petra D'Odorico[5)], Arthur Gessler[1), 6)], Michèle Kaennel Dobbertin[7)], Richard Peters[8)], Andreas Rigling[1), 6)], Volodymyr Trotsiuk[1)], Roman Zweifel[1)], Christian Hug[1)], Stefan Hunziker[1)]

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4) Forest Soils and Biogeochemistry, Swiss Federal Research Institute WSL, Birmensdorf, Switzerland

5) Land Change Science, Swiss Federal Research Institute WSL, Birmensdorf, Switzerland

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7) Communication, Swiss Federal Research Institute WSL, Birmensdorf, Switzerland

8) Tree Growth & Wood Physiology, Technical University of Munich, Freising, Germany

The intensification of droughts through rising evaporative demand (i.e., vapor pressure deficit or VPD) is a considerable concern because of their disastrous impacts on natural systems. For forests, ecosystem services such as wood provisioning and carbon sequestration are severely jeopardized by these changes, leading to significant uncertainties regarding climate regulation. Climate-vegetation models are not only in need of data on atmospheric and soil drought sensing mechanisms but are also critically challenged by insufficient understanding of the processes driving forest vulnerability to climate change. Only by deciphering the single vs. combined VPD and soil moisture effects will we be able to improve global predictions.

We apply a scale spanning approach to disentangle the processes affected by atmospheric (i.e., VPD) and soil droughts from the tissue to the tree and the ecosystem level. We set up the first atmospheric humidity and soil moisture manipulative experiment in a mature natural forest. We combine air humidity (and thus VPD) manipulation using a humidification system in the canopy of adult Scots pine trees exposed naturally to high summer VPD and a below canopy through-fall exclusion system. The system is installed at the long-term Pfynwald irrigation experiment, which is since 2003 a pivotal WSL monitoring and experimental site anticipated to be near its tipping point with respect to climate change (see https://vpdrought.wsl.ch).

This experiment helps us understand how the soil moisture responses of trees, shrubs, and microbial communities are altered by atmospheric dryness from the tissue- to the ecosystem-level. This novel manipulative VPD and soil moisture experiment provides an empirical research platform to address the most critical questions in the context of climate impacts in temperate forests. The data will ultimately allow the development of novel predictive methods to assess climate change impacts on forests.

Relevance of osmotic adjustment during drought in mature temperate trees

Tobias Zhorzel[1)], David Steger[1)], Raphael Dups[1)], Richard Peters[2)], Günter Hoch[1)], Ansgar Kahmen[1)]

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Temperate forests experience increasingly hot and dry climatic conditions, altering European forest structure and composition. Given this trend, it is crucial to understand water-related mechanisms that enable trees to cope with future droughts. In order to prevent leaf turgor loss at drought, trees can adjust their leaf osmotic potential in response to drier conditions, allowing them to remain physiologically active despite decreasing water supply. However, there is currently limited evidence of the extent to which mature trees can adjust osmotically and its significance for species-specific drought vulnerability.

In a recent field study, we addressed this question at the Swiss Canopy Crane II site that enables canopy access to mature trees of nine temperate species. A rain exclusion experiment at the site reduces the canopy throughfall by 50% during the growing season (April to October) since 2023.

We measured osmotic potential at full turgor (π_o) of leaves using freezing point osmometry throughout the growing season in 2023, characterized by extended warm and dry periods, and during the comparatively wet season 2024. To additionally assess tree hydration status, pre-dawn and midday leaf water potentials (ψ_{leaf}) were measured.

Pre-dawn and midday ψ_{leaf} values decreased notably during both growing seasons. In the rain exclusion treatment, pre-dawn ψ_{leaf} values reached notably more negative levels, especially in 2023, indicating significant drought stress across species. We observed a substantial decline in πo for most species across seasons parallel to the increased soil drought, suggesting osmotic adjustment at the leaf level. Interestingly however, we did not observe significant differences in the amplitude of leaf osmotic adjustment between the two climatically contrasting seasons and between the rain exclusion and control plots for most species. Our results therefore likely reflect the species-specific limits of leaf osmotic adjustment to drought, relativizing its overall significance to increase drought resistance in temperate trees.

Recent drought effects on beech, oak and spruce compared to four decades of intercantonal long-term forest observation

Sabine Braun[1)], Sven Hopf[1)], Simon Tresch[1)]

[1)] Institute for Applied Plant Biology AG, Witterswil, Switzerland

The Intercantonal Long-term Forest Observation Program has been monitoring more than 20’000 beech, Norway spruce and oaks over a time period of 40 years. This is the longest continuous time series on forest health. While it is known since a long time that Norway spruce is sensitive to drought and its survival in the lower elevations of Switzerland will be at risk, the dry summer of 2018 caused a drastic break in the health of beech and pubescent oak. Both the proportion of trees with a strong crown transparency (>60 %) and the mortality increased strongly. Multivariate data analysis with a lag regression model suggests that in beech the drought of six preceding years affects both the proportion of trees with strong crown transparency and the mortality, together with phosphorus and potassium nutrition. Together with the cumulation of dry years around 2018, this lag effect explains why 2018 had so much stronger effect on forests compared to the drought of 2003. In Norway spruce the lag effect on strong crown transparency was observed over a time period of three years and on mortality over a time period of five years. In oaks the lag effect can be observed over two years.

Simulating the recent drought-induced mortality of European beech (*Fagus sylvatica* L.) and Norway spruce (*Picea abies* L.) in German forests

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Drought is increasingly recognized as a critical driver of forest dynamics, altering the dominance and survival of tree species. In this study, we tested a recently developed predisposing-inciting (PI) scheme for drought-related tree mortality in the forest gap model ForClim v4.1, focusing on European beech and Norway spruce. Our hypotheses were: (1) the PI scheme remains effectove beyond its original application range, (2) soil water holding capacity (AWC) significantly influences drought-induced mortality in addition to climate, and (3) low soil heterogeneity amplifies mortality risks by reducing microsite variability.

We conducted simulations at hundreds of ICP-Level II sites in Germany, spanning large climate and soil gradients, to evaluate the model's performance in reproducing observed drought-induced mortality and to identify key drivers. ForClim successfully replicated mortality patterns, albeit with some mismatches in magnitude and trends. Discrepancies arose due to sparse mortality data, the drought sensitivity of the bark beetle submodule, and the lack of regional model calibration.

Soil water availability emerged as a pivotal factor for drought resilience. Sites with low AWC experienced accelerated mortality, while high AWC buffered drought impacts, aligning modeled outcomes more closely with observations. Soil heterogeneity further influenced outcomes, with uniform soils correlating with elevated mortality risks, underscoring the role of spatial variability in mitigating drought stress.

Despite its strengths, ForClim requires refinement to enhance predictive accuracy, particularly through higher-resolution mortality and crown condition data, as well as regional calibration. This study highlights the potential of process-based models to elucidate the mechanisms driving drought-related mortality and improve predictions for both past and future events.

Virtual trees

Mirko Lukovic[1)], Arthur Gessler[1)], Roman Zweifel[1)]

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It is very difficult to model and predict the growth of trees because they are biological systems that respond not only to actual conditions but also to the experience of the preceding years. This memory effect, or legacy effect, makes it, besides other known and unknown factors, difficult to develop a reasonable model for tree growth on the short- as well as long-term scales.
We therefore focus on the analysis of near real-time high-resolution dendrometer data from various tree species across Switzerland provided by the TreeNet project (treenet.info). We train different neural networks to use the dendrometer signals and the available metadata as input to infer and forecast stem growth properties.We also use machine learning for gap-filling the dendrometer signals and for reconstructing them altoghether.

TreeAI: A high-resolution global dataset for advancing AI-based forest monitoring

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Accurate and scalable tree species identification remains a major challenge for global forest monitoring. Despite advances in remote sensing, the lack of standardized, high-quality datasets limits machine-learning models in capturing forest diversity across different environments. Studies emphasize the need for global, high-resolution datasets to develop robust algorithms for species identification. To address the need for a benchmark dataset in tree species identification, we introduce TreeAI, an open-access database supporting research in forest dynamics. It includes 53 datasets (47 public) from 32 countries, covering 61,158 annotated trees across >5,000 ha, and continues to grow. TreeAI pairs high-resolution RGB and near-infrared imagery (1–10 cm, avg. 3.5 cm) with annotations, offering three key advantages: global coverage across diverse ecosystems, centimeter-scale detail for precise species differentiation, and a community-driven approach that ensures continuous expansion and adaptation to evolving research needs.

Preliminary deep learning analysis in Switzerland's diverse forest landscapes showed promising results, with an average F1-score of 0.72 for nine common species and *Larix* spp., *Picea abies*, and *Tilia* spp. exceeding 0.80. The mean average precision (mAP) was 0.76, highlighting TreeAI's potential. To further advance its applications, the scientific competition launched in 2025 will challenge participants to develop deep-learning algorithms for improved tree species identification across diverse ecosystems.

TreeAI serves as a benchmark dataset for advancing AI-driven forest monitoring, enabling automated species mapping for applications in forest management, biodiversity monitoring, and conservation. It complements National Forest Inventory (NFI) data, enhancing regional studies and ecological research. Additionally, TreeAI supports AI model refinement, fostering innovation, open science, and collaborative forestry research. Further needs and collaboration potential: Expanding TreeAI to include tropical forests, integrating it with Earth observation platforms (e.g., Sentinel-2, GEDI), and improving data accessibility will enhance its impact. Community feedback will help address standardization, processing, and algorithm performance challenges.

Impact of climate change and extreme events on Swiss (forest) birds

Alex Grendelmeier[1)]

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Despite ongoing climate change and the fact that about 40% of bird species in Switzerland are red-listed, the overall Swiss bird population is faring surprisingly well compared to the rest of Europe. This positive trend is attributed to reduced persecution, increased efforts in habitat protection and management, changes in land use, and especially to the influence of the Alps.

Among the major habitat guilds, Swiss forest birds are doing the best, with only 15% (9 species) on the red list. The winners and losers of these bird species highlight what has worked and what hasn't in the past, providing insights into the future risks and opportunities posed by climate change. Some of these risks and opportunities are linked to indirect factors like forestry adaptations, while others are related to direct factors such as extreme events.

Extreme events, including windfalls, forest fires, gravitational events, and drought stress, create open and richly structured habitats, large amounts of dead wood, and/or rare successional stages like the pioneer phase. The impact of these events on bird communities is well-documented through projects studying for instance the 2003 forest fire in Leuk, Valais, the 1999 Lothar windfall in Rorwald, Obwalden, or the ongoing drought stress in northern Switzerland. These case studies reveal a high diversity of breeding birds in affected forest stands, including bird species that are rare or have declining populations due to the prevailing closed Swiss forest. Lastly and most importantly, in all three examples the “catastrophe” has been used to promote biodiversity.

Leaf spectroscopy reveals drought response variation in *Fagus Sylvatica* saplings from across the species' range

Dave Kurath[1)], Sofia van Moorsel[1)], Jolanda Klaver[2)], Tis Voortman, Barbara Siegfried, Yves-Alain Brügger, Aboubakr Moradi, Ewa Czyz, Marylaure de La Harpe, Guido Wiesenberg[1)], Michael Schaepman, Meredith Schuman[1)]

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[2)] Eastern Switzerland University of Applied Sciences, WERZ Institut für Wissen, Energie und Rohstoffe, Zug, Switzerland

The common European beech (*F. sylvatica*), sensitive to prolonged drought, is expected to shift its distribution with climate change. To persist in novel environments, young trees rely on the capacity to express diverse response phenotypes. Several methods exist to study drought effects on trees and their diverse adaptive mechanisms, but these are usually destructive and challenging for the large sample numbers needed to investigate biological variation.

We conducted a common garden experiment outdoors, but under controlled watering conditions, with 180 potted two-year-old saplings from 16 beech provenances across the species' range, representing three distinct genetic clusters. Drought stress was simulated by interrupting irrigation and stomatal conductance and soil moisture were used to assess drought severity. We measured leaf reflectance of visible to short-wave infrared electromagnetic radiation to determine droughtinduced changes in biochemical and structural traits derived from spectral indices and a model of leaf optical properties.

We quantified changes in pigmentation, water balance, nitrogen, lignin, epicuticular wax, and leaf mass per area in drought-treated saplings, revealing differences in likely adaptive responses to drought. *Fagus sylvatica* saplings from the Iberian Peninsula showed signatures of greater drought resistance, i.e., the least droughtinduced change in spectrally derived traits related to leaf pigments and leaf water content. We demonstrate that high-resolution leaf spectroscopy is an effective and non-destructive tool to assess individual drought responses that can characterize functional intraspecific variation among young beech trees. Next, this approach should be scaled up to canopy-level or airborne spectroscopy to support drought response assessments of forests.

Flush to Crush: The paradox of favourable springs leading to tree mortality

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European forests are increasingly vulnerable to climate change, with mortality rates rising across major tree species. Using the French National Forest Inventory, we examined mortality from 2014 to 2023 for over 600,000 trees spanning 52 species and major climate zones. Mortality rates significantly increased, particularly in northeastern France, matching spatial patterns of warming temperatures and declining precipitation. Employing explainable machine learning, we identified forest demography (e.g., tree size, competition) and climate anomalies as primary risk factors. In addition to warmer, drier summers being associated with higher mortality through intensified drought stress, an unexpected contributor to mortality was the occurrence of warmer and wetter springs. This result is consistent with the 'structural overshoot' hypothesis that rapid canopy growth during favorable warmer, wetter springs predisposes trees to hydraulic failure during subsequent droughts. Species-specific analysis revealed diverse responses, with drought-adapted Mediterranean tree species showing a lower risk of structural overshoot than temperate trees. Different drought stress mechanisms revealed by our empirical data appear to play compounding roles, with emerging drivers of mortality being chronic dryness (possibly depleting tree reserves and weakening them), acute droughts (causing hydraulic failure), and insufficient post-drought rainfall (hindering recovery). Milder winters and springs also contributed to increased mortality, likely because they enhanced pest survival and disrupted winter dormancy, further exerting stress. With rainfall projected to shift from summer to winter and rising temperatures, future droughts are expected to become increasingly harmful. These findings underscore the urgent need for adaptive policies to safeguard forest ecosystems and their essential functions.

The underlying physiological reasons cause delayed spring photosynthesis resumption

Yunpeng Luo[1)], Petra DOdorico[2)], Arthur Gessler[1), 3)]

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Previous studies showed that observed spring photosynthesis resumption in forest ecosystem can be delayed compared to predictions of current models, resulting in an overestimation of modelled photosynthesis in temperate and boreal forests. This phenomenon, termed delayed spring photosynthesis resumption (DSPR), however, not uniformly observed across all forest sites.

To causally understand the phenomenon of DSPR in boreal and temperate forests, we selected two well-established eddy covariance sites in Europe. Both sites feature the same dominant evergreen species but differ in their spring photosynthesis resumption trajectories: one site shows a significant DSPR while the other does not. Through both leaf-level and ecosystem-level measurements, we aim to gain insights into the differences in eco-physiology related to photosynthesis, photoprotection and hydraulics between the paired sites. We hypothesize that the site with DSPR, compared to the other site, would exhibit the following characteristics: 1) significantly colder conditions and more intensive radiation during winter and early spring, leading more great stress on plants; 2) a higher proportion of photoprotective pigments, which would also be reflected in vegetation indices; 3) significantly lower photosynthetic efficiency and ecosystem light use efficiency as a higher proportion of light cannot be used; 4) a significant slower water transport or impairment of water transport systems. By testing these hypotheses, we can gain a deeper understanding of the underlying physiological mechanisms driving this phenomenon and evaluate the similarities and differences across various spatial scales. This knowledge will enhance our photosynthetic and vegetation models, leading to more accurate predictions of carbon dynamics in the context of climate change.

Photosynthetic and respiratory acclimation cannot compensate reduced plant-level carbon uptake in beech and oak saplings under prolonged warming and drought

Janisse Deluigi[1), 2)], Christoph Bachofen[1), 2)], Margaux Didion-Gency[1), 2), 3)], Jonas Gisler[4)], Eugénie Mas[1), 2), 5)], Laura Mekarni[1), 2)], Alvaro Poretti[1), 2)], Marcus Schaub[4)], Yann Yitasse[4)], Charlotte Grossiord[1), 2)]

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The combination of higher air temperatures and lower precipitation has become increasingly frequent under global warming, potentially exacerbating their individual effects. Higher air temperatures constrain photosynthesis while simultaneously accelerating respiration, and might result in lower tree net C uptake. Thermal acclimation may mitigate this negative effect, but its capacity to do so under concurrent soil drought remains uncertain.

Using a five-year open-top chamber experiment, we determined acclimation of leaf-level photosynthesis (thermal optimum T_{opt} and rate A_{opt}) and respiration (rate at 25°C R_{25} and thermal sensitivity Q_{10}) to chronic +5°C warming, soil drought, and their combination in European beech (*Fagus sylvatica* L.) and downy oak (*Quercus pubescens* Willd.) saplings. Using a process-based model, we evaluated the impacts of acclimation on plant-level net C uptake (A_{tot}).

Our study showed that both species acclimated to warmer conditions by shifting their T_{opt} to higher temperatures, but to a lower extent when combined with drought, and slightly reducing R_{25} and Q_{10}. In contrast, drought reduced T_{opt} (in oak), A_{opt}, and, to a lower extent, R_{25} and Q_{10} (in beech). However, despite these acclimation processes, A_{tot} decreased drastically under warming and drought, mainly due to reduced plant leaf area. Our results suggest that, while photosynthetic and respiratory acclimation might moderate the adverse impacts of warming and soil drought on leaf-level C exchange, plant-level net C uptake may still decline in a persistently hotter and drier climate because of structural adjustments toward sparser canopies.

Mountain forests in a changing climate: hallenges, insights, and adaptation strategies

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Mountain forests are vital ecosystems that provide essential services and functions, including protection against gravitational natural hazards, carbon storage, and biodiversity conservation. However, they are increasingly vulnerable to climate change, with rising temperatures, altered precipitation patterns, and more frequent extreme events and disturbances reshaping their structure and function.

This talk will explore the challenges that climate change poses to mountain forests, with a particular focus on protective forests and how their critical functions may be affected. We will examine how climate change and shifting disturbance regimes influence tree species composition, growth patterns, and regeneration processes. A major obstacle in addressing these changes lies in effective monitoring and assessment. Mountain forests are often "extremes" in multiple ways—characterized by harsh weather, complex topography, and difficult accessibility. These limitations not only constrain data collection but also complicate long-term monitoring efforts, making it challenging to capture the full scope of climate- and disturbance-induced changes. Using insights from different data sources and research approaches, we will examine both vulnerabilities—such as increased drought stress and insect outbreaks—and the challenges these pose for sustainable forest management.

Beyond identifying challenges, we will also explore possible solutions. How can we manage mountain forests to enhance their resistance and resilience while maintaining their essential ecosystem services? Through predictive modeling and real-world case studies, we will examine how data-driven approaches can inform evidence-based decision-making. In times of uncertainty, fostering genuine, collaborative partnerships between research and practice is essential to addressing these challenges effectively. As we navigate rapid environmental change, integrating science with strategic action will be key to sustaining these critical forest ecosystems.

Tree crown defoliation and tree mortality in Swiss forests

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Crown condition is considered as one of the most important indicators of a tree's vitality. As part of the monitoring program Long-term Forest Ecosystem Research, the defoliation of tree crowns in Swiss forests has been monitored on an annual time scale since 1985. This long-term data set makes it possible to track the progress of defoliation until the trees die and to take into account a variety of stress factors that may have played a role in this process.

In Swiss forests, the average defoliation of trees and tree mortality has increased in the past decades. However, this only occurred in areas at lower altitude, where climate change has particularly intensified the atmospheric water demand. The importance of water stress as a driver for this development is also confirmed by some of the highest annual increases of defoliation that directly followed exceptionally dry and hot summers.

The probability that individual trees die within a few years starts to increase when the crown defoliation exceeds about 30%. Around 75-85%, most trees seem to reach a point of no return, from which they cannot recover, and which leads to death within a few years, even if no further stress occurs. In the needles of such strongly defoliated Scots pines (*Pinus sylvestris* L.), we found elevated levels of many stress-related metabolites (particularly osmoprotectants, defense compounds and antioxidants), whereas the levels of these metabolites were homeostatic in the needles of trees in lower defoliation classes. In contrast to the needles, these metabolites were reduced in fine roots of the strongly defoliated trees, suggesting that mainly belowground carbon starvation may impair key functions for tree survival, consequently leading to early death.

Drought resilience of 14 native and non-native tree species in the long-term experimental plantation Copera, based on tree-ring analyses and quantitative wood anatomy

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Forest ecosystems are threatened by climate change that is characterized by the increasing occurrence of extreme droughts and heatwaves. Those increasingly stressful conditions are leading to a loss of vitality and unprecedented mortality of forests. Thus, solutions to increase their resilience are urgently needed. A strongly advocated option for forest management is to increase tree species diversity. This could be achieved by increasing the share of rare native species as well as by introducing non-native species with high adaptation potential to future climate. However, only limited information on their autecology and growth performance is available, making it difficult to predict their performances in this scenario.

This study aims to explore the impacts of extreme drought events on the growth of native and non-native tree species to assess their potential to increase the resilience of future Central European forests. The site of Copera (Ticino, Switzerland) represents a unique opportunity to explore this subject as more than 70 native and non-native tree species were planted in homogeneous conditions during the 1970ties, making interspecific comparisons possible.

Dendrochronological analyses were performed on 273 trees from 14 species representing coniferous, diffuse-porous and ring-porous hardwood trees. Pairs of native and non-native species of the same wood type were selected to explore the differences in climate-growth relationship and response to droughts.

The analyses highlighted interspecific differences of resilience components, as well as in climate-growth relationships despite the relatively good growth conditions of the site.

Quantitative wood anatomy will be used to show wood functional traits responses to climate which will help unravel the potential of 14 native and non-native tree species response to drought. This is one of the few systematical assessments of native and non-native species which will help informed decision making on forest management in Central Europe in the face of accelerating climate change.

Enhancing resilience of temperate European forests by promoting rare native tree species (RareSpec Project)

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Forest ecosystems face increasing threats from climate-induced stressors, including severe droughts and heatwaves, leading to reduced growth and higher mortality rates of trees. These changes affect the resilience of forests and thereby important ecosystem services such as carbon storage, water regulations, biodiversity conservation, and timber production. European forests are widely dominated by a few tree species (i.e. *Fagus sylvatica*, *Picea abies*, *Quercus* sp. and *Pinus sylvestris*), which have shown increasing vulnerability to climate change. Increasing tree species diversity and integrating drought-resistant tree species have been suggested to enhance forest resilience. Thus, native tree species with higher stress tolerance should be considered as potential alternatives or additions to forest stands. In this context, we selected species of the genera *Acer*, *Carpinus*, *Ostrya*, *Prunus*, *Sorbus*, and *Tilia* based on their lower sensitivity to droughts compared to common tree species, although they have been far less studied. By analysing growth patterns and tree species interactions, we aim to provide a deeper understanding of growth and physiological responses of species of these genera to extreme climatic events by 1) assessing long-term growth patterns and climate sensitivity using dendrochronology of ten rare tree species compared to four common tree species, 2) evaluating species-specific tree physiology of rare and common tree species using stable isotope analysis and, 3) understanding the effect of neighbourhood diversity and mixing of rare tree species in mixed lowland forests. Fieldwork will be conducted in seven countries in Europe (i.e. France, Germany, Italy, the Netherlands, Norway, Romania, and Switzerland), to encompass a wide range of environmental conditions. Using dendrochronology and isotope analysis, our expected outcomes include i) identifying drought-resistant tree species that can enhance forest resilience, ii) understanding species compatibility in mixtures, and iii) providing insights for adaptive forest management of mixed forests in lowlands under future climate scenarios.

Assessing forest dynamics tools for tackling emerging challenges in forest management

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Tools such as empirical models, process-based models, and forest yield tables, are used to project forest dynamics and address specific questions in forest ecology and management. The design of these tools impacts their capacity to address specific questions, highlighting the importance to evaluate the applicability of current tools for relevant questions. In this study we assess how different tools impact our ability to answer questions in three key topic areas: risk inclusion, species diversity, and ecosystem services development. We compile a database of 3000 questions related to the three topic areas by combining 50 assessment criteria across nine indicators. We review 40 tools used to project forest dynamics and assess their capabilities of answering the proposed questions. We then use the tools LandCim and 3PGmix to assess how suited they are to answer how landscape functional zoning and forest types affect ecosystem service provision until the end of the century. For that we run simulations in a theoretical landscape using two climate scenarios, three initial forest types, and five management scenarios. The tool review shows that 10% of the questions in the database can be answered by the tools due to the lack of implementation of key processes and dynamics (e.g., related to water ecosystem services). Simulations show that both tools can model landscape functional zoning and adapt to variations in forest types, climate, and management scenarios, but their projected outcomes differ due to variations in model structure, forest dynamics representation, and management process implementation. This research emphasizes the importance of selecting tools based on their ability to address specific questions and highlights the need for continuous development to fill current gaps.

Poster Presentations

Exploring the influence of forest dynamics on flood events in alpine watersheds

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Alpine human communities demand flood mitigation, often through costly engineering. Integrating a forest dynamics model with a hydrological model revealed how forest cover influences runoff, via soil water storage saturation and PET. Based on this, we develop sustainable management approaches.

The 40-year trend in soil water balance in Switzerland and its link to forest vegetation responses

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The frequency of extreme droughts has increased in recent decades across Europe and other parts of the world. Droughts reduce soil moisture, limit water availability to trees, and cause physiological stress in trees, significantly impacting the ecosystem's carbon cycle by disrupting the balance between carbon uptake and release. However, the assessment of physiological stress often focuses on above-ground tree traits and functions, overlooking the crucial roles of below-ground processes and soil-vegetation interactions. To address this, we used the mechanistic soil-plant-atmosphere continuum model (LWF-Brook90R) to simulate the soil water balance and expressed drought stress as the ratio of actual to potential transpiration. First, we identified the spatial distribution of climatic and soil droughts over the past 40 years across Switzerland's forest area at a 250 m resolution. We then aimed to (i) quantify the temporal trends of soil and climatic droughts and their relationship to forest responses at selected sites where measured plant data is available (e.g., defoliation percentage, radial growth, and tree water deficit (TWD)) and (ii) examine the legacy effects of extreme drought years (2003, 2015, and 2018) on the recovery of soil water and tree growth in the post-drought years. This poster presents preliminary findings on the spatial distribution of soil and climatic droughts in Swiss forests over the past 40 years, highlighting areas with increased drought severity and examining how water balance (both soil and climatic) relates to forest responses, such as crown defoliation, growth, and TWD. Understanding drought occurrence and distribution and how it impacts forests is crucial for assessing regional vulnerabilities, managing water resources, and developing climate-smart forest management strategies.

Decision support for climate-adapted management of mountain forests: balancing ecosystem services and disturbance predisposition

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Strategic long-term planning of mountain forests in the European Alps requires a balancing act between sustaining forest biodiversity and ecosystem services (BES) and mitigating disturbance risks, particularly under climate change. In this context, close-to-nature forestry (CNF) is considered an effective strategy. However, it remains unclear whether current CNF strategies sufficiently reduce forests' predisposition to climate-change-induced shifts in disturbance regimes, including the occurrence of novel disturbances such as forest fires. To address this complexity, we integrated the forest gap model ForClim with predisposition assessments for fire, bark beetle, and windthrow disturbances – as well as evaluations of BES provision – into a decision support system (DSS). Simulations were conducted for a forest enterprise in the Central Swiss Alps, covering a large elevation gradient, under three climate scenarios (historical, SSP2-4.5, and SSP5-8.5) and six management strategies, including CNF variants with different management intensities and climate-adapted approaches. Our results indicate that climate change will dynamically alter disturbance predisposition across elevation gradients: For example, under severe warming (SSP5-8.5), long-term reductions in stand-related disturbance predisposition occurred at lower elevations due to declining forest productivity, while predisposition increased at higher elevations with improved growing conditions. CNF emerged as a balanced approach for reducing predisposition to bark beetle infestation and windthrow while maintaining BES. However, CNF promoted stand characteristics that increased stand-related predisposition to forest fires. Our results further show that increasing management intensity generally reduces stand-related disturbance predisposition but can also lead to trade-offs, such as reduced BES provision. We conclude that proactively reducing disturbance predisposition may involve short-term trade-offs regarding BES provision but may be crucial to avoid larger, long-term BES losses caused by severe disturbances. Our study underscores the need for decision support systems to support informed decision-making in mountain forest management.

Volatile emissions of coniferous and broadleaf tree seedlings - Extreme events and future climate scenarios

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Biogenic volatile organic compounds (BVOC) are a highly complex and highly diverse set of chemicals emitted into the atmosphere by the Earth's biosphere. They affect atmospheric composition of trace gases such as the mixing ratios of methane, carbon monoxide, and tropospheric ozone through their atmospheric oxidation. Atmospheric oxidation products also lead to formation of atmospheric aerosol, which plays a crucial role in defining Earth's radiative balance and impacts air quality.

Further increases in the average global temperature are expected for the following decades, with warmer and dryer conditions for Alpine regions. Warm winters appear to lead to earlier leaf-out. This may put trees at higher risk of late frost in spring. Thus, in addition to long-term changes in abiotic factors (temperature, water availability), the frequency of stress and double-stress events, such as a late spring frost and an extreme summer drought occurring in the same year, is expected to increase. How trees respond to such changes in abiotic factors and to abiotic (double) stress regarding their BVOC emissions composition and quantities is critical in understanding how atmospheric chemistry and SOA properties may be impacted.

During the summer of 2022, we studied the impact of elevated temperatures (heat), reduced water availability (drought), extreme events (early spring frost) and double stress (early spring frost followed by extreme summer drought) on tree seedlings BVOC precursors in plant tissues (i.e., secondary metabolites) and BVOC emissions.

We will present first results from experiments with Scots Pine, Beech, and Oak seedlings, showing BVOC emissions under various abiotic stress conditions. Our findings provide crucial insights for improving predictions of future BVOC emissions and their atmospheric impacts.

Transpiration phenology from dendrometer data - A new method for leaf presence detection

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Leaf phenology, including the timing of leaf emergence and senescence, is crucial for understanding carbon and water cycles in extratropical ecosystems. Current monitoring methods, such as ground observations, PhenoCams, drones, and satellites, often face limitations in spatial coverage, resolution, or practicality. To address these challenges, we developed a machine learning-based method to infer leaf phenology from daily stem shrinkage patterns measured with point-dendrometers, focusing on detecting the start and end of the transpiration season, defined by active leaf transpiration.

Our model was trained on daily stem shrinkage data from five broadleaf tree species, collected over five years at the Swiss Canopy Crane II research site, a mixed temperate forest in Switzerland. The inferred phenological patterns were compared to independent measurements of leaf phenology to evaluate accuracy. Additionally, the model was applied to historical dendrometer datasets to reconstruct long-term phenology time series.

This approach demonstrates the potential for automated collection of leaf phenology time series, enabling detailed insights into tree and ecosystem processes such as transpiration season length, growing season length, and their responses to environmental change. Point-dendrometers offer a cost-effective, integrated solution for simultaneously monitoring tree growth, water relations, and phenology at high temporal resolution.

Genetic adaptation of young beech trees (*Fagus Sylvatica*) through weather extremes – Establishing a monitoring method

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Extreme weather events and their effects on the genetic structure of forest tree populations are a central yet under-researched topic. Preserving genetic diversity is crucial for the sustainability of forests adapting to climate change. Current forest monitoring systems track changes in biodiversity, soil chemistry, nitrogen deposition, ozone, weather, etc. (biotic and abiotic gradients) but rarely consider tree genetic aspects. Genetic monitoring could document changes in the genetic structure of forest stands over time. This is especially relevant for European beech, a key forestry resource that, despite its adaptability, suffered severe losses during the 2018 drought.

Beech dieback, coupled with increasing drought periods and the need for resilient forest regeneration motivated this project. The aim is to create a foundational dataset for long-term monitoring and to develop methodologies to study the genetic profiles of beech following extreme weather events, with periodic re-assessments. A central hypothesis is that beech germinating after the 2018 drought exhibit a different genetic composition compared to previous generations, with these changes attributable to drought conditions.

The project encompasses ten sites in the Basel and Zürich regions with varying levels of drought (dry, dry and damaged, and moist). Each site involved sampling 20 seedlings that germinated after the 2018 drought and their presumed mother trees (i.e., the tree closest to the seedling) in February 2024. The 400 samples were prepared for DNA extraction for Illumina whole-genome sequencing. Population genetic studies enable detailed analyses of genetic differences among mother trees and seedlings which allow investigating potential adaptation mechanisms in response to the 2018 drought event. The results will form the basis of a genetic long-term monitoring system. This could provide critical insights for sustainable forest management and the adaptation of tree species to future climate changes.

Increased mature forests carbon sink across biomes

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Global forest growth has increased in recent decades, but its contribution to sustained biomass accumulation remains uncertain, particularly in mature forests. Biomass gains may result from accelerated tree growth but also from forest recovery, and disentangling these effects is challenging due to confounding factors such as stand history and environmental influences. This study explores the relationship between growth and biomass by examining shifts in the forest stand carrying capacity. We compiled forest ground-based measurements of unmanaged old-growth forests from five forest biomass to create a global record of forest inventory data from 1931 to 2024. We observed a long-term increase in stand density for a given mean tree size in unmanaged closed-canopy forests across all biomes. We examined how environmental factors influenced shifts in the size-density relationship, finding that increases in stand carrying capacity over time were more pronounced in drier regions and soils with low organic carbon, elevated nitrogen deposition, and high phosphorus availability. Based on the observed increase in the forest carrying capacity, we estimated the mature forest carbon sink in aboveground biomass (0.88 ± 0.06 Pg C yr^{-1}). Our analysis reveals forest structural shifts in response to environmental change that underlie the observed land carbon storage. This suggests that mature forests keep acting as persistent carbon sinks, with their capacity to sequester carbon being influenced by environmental conditions.

Genetic basis of intraspecific variation of leaf specialized metabolites in sessile Oak populations

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Specialized metabolites play a key role in plant response and interaction with their environment. For example, in sessile oaks Quercus petraea, some specific compounds such as phenolics contribute to biotic and abiotic stress responses. In the context of global climate change, the extensive diversity of compounds and variation of biosynthesis within species may play a key role in mitigating the increased frequency of stressful events such as drought, heat waves, or emergent pathogens. In this study, we explored the natural variation of specialized metabolites and detected the underlying genetic bases in European populations of sessile oaks growing in a common garden. We sampled leaves from two heights with the canopy on 218 trees and used untargeted metabolomics combined with whole genome low-depth sequencing to identify the underlying genetic basis of specialized metabolites. We observed for 217 quantified molecules an extensive within-provenance variation and a low differentiation between provenance. Our results suggest that genetic variation of the molecules we quantified is unlikely to be locally adaptive and that varying selection pressures may act to maintain diversity within oak populations across Europe.

Germination and survival of Abies and Fagus provenances sown across Europe

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Strong selection during early life stages could foster local adaptation in forest trees. However, due to the stochastic nature of spring environmental conditions, selection might favor plasticity. We studied the phenotypic plasticity of germination and early survival in two forest tree genera represented by 13 (Abies) and 10 (Fagus) provenances using 18 common gardens established directly under the forest canopy. Additionally, all provenances were tested in climate chambers. We considered environmental factors known to affect the germination and spring phenology in trees, such as chilling, precipitation, photoperiod and temperature. Germination rates of different provenances ranged from 0 to 70%. For Abies and Fagus, respectively, on average, 10.9 and 6.7% of the seeds sown in the gardens germinated, 2% and 1.8% were still alive in the second year, and 0.7% and 0.6% in the third year. Some provenances were able to germinate in warmer and drier environments than their environment of origin, which shows plasticity. Higher precipitation in spring was associated with higher germination rates for most provenances. Forest regeneration is a key step in forest adaptation to climate change and our results bring novel information about the germination potential of various provenances from two major genera in European forests.

Tree species composition governs urban phenological responses to warming

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Urban environments are typically warmer than surrounding rural areas, providing a unique setting for studying phenological responses to climate warming. Phenological differences between urban and rural trees are driven by local climate and species composition. Yet, the extent to which species composition influences phenological responses to urbanization remains poorly understood. To address this, we combine manipulative experiments, satellite-derived phenology data, and georeferenced tree occurrence records. Our findings show that, across Northern Hemisphere cities, differences in the temperature sensitivity of spring phenology between urban and rural areas are largely driven by urban-rural variation in species composition, surpassing the effects of preseason temperature. This pattern is particularly pronounced in Asian cities, where urban areas exhibit 0.75±0.49 days/°C higher temperature sensitivity than rural areas. In-depth analyses using experiments and high-resolution satellite imagery from Beijing further demonstrate species-specific phenological responses to urbanization, with urban-dominant species exhibiting higher temperature sensitivity in urban environments compared to rural ones. These findings show that both interspecific variation in temperature sensitivity and species-specific responses to urbanization contribute to the pronounced impact of species composition on urban-rural phenological patterns. Our study underscores the importance of considering species composition when studying phenological responses to climate warming, especially in urban contexts.

Modelling forest functions over Swiss NFI plots and disentangling the role of historical nitrogen deposition

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Forests provide various ecosystem services (ES), including the delivery of natural resources, the regulation of atmosphere-land surface interactions, and the facilitation of social and cultural activities. However, the acceleration of climate change is increasingly threatening the sustainability of these ES by modifying essential ecological processes via biogeophysical-chemical determinants of critical processes such as fluxes of gases, water, energy, and nutrients. Atmospheric nitrogen deposition is a major air pollutant that affects forest ecosystems through nitrogen cycles. Across the European Alps, though the total nitrogen deposition has steadily decreased since the late 1980s, the present annual deposition remains at medium to high levels (on average 15 kg N/ha), while temperate forests are generally nitrogen-limited. How nitrogen deposition affects forests in the Alps, particularly in the context of reduced nitrogen deposition, is critical for anticipating future forest functions and ES. In addition, the promotion of some essential forest ES is inherently contradicting. For instance, timber production requires massive logs of standing trees, whereas mitigating abiotic disturbances and hazards generally necessitates retaining high biomass and biological diversity. Balancing forest multi-functions is, therefore, integral to ensuring better, more sustainable use of natural resources benefiting our societies in the context of rapid global change. Here, we focus on (i) building a framework to identify and integratively quantify various ES across 6000 Swiss National Forest Inventory plots; (ii) quantifying and comparing the impact of nitrogen deposition on various ES at the stand level since 1990 in a multivariate inference framework while explicitly taking into account potential spatial dependence and confounding factors using a stochastics process embedded in the multivariate framework; (iii) quantifying the overall impact of two-decadal nitrogen deposition rates on forest multi-functionalities accounting for the synergies between each ES. Finally, we discuss the potential and conditions for transposing these impacts to other forest ecosystems.

Quantitative genetic aspects of accuracy of tree biomass measurement using LiDAR

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The growing focus on the role of forests in carbon sequestration highlights the importance of accurately and efficiently measuring biomass traits, such as diameter at breast height (DBH) and tree height. Understanding genetic contributions to trait variation is crucial for enhancing carbon storage through the genetic improvement of forest trees. Light detection and ranging (LiDAR) has been used to estimate DBH and tree height; however, few studies have explored the heritability of these traits or assessed the accuracy of biomass increment selection based on them. Therefore, this study aimed to leverage LiDAR to measure DBH and tree height, estimate tree heritability, and evaluate the accuracy of timber volume selection based on these traits, using 60-year-old larch as the study material. Unmanned aerial vehicle laser scanning (ULS) and backpack laser scanning (BLS) were compared against hand-measured values. The accuracy of DBH estimations using BLS resulted in a root mean square error (RMSE) of 2.7 cm and a coefficient of determination of 0.67. Conversely, the accuracy achieved with ULS was 4.0 cm in RMSE and a 0.24 coefficient of determination. The heritability of DBH was higher with BLS than with ULS and even exceeded that of hand measurements. Comparisons of timber volume selection accuracy based on the measured traits demonstrated comparable performance between BLS and ULS. These findings underscore the potential of using LiDAR remote sensing to quantitatively measure forest tree biomass and facilitate their genetic improvement of carbon-sequestration ability based on these measurements.

Drought effect on alpine conifers: A xylogenetic approach

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Drought is increasingly impacting forests, even in mountainous regions. The Matsch valley in the Alps, one of the driest areas in Bolzano, Italy, may serve as a model for future conditions in broader Alpine regions. This study aims to understand the relationship between xylem formation and environmental factors to predict the effect of climate change on tree growth. To this end, we sampled four plots along an elevation transect, including four species and 40 trees in total: 20 *Larix decidua* Mill., 10 *Pinus cembra* L., 5 *Pinus nigra* Arnold, and 5 *Picea abies* L. .These were distributed as follow: 1070 (F1, low elevation), 1715 (F2, mid- elevation), 2100 (F5, high elevation) and 2250 (FL, forest line) meters a.s.l. based on temperature alone, we would expect growing season length - defined as the difference between the start of the enlarging phase and the end of the secondary cell wall thickening - to decrease with increasing elevation. However, lower elevations may experience drought-induced premature growth cessation. We also expected deciduous larch begin growing later than the evergreen spruce or pines as it must first leaf out before growth. Preliminary results from 2023 support these hypotheses. At F1 and F5, larches exhibited a 135-day growing season, though their start and end dates differed by 20 days. Surprisingly, at F2 - where growth was expected to continue longer than at F5 and FL - the growing season ended earlier, suggesting that drought impacts extend up to 1700 m. Pines initiated growth earlier than larches at all sites. Black pine has the longest growing season, while Swiss stone pine at FL had the shortest. To validate these preliminary findings, we conducted a second sampling season in 2024. These data will be correlated with climatic variables: soil moisture, dendrometer and sap flow measurements.

A systematic review: Individual tree species identification using deep learning and high-resolution imagery

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Accurate and efficient tree species inventories are essential for sustainable forest management, enabling biodiversity assessments, ecological studies, and invasive species monitoring. In the past decade, rapid advancements in remote sensing and machine learning, particularly deep learning, have revolutionized tree species identification at the individual tree level. However, a systematic synthesis in this active research topic remains lacking.

To bridges existing gaps, this review conducts a meta-analysis of 96 peer-reviewed studies published between 2012 and 2024, evaluating forest types, data sources, and machine learning approaches for ITSI. Results indicate that temperate forests were the most studied, with research predominantly conducted in rural forests, followed by urban settings. Quercus was the most researched genus in terms of species diversity, while Pinus appeared in the most publications. Most studies utilized UAV-derived RGB imagery with resolutions ranging from 0.69 cm to 320 cm per pixel. LiDAR data, which improves crown segmentation, was used in about one-third of studies, while only 11% incorporated multi-temporal datasets, highlighting a research gap. CNNs dominated deep learning applications (88%), whereas advanced models such as GNNs, RNNs, and attention-based architectures were rarely explored but show promise.

The review demonstrates that AI-driven ITSI is evolving with increasing availability of fine-grained, high-resolution imagery and CNN-based approaches. Key challenges include the lack of standardized datasets, underutilization of multi-temporal data, and insufficient exploration of diverse forest types and species. Addressing these issues will enhance model generalization and applicability. Future research should prioritize these areas to support effective forest management practices and further advance the field.

Thermal acclimation fails to confer a carbon budget advantage to invasive species over natives

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Both native and invasive plants can adjust photosynthesis and respiration when exposed to warmer temperatures. However, it is uncertain if invasive plants are more plastic and exhibit higher acclimation to rising temperatures than native ones, a trait that could contribute to their invasive behavior in novel environments. We compared the capacity of a highly invasive palm in central Europe (*Trachycarpus fortunei*) and two native co-occurring species (*Ilex aquifolium* and *Tilia cordata*) to acclimate photosynthesis and respiration to air temperature changes using a two-year-long transplant experiment across Europe (mean temperatures ranging from 8.4 to 21.8°C). We measured the optimal temperature of photosynthesis (T_{opt}), the assimilation at optimal temperature (A_{opt}), the thermal breath of photosynthesis (T_{80}), the respiration at 25°C (R_{25}), the temperature sensitivity of respiration (Q_{10}), and simulated the whole-plant carbon budget. For all species, T_{opt}, A_{opt}, and T_{80} increased with warming, while R_{25} decreased in the native species and Q_{10} decreased in the invasive species only. Consequently, acclimation enhanced the carbon budget of the invasive and native plants in the warm and hot sites. The invasive palm had a similar or lower acclimation capacity than other species and a lower but constant carbon budget across the European temperature gradient. Our work reveals that not all invasive plants exhibit greater photosynthetic plasticity than native ones, suggesting that temperature-driven enhancement of their carbon budget may play a limited role in future invasion processes.