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Monitoring for Future Forests

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Ministry of the Environment of the Czech Republic

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Dear members of the ICP Forests community, ladies and gentlemen,

I am very pleased and consider it a great honour that we can host the Task Force Meeting of ICP Forests in the Czech Republic for the third time. A lot of time has passed since one of the first meetings in Ústí nad Labem (1987). Over almost four decades, the programme has developed into the most comprehensive and harmonised pan-European network focused on long-term monitoring of forest ecosystems. A comprehensive set of evaluated parameters both on the regular level I network and on level II areas of intensive monitoring currently provides a lot of important information not only about the impact of air pollution on forest ecosystems. The data and methods obtained within the BioSoil project (2005-2008) serve as a basis for forest soil surveys in many countries and can be used as a basis for assessing changes in forest biodiversity. Information from continuous measurement of trunk circumference can help to explain trends in forest tree growth and forest production shown by the results of the National Forest Inventory, trends in soil moisture development can help to better understand the risk of climate change for forest tree species. I consider it welcomed and very beneficial that monitoring creates a unique set of information about the forest as a set of data for use in science and research. This demonstrates the legitimacy and necessity of forest monitoring, and its benefits for our society and, ultimately, for forests themselves. A lot of interesting information based on the long-term ICP Forests data series will be presented at the FORECOMON conference. I firmly believe that new information, new monitoring techniques and new scientific questions will help to further develop knowledge, develop cooperation and thus create better chances for our forests in the future.

I wish you a successful meeting and a pleasant stay in Prague.

Marek Výborný
Minister of Agriculture of the Czech Republic

Dear participants of the FORECOMON conference,

welcome to Prague, the capital of our country! It has been 39 years since the establishment of the ICP Forests program under the UNECE Convention on Long-Range Transboundary Air Pollution. As part of several international cooperative programs (including Waters, Materials, Vegetation, Integrated Monitoring, Modeling, Mapping, and Health), ICP Forests focuses on monitoring and adopting a science-based approach to understand the impact of air pollution on natural ecosystems, human society, and cultural heritage.

While air pollution has significantly decreased in Europe over the past four decades, its influence on forest health and production remains relevant. Fortunately, the historical decline in forests due to high sulfur dioxide concentration is behind us. Nowadays, the impact on ecosystems is more subtle, affecting nutrient and water cycles, altering biodiversity patterns, and intensifying stress in the face of changing climate conditions.

The complexity of dose-response effects necessitates long-term monitoring schemes and innovative methods. As the conference precedes the ICP Forest Task Force Meeting, I consider its main topics highly interesting and important. Wishing you an inspiring meeting!

Petr Hladík

Minister of the Environment of the Czech Republic

Programme

08:00 – 09:00 Registration & coffee

09:00 – 09:30 Opening / welcome

09:00 – 09:05 Opening of FORECOMON 2024

09:05 – 09:10 Welcome by host country, Czech Republic

09:10 – 09:15 Welcome by host institution, Forestry and Game Management Research Institute

09:15 – 09:20 Welcome by ICP Forests Chair

Session 1: Long-term forest ecosystem processes as affected by air pollution, drought or other extreme weather events

09:30 – 09:45 **D. Pitar et al.:** Air quality in European forests – ozone and nitrogen dioxide trends in the ICP Forests level II network

09:45 – 10:00 **J. Foest et al.:** Rising summer temperatures dampen masting of European beech (*Fagus sylvatica*) across range

10:00 – 10:15 **Y. Sun et al.:** Crown density, growth and carbon sequestration in European forests over the period 1990-2022

10:15 – 10:30 **H. Hartmann et al.:** Monitoring forest damage to shape Future Forests

10:30 – 11:00 **Coffee break**

11:00 – 11:30 **Poster pitch,** 19 posters, there is one minute for the poster presentation

11:30 – 11:40 **G. Delhaye et al.:** Spatiotemporal drivers of ectomycorrhizal diversity in Europe

11:40 – 11:50 **P. Žemaitis et al.:** Norway spruce health and vulnerability in Lithuania – wind, decay and *Ips typographus* as the main drivers

11:50 – 12:00 **P. Krám et al.:** Soil water dissolved organic carbon patterns at spruce sites with geochemically contrasting substrate in the last three decades

12:00 – 12:10 **S. Etzold et al.:** 25 years of forest growth in Swiss Level II plots

12:10 – 12:20 **T. Dirnböck et al.:** Multi-decadal drought and disturbance effects on forest carbon sequestration in a mountain forest landscape

12:20 – 12:30 **Further questions to all session 1 speakers**

12:30 – 13:30 **Lunch**

Session 2: Novel monitoring approaches to support the development of resilient forests

13:30 – 13:45 **R. Shackleton et al.:** Towards Advanced Forest Inventory and Monitoring (AIM): a Swiss example

13:45 – 14:00 **C. Guidi et al.:** From litter to soil carbon - harmonizing soil carbon stock estimates for a common European forest monitoring system

14:00 – 14:15 **R. Guerrieri et al.:** Quantifying tree canopy nitrification across European forests by combining stable isotope and molecular analyses

14:15 – 14:30 **M. A. Anthony:** From soils to canopy: a call to collaborate to disclose foliar microbiome diversity and function

14:30 – 15:00 **Poster pitch,** 13 posters, there is one minute for the poster presentation

15:00 – 15:30 **Coffee break**

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15:50 – 16:00 **A. Principe et al.:** Scaling up tree mortality and survival in Mediterranean oak woodlands

16:00 – 16:10 **T. Molnár et al.:** Satellite-based forest health survey on ICP Forest Level II plots in Hungary

16:10 – 16:20 **E. Gril et al.:** Forest microclimate: how to quantify and predict the temperature buffering capacity of canopies

16:20 – 16:30 **N. Knapp et al.:** From single trees to country-wide maps: modeling tree mortality across Germany based on Level I data

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16:40 – 17:00 **Mentimeter survey – and end of orals**

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4. **Fadrhonsová et al.:** Development of soil chemistry on Level II plots in the Czech Republic
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17. **van Straaten et al.:** Transformation of forest humus forms in northwest Germany across three decades
18. **Wohlgemuth et al.:** Environmental impacts on foliar nutrient trends of ICP Forests Level II data
19. **Zolles et al.:** Analysis of the effects of soil parameters on radial stem growth for four spruce stands in Austria

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20. **Češljar et al.**: Identification of the decline of individual trees due to the impact of drought using a database (Defoliation) as a „health card“ of previous events
21. **Fririon et al.:** can silviculture foster forest genetic evolution? A demo-genetic modelling approach accounting for within-stand individual variability estimated from ICP forest data
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Lectures

Session 1: Long-term forest ecosystem processes as affected by air pollution, drought or other extreme weather events

Air quality in European forests – ozone and nitrogen dioxide trends in the ICP Forests level II network

Diana Pitar[1)], Iva Hůnová [2)], Elena Gottardini [3)], Ștefan Leca [1)], Lena Wohlgemuth [4)], Georgi Kardinov[5)], Andreas Schmitz [6)], Vicent Calatayud [7)], Matej Rupel [8)], Radek Novotny [9)], Marcus Schaub[10)], Marco Ferretti[10)], Alexandru Dobre [1)], Ionut Pascu [1)]

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Ozone and nitrogen dioxide, and, subsequently, their effects on forests were and still are of concern for the scientific community, policy makers and general public. Tropospheric ozone is a pollutant that is formed from chemical reactions of nitrogen oxides and volatile organic compounds in the atmosphere, primarily as a result of anthropogenic activities such as transportation and industrial production, having adverse effects on human health, vegetation, and climate. ln Europe, high tropospheric ozone concentrations are typically observed in the summer months due to increased solar radiation and stagnant atmospheric conditions. Various studies have shown that Mediterranean countries often experience high ozone levels during the summer. Nitrogen dioxide is primarily emitted from burning fossil fuels, particularly in transportation, being associated with respiratory problems and can lead to the formation of ground-level ozone. ln Europe, nitrogen dioxide concentrations are highest in urban areas. In the ICP Forests Level II network, air quality (ozone, nitrogen dioxide, ammonia, sulphur dioxide) is assessed both by active and primarily by passive monitoring. The aim of our study is to explore (1) How does ozone and nitrogen dioxide concentrations vary during the year at plot/country/biogeographical region level? and (2) Is there a temporal trend in ozone nitrogen dioxide concentrations at plot/country/biogeographical region level? We will assess long-term trends in ozone and nitrogen dioxide from more than 150 forest monitoring sites from 19 countries across Europe, and results will be presented and discussed. Preliminary results show an increasing trend in ozone concentrations in almost half the plots with data for more than 5 years (in 10% of them being statistically significant).

Rising summer temperatures dampen masting of European beech (*Fagus sylvatica*) across range

Jessie Foest[1)], Michał Bogdziewicz[2)], Mario Pesendorfer[3)], Davide Ascoli[4)], Andrea Cutini[5)], Anita Nussbaumer[6)], Arne Verstraeten[7)], Burkhard Beudert[8)], Francesco Chianucci[5)], Francesco Mezzavilla, Georg Gratzer[3)], Georges Kunstler[9)], Henning Meesenburg[10)], Markus Wagner[10)], Martina Mund[11)], Nathalie Cools[7)], Stanislav Vacek[12)], Wolfgang Schmidt[13)], Zdeněk Vacek[12)], Andrew Hacket-Pain[1)]

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Climate change effects on tree reproduction are poorly understood even though the resilience of populations relies on sufficient regeneration to balance increasing rates of mortality. Forest-forming tree species often mast, i.e. reproduce through synchronised year-to-year variation in seed production, which improves pollination and reduces seed predation. Recent observations in European beech show, however, that current climate change can dampen interannual variation and synchrony of seed production, and that this masting breakdown drastically reduces the viability of seed crops. Importantly, it is unclear how widespread such masting breakdown is in this pan-European species and under which conditions it occurs. Here, we analysed 50 long-term datasets of population-level seed production, including ICP Forests sites, sampled across the distribution of European beech. We identified increasing summer temperatures as the general driver of masting breakdown. Specifically, increases in site-specific mean maximum temperatures during June and July were observed across a majority of the species range, while the interannual variability of population-level seed production (CVp) decreased. Additionally, the occurrence of crop failures and low-seed years has decreased during the last four decades, signalling altered starvation effects of masting on seed predators. As lowered CVp can reduce viable seed production despite the overall increase in seed count, our results warn that a covert mechanism is underway that may hinder the regeneration potential of European beech under climate change, with great potential to alter forest functioning and community dynamics.

Crown density, growth and carbon sequestration in European forests over the period 1990-2022*

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Changes in crown density (popularly termed "defoliation") can reveal important modifications in tree health and vitality and is a common indicator used for monitoring forests in Europe and elsewhere.

The present study aimed to evaluate changes (if any) in tree crown density across Europe between 1990 and 2022, and potential associated changes in growth and carbon (C) sequestration. We leveraged different methods: firstly, we used data collected by ICP Forests (Level I) to analyse the spatial and temporal patterns of tree defoliation across Europe. Secondly, by synthesizing published data through a systematic literature review, we developed general and species-specific relationships between crown density and relative growth (see Ferretti et al., 2021). Thirdly, we used these functions to estimate the potential changes in the cumulative growth of the tree population examined.

Here we present the preliminary results on (i) the spatial and temporal trends in crown density across different biogeographic regions of Europe for different species, (ii) shifts in the distribution of the tree populations examined along the crown density range over time, and, (iii) the resulting estimated changes in tree growth. Finally (iv) we present results on the relationship between crown density and C sequestration reported over the investigated spatial and temporal domain.

Our preliminary results show an accelerated, though regionally variable, reduction in tree crown densities with estimated negative implications for tree growth and C sequestration. The latter supports increasing evidence of this trend (e.g., Korosuo et al., 2023; van der Woude et al., 2023) and suggests a reconsideration of the role of European forests for climate change mitigation. Our preliminary results also suggest that the collection of additional attributes (e.g., tree diameter) on Level I plots would bring enormous added value for interpreting forest health monitoring data in the future.

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The evaluation was based on data that was collected by partners of the official UNECE ICP Forests Network

(http://icp-forests.net/contributors). Part of the data was co-financed by the European Commission. Data achieved at *05.09.2023* – last access. Data request no. 287.

** Results of this research are being finalized for a manuscript, which will involve ICP Forests experts in agreement with the ICP Forests data and Intellectual Property policy.*

Monitoring forest damage to shape future forests

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Climate change is threatening forest health across the globe and recent declines have even occurred in forest regions that were previously considered invulnerable or unsusceptible to drought or heat stress (Hartmann et al. 2022). Forest area damaged by biotic disturbance has increased during the last decades in Europe, because insect population dynamics are tightly linked to increasing temperatures, and more frequent and more severe damage is likely under further warming (Forzieri et al. 2021). At this point, however, realistic prediction of future forest damage is hampered by a lack of georeferenced data on forest damages. This information is essential for shaping forests that are resilient against climate change-induced insect damages and diseases, as it allows to: 1) identify which forest tree species are particularly threatened under ongoing climate change, and 2) better understand interactions between abiotic stress (drought, heat), biogeochemical site conditions (e.g., stand structure and composition, soil structure, fertility, and depth) and epidemic occurrences of insects and diseases. The recently published Database of European Forest Insect and Disease Disturbances (DEFID2, Forzieri et al. 2023) comprises an important first step to providing such data, however, the database is based on voluntary contributions by mainly scientific institutions, and thus still has substantial gaps in coverage, both spatially and in terms of damage agents. A more systematic data contribution, including state agencies that already assess forest damage at the national level, would greatly improve the usefulness of the database.

At the Julius Kuehn-Institute for forest protection, a newly founded German federal research institution, we currently establish a nation-wide database of biotic forest damage by combining forest damage assessments carried out by the individual state agencies. To do so, we harmonize data formats, damage metrics, or spatial resolution, across available data sets. This activity could thus serve as a template for a larger, pan-European initiative for data collection on forest damage. In this presentation, I will present our work with the aim to initialize cooperation between European state agencies responsible for forest damage assessment.

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Spatiotemporal drivers of ectomycorrhizal diversity in Europe

Guillaume Delhaye[1)], Elena Arrigoni[1)], Sietse van der Linde[2)], Martin I. Bidartondo[1,3)], Vladislav Apuhtin[4)], Sue Benham[5)], Nathalie Cools[6)], Bruno De Vos[6)], Di Martino Domenico[7)], Tine Grebenc[8)], Martin Greve[9)], Pawel Lech[10)], Päivi Merilä[11)], Juan Molina[12)], Manuel Nicolas[13)], Giancarlo Papitto[7)], Gunilla Pihl Karlsson[14)], Vít Šrámek[15)], Arne Verstraeten[6)], Laura M. Suz[1)]

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Ectomycorrhizal (ECM) fungi are symbiotic partners to the major tree species in Europe. They play a crucial role in tree nutrition and are increasingly recognised for their role in soil carbon sequestration. However, forests and ECM communities may be approaching a tipping point in response to nitrogen (N) pollution, leading to phosphorus deficiency in trees and cascading negative effects on forest health and the services that they provide. Therefore, it is urgent to quantify the responses of ECM fungal taxonomic, phylogenetic, and functional diversity to changes in climate, soil chemistry and the atmosphere.

With a large dataset of ECM communities collected in 137 Level II ICP Forests plots, we showed that ECM diversity and species composition are driven by host distribution, soil chemistry, climate, and atmospheric N deposition across Europe. New taxonomic and phylogenetic diversity analyses indicate both selection for competitive N-tolerant species and local species extinctions across different fungal clades. We also find tree host-specific climate influences, and selection of nutrient acquisition and C sequestration-related functional traits by N pollution. Moreover, using distance-decay models, multivariate analyses, and indicator species analyses we observed that biogeographic patterns in ECM communities are independent from climate and host tree distribution, and show adherence to ecoregions, unlike previously claimed by studies based on fruitbody occurrences. We are currently resampling a subset of beech and pine plots, to study temporal changes in community composition and diversity and to measure the effect of changes in climate and N pollution 10 years after the first collection.

Mycorrhizas are crucial to understand forest nutrient dynamics, resilience, and recovery from change; understanding them at the large-scale will inform forest management, conservation, and global change mitigation efforts.

Acknowledgement

We are thankful to the many local field staff and Kew research assistants for their help in obtaining data.

Norway spruce health and vulnerability in Lithuania – wind, decay and *Ips typographus* as the main drivers

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In recent years the local Norway spruce (*Picea abies* (L.) Karst) population in Lithuania has faced a series of severe *Ips typographus* (L.) outbreaks. Meanwhile, root/stem decay alongside wind damage, remain integral stressors that affect spruce health or induce mortality. The aim of this study was to highlight the effects of wind, wood decay and *I. typographus* on spruce health indicators, as well as interrelation of the stressors, by combining different data sources. Objectives: i) by using data collected from 20 spruce stands, we aimed to explore the interaction between decay and crown defoliation, as well as radial increment; ii) by using data collected from 34 observation plots established in wind affected stands; two transects (36.8 ha area combined); spruce plantation thinning experiment affected by wind; National Forest Inventory (NFI) and ICP forests level I data, we aimed to investigate how decay affects wind damage occurrence in spruce stands, as well as reveal forest managements impact on decay and wind damage occurrence; iii) to assess bark beetle outbreak dynamics during the 1968-2023 period, and identify outbreak drivers, by combining annual reports of the Lithuanian State Forest Service, NFI, and meteorological observation datasets. Study results show that decay causes reduced radial increment growth and increased crown defoliation. Wood decay is a potential risk factor associated with wind damage occurrence in spruce stands, while management practices such as thinning intensity in pure spruce plantations increase decay incidence and wind damage occurrence. We also found broadleaved deciduous tree species to have a positive effect on the reduction of wind damage probability in spruce individuals with no signs of decay. The 2022-2023 outbreak was the second heaviest *I. typographus* outbreak since 1992-1996, induced by vegetation period droughts, which reduced tree vitality and produced favourable meteorological conditions for bark beetles reproduction.

Soil water dissolved organic carbon patterns at spruce sites with geochemically contrasting substrate in the last three decades

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European surface waters have often shown increase in dissolved organic carbon (DOC) concentrations during the last decades. It could be driven by decline in acidic deposition, leading to a decrease in ionic strength (IS) of precipitation and soil water and subsequently to increase in the solubility of humic substances in forest soils (Monteith et al., 2023). More than three decades of monitoring at two forest catchments in the Slavkov Forest (latitude 50°N), western Czechia, documented large reduction in atmospheric load of sulfur, from 34 kg/ha/yr in the beginning of 1990s to less than 3 kg/ha/yr in the beginning of 2020s. Two Norway spruce (*Picea abies*) catchments were monitored: Lysina (LYS, area 0.27 km^2, altitude 829–949 m a.s.l., the ICP Integrated Monitoring, ICP Waters, ILTER and GEOMON site), with prevailing Podzol developed on felsic leucogranite and Pluhův Bor (PLB, area 0.22 km^2, altitude 690-804 m a.s.l., the ILTER and GEOMON site), with mostly Cambisol on ultramafic serpentinite. Fourty zero-tension and tension lysimeters were installed in five depths at LYS and PLB during the period 1989-2011. This contribution is focused on evaluation of samples collected by zero-tension lysimeters situated in uppermost mineral soils (E horizon at LYS and A horizon at PLB) which offer the longest time series. DOC was measured there since 1993, few years later than the inorganic constituents. Most DOC measurements were performed by Techman-Dohrmann Apollo 9000. Changes in soil water quality were driven by decrease of sulfate concentrations at both sites (1.1 at LYS and 1.3 mg/L/yr at PLB, $p<0.01$). Decrease of IS of the soil waters was correlated with SO_4 (R^2 0.82 and 0.87, at LYS and PLB, respectively, $p<0.01$). IS decreased significantly, 26 µeq/L/yr (LYS) and 36 µeq/L/yr at PLB ($p<0.01$). Soil water annual mean values of pH increased significantly at PLB, from 5.4 to 6.4 ($p<0.01$) but stayed around 3.5 at LYS due to properties of humic and fulvic acids, which are highly acidic and effectively prevent pH rise. The most pronounced increase of DOC was 1.25 mg/L/yr (R^2 0.31, $p<0.01$, from 30 to 70 mg/L) at PLB. Long-term increase of 0.85 mg/L/yr (R^2 0.15, $p<0.05$, from 50 to 75 mg/L) was observed in the extremely acidic soil water at LYS.

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25 years of forest growth in Swiss Level II plots

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Forests are under increasing pressure since recent decades due to climate change, increasing frequency of extreme events such as heat waves and storms, and air pollution. On the other hand, our forests are the most important terrestrial CO2 sinks, and provide important ecosystem services, such as protection from avalanches and erosion, cleaning water and air, recreation, as well as a huge economic value. Therefore, it is important to know how the sink capacity and health of forests is developing under the changing environmental conditions. To assess the variability of tree and forest growth of various Swiss forest ecosystems, we analyzed 25 years (1995-2020) of growth monitoring data, measured at 18 Level II plots in Switzerland, spanning a wide range of altitude and climatic conditions. We combined growth measurements, conducted on multiple temporal and spatial levels: (i) The forest inventory data, conducted approximately every 5 years on all Level II plots, in which the diameter at breast height (dbh) and height of every tree is measured. Based on allometric relationships and additional measurements (e.g. litter production), we can quantify the net primary productivity (NPP) of selected Level II plots over the last 25 years. (ii) Annual manual dbh as well as continuous dendrometer measurements on selected trees at the sites allows to down-scale the 5-yearly NPP to annual values. (iii) Along with climatic data and information on air pollution, we will analyze the variability of tree and forest growth to get an insight in the forests' sink capacity over time, allowing a better understanding how the forests develop when the environment is changing.

Multi-decadal drought and disturbance effects on forest carbon sequestration in a mountain forest landscape

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Disturbances and droughts are major threats to the forest carbon sink in Europe. While there are numerous studies at plot and continental scales, mostly showing that drought years have reduced C sequestration in the 21st century, the variation in these effects, both temporally between drought events and spatially within a landscape, has rarely been addressed. Here we present the results of a study in which we upscaled three decades of high-resolution (weekly) tree growth data from intensively monitored plots (ICP Forests Level II) to the landscape scale (90 ha) using a 100x100 m grid of forest inventory plots. The forest area is a particularly heterogeneous mountainous mixed deciduous and coniferous forest in the northern limestone Alps of Austria. We show that the substantial gap and stand replacement disturbances have not generally led to a decrease in stem C sequestration in the area due to higher growth of the remaining trees. The 2003 drought caused a 16% loss in C sequestration, but the 2011 and 2015 droughts had an average positive effect due to increased temperature, radiation and disturbance-induced growth. Mixed forests on steep slopes and coniferous forests on the plateau showed partly opposite effects of disturbance and drought. Our study exemplifies that mountain mixed forests have shown high resistance, recovery and resilience to both disturbances and droughts over the last 30 years. In this precipitation-rich area, three years of exceptionally low precipitation resulted in only < 10% loss of C sequestration in tree stem biomass. We conclude that variation in the effects of disturbance and drought within a forest catchment can weaken or strengthen forest C sequestration at the landscape scale. It is therefore important to use long-term data with sufficient spatial resolution for landscape-scale C sequestration assessments.

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Session 2: Novel monitoring approaches to support the development of resilient forests

Towards Advanced Forest Inventory and Monitoring (AIM): A Swiss example

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Forests are under pressure and going through rapid changes, as such, good monitoring and inventorying (IM) initiatives are needed to inform understanding and management. However, current IM programs are often either disjointed, too narrow in their scope or do not operate at fine enough temporal resolutions. This can impact the timely supply of information, decision-making and lead to the sub-optimal use of limited resources (financial and human capacity).

Therefore, there is an urgent need for advanced forest inventorying and monitoring (AIM) programs to (i) achieve expanded relevance (by augmenting the data/information catalogue across ecosystem properties and trophic levels), (ii) have increased temporal resolution (by tailored data collection frequency), and, (iii) make use of technological advances (by incorporating novel tools and technologies) (Ferretti et al. 20204). In this presentation, we introduced the Advanced Inventorying and Monitoring for Swiss Forests (SwissAIM) initiative which was launched in 2020 to address these needs. SwissAIM builds upon the foundation offered by the existing programs (e.g., national forest inventory - NFI; long-term forest ecosystem research, LWF i.e. ICP Forests networks in Switzerland; and, biodiversity monitoring, BDM). SwissAIM offers a collaborative and adaptive framework enabling integrated data collection, evaluation, interpretation, analyses and modelling. To develop SwissAIM we identified information needs of different stakeholders (e.g., science, policy, practice), related technical requirements, and governance frameworks. In this talk we present (i) the main features of the SwissAIM initiative (innovative vision; scientific questions and variables; governance and engagement), (ii) the main outcomes of the participatory design process (measurements, sampling and plot design), (iii) the potential transferability of AIM initiatives outside Switzerland (timing, relevance, practicability), and, (iv) the key messages that emerged from the development process (i.e., need for advancement, integration and transdisciplinarity, statistical underpinning) (Ferretti et al. 2024). Since similar needs related to forest IM are emerging throughout Europe and elsewhere (as highlighted by the preparation of a new European Commission framework for forest monitoring), we share our experience to help guide others and promote a dialogue with those interested in developing AIM initiatives elsewhere.

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From litter to soil carbon - harmonizing soil carbon stock estimates for a common European forest monitoring system

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Forest soils are a major, but challenging to estimate, C reservoir. In a context of global changes, monitoring and predicting possible changes in soil C stocks in forest ecosystems is essential. Improving the estimation of soil C responses to forest management practices and climate would help decision-makers to frame appropriate climate mitigation strategies. However, accurate field observations of litter-derived C inputs are particularly scarce at large scales, and different methods are used to obtain such estimates e.g. for reporting the C balance of soils in greenhouse gas inventories. Within the EU-funded project PathFinder, our study aims to derive European-wide harmonized soil C inputs and stock estimates since 1990s, and further develop the current estimation methodology.

Here, we use observations of litterfall and deadwood production from plots in the pan-European forest monitoring network of the “International Co-operative Programme on Assessment and Monitoring of Air Pollution Effects on Forests” (i.e. ICP forests). Litterfall and deadwood observations, together with repeated stand inventory data, are used to improve current regional allometric functions by biogeographical regions and forest types. For validation purposes: (i) harmonized estimates of soil C inputs are compared with independent net primary production (NPP) estimates from MODIS, and (ii) historic changes in soil C stocks simulated with the model Yasso20 are compared with measured soil C stock changes from additional ICP forest sites.

Overall, this study will provide a harmonized framework for estimating and reporting changes in soil C stocks in European forests, which can also be applied for simulating soil C stock changes in response to different scenarios of forest management and climate.

Quantifying tree canopy nitrification across European forests by combining stable isotope and molecular analyses

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Fluxes and chemical composition of precipitation is substantially changed after passing through tree canopies, particularly in the case of atmospheric nitrogen compounds, with important implications on forest nitrogen cycling (Guerrieri et al. 2021). Discussions on causes of these changes, however, have mostly focused on the passive role of foliar surfaces to scavenge pollutants from the atmosphere and to ion exchange processes (Lindberg et al. 1986; Staelens et al. 2008), while biological trasformations involving microbes hidden in the phyllosphere have been overlooked. We combined triple oxygen isotopes approach in nitrate collected in forest water samples and molecular analyses with the aim of quantifying canopy nitrification and identify microbes responsible for it, respectively. Ten sites within the ICP Forests monitoring network, chosen along climate and nitrogen deposition gradients, were selected to include the two most dominant tree species in Europe (*Fagus sylvatica* L. and *Pinus sylvestris* L.).

We found that up to 80% of the nitrate reaching the soil via throughfall derived from biological transformations in the phyllosphere, equivalent to a flux of gross canopy nitrification of up to 5.76 kg N ha^{-1} y^{-1} (Guerrieri et al. 2023). The fraction of microbiologically derived nitrate increased with rising nitrogen deposition, thus suggesting that the process can be substrate limited. Molecular analyses confirmed the presence on foliar surfaces of bacterial and archaeal nitrifiers across the investigated forests, regardless of the nitrogen deposition level. Our study demonstrates the potential of integrating stable isotopes with molecular analyses to advance our understanding on key processes underpinning forest nitrogen cycling, which should no longer neglet biological transformations by phyllospheric microbiota. Moreover, it highlights the need to integrate isotopic tracers to improve current approaches used to estimate nitrogen deposition.

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From soils to canopy: a call to collaborate to disclose foliar microbiome diversity and function

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Large-scale observation networks are essential tools for monitoring forest health and biodiversity, but they have traditionally overlooked the microbial domain of life. Microbes are engines of biogeochemical cycles, essential mutualists of trees via mycorrhizae, and they are some of the most destructive and ubiquitous stressors to forests as pathogens. Bacteria, fungi, and viruses (i.e., microbes) profoundly impact forest health and sustainability, and their ecology and biodiversity must be better integrated into monitoring networks to understand current and future forest composition and functioning. With dozens of ICP Forest collaborators, I have previously organized a large-scale soil sampling campaign conducted in 2019-2020. From this effort, we generated soil microbiome data profiles for hundreds of ICP Forest level II plots, and we discovered novel linkages between soil fungal and bacterial communities and above- and belowground carbon storage. We show that variation in tree-associated, symbiotic ectomycorrhizal and endophytic fungal biodiversity is uniquely correlated with tree growth rates, whereas free-living bacterial and fungal species biodiversity is negatively correlated soil organic carbon stocks, even after accounting and controlling for other important covariables. These results raise important new hypotheses around what controls forest structure and function at an unprecedented scale. In this presentation, I will share key results from our soil microbiome sampling initiative, and I will outline a new chance to collaborate to characterize foliar microbiomes and their biological linkages to foliar nutrition, crown conditions, leaf area, tree growth and death, and forest responses to environmental stressors like o-zone, nitrogen deposition, and pathogen outbreaks. I will provide a sketch of how the collaboration will look and function, how contributors can collect and send us samples, and what we expect to discover and produce from this initiative. While we have always seen the forest for the trees, the time is here to look a little closer at the microbes.

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Optimisation of the measurement design for precise Green Leaf Area Index (GLAI) estimation by gap fraction methods in mature Norway spruce stands

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This study investigates the optimisation of the measurement design for accurate estimation of the Green Leaf Area Index (GLAI) in mature Norway spruce stands. GLAI, defined as half of the total green leaf area per unit of ground surface area, is critical for understanding mass and energy fluxes between vegetation and the atmosphere. While direct methods for measuring GLAI are accurate, they are impractical for large-scale applications due to their labour-intensive nature. Therefore, this research focuses on indirect methods, in particular gap fraction methods, which are less laborious and allow for broader spatial and temporal monitoring. The study primarily uses two indirect optical methods: the LAI-2200 Plant Canopy Analyser (LAI-2200 PCA) and Digital Hemispherical Photographs (DHPs) analysed by WinSCANOPY software. Despite their rapid application, these methods are prone to errors caused by factors such as foliage clumping, particularly in coniferous species such as the Norway spruce. The research aims to refine these methods by integrating the apparent clumping factor (ACF) from LAI-2200 PCA measurements and the canopy clumping index (CI) from DHP. This approach aims to minimise error and optimise the accuracy of GLAI estimation in coniferous forests. Field measurements were carried out in 15 mature Norway spruce stands in the Czech Republic, using a 9 x 9 grid sampling method. Different sampling designs, including random, block, and “Sudoku” strategies, were evaluated for their effectiveness in estimating GLAI. The research also investigated the role of various factors, such as sensor field of view (FOV) and spatial arrangement of sampling points, in influencing the accuracy of GLAI estimates. The results of the study indicate that structured sampling strategies, such as the “Sudoku” method, provide more accurate GLAI estimates than random sampling, especially when spatial heterogeneity of the canopy is taken into account. This research contributes to the standardisation of ground-based LAI measurements and provides improved methods for effective monitoring and management of forest ecosystems.

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Scaling up tree mortality and survival in Mediterranean oak woodlands

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Forests and their trees are key in water-limited ecosystems, such as drylands. Over the last century, the increase in tree mortality of adult and young trees has undermined the long-term sustainability of dryland forests. Therefore, it is important to monitor and identify the underlying causes of tree mortality and survival at different stages of tree development. Tree mortality is often addressed at broad scales (> 1 km), but the influence of the local-scale factors remains unclear. The absence of systematic monitorization schemes with high spatial resolution and long-term tree mortality at different stages of tree development is a limitation. Here, we used data from stakeholders to monitor tree mortality and survival of cork oak and holm oak to overcome this limitation. We modelled tree mortality data with 6 years on a Mediterranean evergreen oak woodland and tree survival on reforestations with more than 20 years in Southwest Portugal, combining local data on tree mortality and remote sensing. Topographical and edaphic variables with high spatial resolution were used to explain tree mortality and survival. Results show that local environmental factors significantly explain the tree patterns in the different stages of tree development. Tree mortality was higher in sites where water availability was limited, mostly related to low water accumulation and deeper water table, varying at local scales. These findings allow mapping potential tree mortality with high spatial resolution, to identify areas with higher susceptibility, and where to focus active forest management, particularly under climate change scenarios.

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Satellite-based forest health survey on ICP Forest Level II plots in Hungary

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An increasing number of forest damage has been observed in the last decade in Hungary. For surveying this large-scale damage, remote sensing with satellites offers a fast and convenient way. Utilizing high-resolution Sentinel-2 satellite imagery and Google Earth Engine cloud computing a forest monitoring method was created to detect forest disturbances remotely. To find disturbances, vegetation index (NDVI and standardized, Z NDVI) maps were made from satellite imagery for the vegetation periods of years 2017–2023. The study sites were the currently active seven ICP Forests Level II plots of Hungary. The whole forest compartment was studied containing monitoring plots. Z NDVI majority values were calculated for each compartment and classified into five classes: severe damage (Z NDVI< -2), damage (<-1), moderate (<0), good (<1), and excellent condition (>1).

Examining the seven monitoring plots, differences have been observed between the sites. The forest health state was analyzed at each site based on the vegetation index values indicating photosynthetic activity. We observed that Bajánsenye (M16), Gyöngyössolymos (M03), and Szentpéterfölde (M17) had the best index values, thus the most vital forest condition. In contrast, Kecskemét (M19), Biatorbágy (M21), and Bajánsenye (M16) showed a deterioration in health condition. In M19 and M16, the severe drought of 2022 was visible in 2023, while in M17 the negative change was observed in 2022 and 2023. On the other hand, M03 showed a significant improvement in the second half of the study period, which was not affected by the drought.

ICP level II defoliation reports with 5 classes showed excellent condition at plots M21 and M03 throughout the investigated period, as they were not damaged by the drought. In accordance with satellite imagery, plot M19 showed a constant health decline, reaching its peak in 2022, with 62% defoliation. Plot M15 showed an evenly good health state, while M17 changed a lot. In 2017 due to late frost and wind severe damage took place, while in 2018 the forest recovered. Another decline was observed in 2021 due to wind and in 2022 due to drought with 24% defoliation. Plot M01 showed regeneration after 2017 until 2021, where damage occurred. The latter was visible on satellite imagery as well. Plot M16 varied in the seven years, with a decline in 2017, and gradual regeneration between 2018-2020, while in 2021 another decline occurred and 2022 was a better year again, this is in contrast with satellite data where good health was registered in 2017, a decline in 2018, 2020, 2021, 2023, and incline in 2019 and 2022.

Generally, we found good agreement between field and satellite data on forest health, however, accuracy could be increased. In the future, we wish to expand our study with the 78 ICP Forests Level I plots in Hungary, which could represent the conditions more precisely.

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Forest microclimate: how to quantify and predict the temperature buffering capacity of canopies

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In forests, local microclimate temperatures experienced by understory plants differ from macroclimate temperatures measured by weather stations in open areas. Canopies usually buffer temperature extremes, mainly through shading and evapotranspiration, with lower maxima and higher minima inside dense forests. Using data from a long-term forest monitoring network in France (RENECOFOR, which is part of the ICP Forests Level II network), we developed an innovative statistical approach to model microclimate temperature. Our "slope & equilibrium" method relies on the linear relationship between microclimate and macroclimate temperature. We installed temperature sensors in 13 deciduous and coniferous RENECOFOR sites, and used stand inventory metrics to model microclimate buffering (less extreme) or amplification (more extreme) relatively to macroclimate temperature fluctuations. We then used this method to spatialize microclimate temperature over one entire forest (Blois, covering 2700 ha). To do so, we extended our sampling from the single RENECOFOR plot to 53 plots representative of the different silvicultural stages, from juvenile to mature stands, across this forest. To obtain maps of the thermal environment below canopies at a 10-m resolution, we used three forest structure metrics derived from airborne LiDAR (light detection and ranging): maximum height, Plant Area Index and Vertical Complexity Index. Finally, we explored the response of understory plants to this microclimate buffering or amplification effect. We related in-situ microclimate measurements to floristic inventories in 157 plots across three French forests related to the RENECOFOR network (Blois, as well as Mormal and Aigoual). We observed a shift of microclimate preference along a forest affinity gradient for vascular plants. Bryophytes almost systematically preferred buffered microclimate temperatures. For bryophytes as well as vascular plants, the more thermally buffered, the higher the proportion of forest core specialists. Future studies will bring further insights into microclimate modelling, as 56 forests of the RENECOFOR network were recently equipped with TMS (temperature-moisture sensors) over a two-year period. Forest canopies can enhance or mitigate the effects of climate change on plant communities through temperature amplification or buffering, underpinning the importance to monitor microclimate in forests.

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From single trees to country-wide maps: Modeling tree mortality across Germany based on Level I data

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Several extremely dry years have caused dramatic increases in tree mortality since 2018 in many regions of Central Europe. In particular Norway spruce has been strongly affected, but also other species have shown signs of decreased vitality and increased mortality risk. Long term monitoring programs such as the ICP Forests Level I monitoring provide valuable information about tree loss rates at annual resolution and on a systematic sampling grid. The German Level I monitoring (crown condition survey) consists of 410 plots on a 16 km × 16 km grid with a total of ca 10,000 trees. The loss reasons for sample trees have been recorded since 1998. In this project, the goals were 1) to model tree mortality at the survey plots as a function of environmental drivers and 2) to produce country-wide maps of predicted mortality for a number of common tree species in Germany.

All trees in the dataset that died due to a cause other than planned management or windthrow were included as mortality events in the analysis, while all other trees were labelled as survivors. A set of more than 400 candidate predictor variables were derived with the condition that the data had to be available wall-to-wall for whole Germany. These environmental predictors covered the domains of climate, soil, topography, landcover and deposition. A multiple logistic regression model with the binary response “dead or alive” was fit to the data. The most important predictors for every tree species were identified via feature selection. Prediction accuracy and model robustness were tested via leave-one-location-and-year-out cross validations (AUCs between 0.5 and 0.9). Germany-wide maps of average mortality at 1-ha resolution were derived for Norway spruce (*Picea abies*), Scots pine (*Pinus sylvestris*), European beech (*Fagus sylvatica*), pedunculate+sessile oak (*Quercus robur+petraea*) and other conifer and broadleaf species pooled.

The maps provide insights into the spatio-temporal patterns of mortality and enable the derivation of summary statistics at regional scales. The cause-effect relationships from the regression models will be combined with climate scenarios and process-based forest models to predict trajectories of future forest development.

Posters

Session 1: Long-term forest ecosystem processes as affected by air pollution, drought or other extreme weather events

Assessment of atmospheric deposition in context of climate warming in Romanian forest ecosystems

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Meteorological factors are of direct importance when considering changes in pollutant concentrations for all sites. The impacts of air pollution in the context of continuous climate warming are likely to affect nutrient turnover and nutrient availability, soil moisture, and, ultimately, growth and primary productivity in forest ecosystems. Atmospheric deposition and its transformation in contact with vegetation are of high importance in understanding its effects on forests. It has an impact on forest ecosystems through eutrophication by nitrogen and soil acidification, thus altering soil properties and processes.

The aim of this study was to examine the trends of air pollution in Level II ICP Forests from Romania. The study period spans 10 years, from 2013 to 2023. Furthermore, it was analyzed the relation between air pollution and forest ecosystem's condition by analyzing annual tree growth. The study area was chosen to represent the most important and the most common species in the Romanian forest ecosystem.

The main objectives of the study were to analyze the long-term monitoring results of forest ecosystem conditions to the disruptive action of pollutants and atmospheric deposition in relation to climate variability. The quantitative assessment of liquid and solid atmospheric precipitation flow was made based on periodic sampling in permanent research areas (in free land and under forest canopy). The evaluation of the water flow on the soil profile and determination of the concentration of mineral ions of the precipitation samples and the soil solution was assessed according to the methodology in the ICP manual to estimate actual atmospheric deposition loads and compare them to critical loads. Our preliminary results showed a decreasing trend in air pollution and atmospheric deposition.

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Phenophase dynamics of European beech and sessile oak in the intensive forest monitoring plot of Mihăești, part of the Level II ICP Forests network

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In the context of climate change, particularly as temperatures rise from year to year, trees are expected to respond differently both in terms of phenophase production and length of growing season. Plant phenology is represented by the synchronization of seasonal activities with the thermal regime, the production of plant phenotypes being dependent on the variation of temperatures. The most important being spring temperatures, which start the production of phenotypes. It was found that some phenophases are also influenced by winter temperatures. In the present paper a phenophase dynamics of 2 tree species from the Mihăești area is presented, from budding to leaf fall over a period of 10 years. In the case of temperatures from 2013 to 2023, an increase was observed. These variations in the thermal regime and the increase in temperatures have direct influences on the formation of phenophase as well as on the length of the growing season, this was also observed in the phenophase dynamics of the species analyzed. Analysis of the phenophase of the species showed that in 2021 leafing and flowering were delayed due to lower spring temperatures than in previous years. In terms of phenophase dynamics, a trend towards a delay in the production of spring phenophses was observed, especially for flowering. While in the first part of the period analysed the autumn phenotypes also show a delay in production, in the second part there is an earlier production which leads to a shorter growing season.

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Changes in forest floor P availability in an unmanaged mountain spruce forest after bark beetle-induced tree dieback: A 15-year study from Šumava mountains

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Bark beetle invasions pose a significant threat to forest ecosystems in Europe, triggering substantial changes in nutrient cycles and altering the chemistry of the forest soil. In this study, we examined the variations in different phosphorus fractions in the forest floor (O and A horizon) of unmanaged Norway spruce stands in the Plešné and Čertovo Lake catchments in the Czech Republic over the period from 2008 to 2022. The forest in the Plešné catchments was infested by the bark beetle (*Ips typographus*) from 2004 to 2008, resulting in the death of approximately 90% of trees. In the catchment of Čertovo Lake, tree dieback has recently accelerated. After a tree dies, a large amount of organic material reaches the soil, leading to an increase in nutrients. Ratio between total carbon and phosphorus in soil has been increasing over the years in catchments of Plešné lake, indicating loss of P during microbial decomposition. The concentrations of total phosphorus in water extracts (TP_{H20}) started to increase and reached a peak (1.05 mmol/kg in the O horizon and 0.65 mmol/kg in the A horizon) a few years after tree dieback in the disturbed forest of Plešné Lake. A similar trend also occurred for soluble reactive phosphorus (PO_4-P), which represented the major fraction of TP_{H20} during the period of peaking TP_{H20} concentrations. Due to forest regeneration and an increase in phosphorus uptake by trees in subsequent years, the TP_{H20} began to decrease, and proportion of organic P increased. During the last years, a similar (but less pronounced) trend was observed in the forest floor at CT catchment with ongoing tree dieback.

Development of soil chemistry on Level II plots in the Czech Republic

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The region of central Europe and also Czech Republic was historically strongly impacted by air pollution load (mainly SO_2 and NO_x) and acid deposition, which peaked in the 1970s and '80s and led to acidification of forest soils, mainly on poor substrates and in coniferous stands, followed by decreasing pH values and loss of base nutrients. New technologies and measures in energy production and industry were implemented at the beginning of the 1990s, and while air quality improved rapidly after desulfurization of main pollution sources, forest soil still remains acidified and base saturation of sorption complex is still very low. Recovery process of the acidified soils is very slow and thus it is very important to stay focused on soil status, acidification process, its changes and development.

Data of soil chemistry from seven plots of intensive monitoring of the ICP Forest Programme (Level II) were evaluated for periods ranging from 13 to 30 years. The results of chemical analyses confirmed that most of the soils have low pH values and there are only minor changes over time period evaluated, mainly in the upper part of soil profile. Subsequently, base saturation of sorption complex (BS) is very low, on all plots in the depth 0-20 cm of mineral soil values of BS are lower than 20%, on three plots values of BS did not reach 10% in whole profile. Content of exchangeable base nutrients (Ca, Mg, K) as well as available phosphorus is low and its addition or input to the soil are limited by weathering rate, decomposition of litter and atmospheric deposition (mainly Ca and Mg) as the only one source of these elements.

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First data of carbon dioxide (CO_2) emission from soil in two Level II monitoring plots in Serbia

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The II level intensive monitoring plots in Serbia covers 5 plots in selected forest ecosystems with the goal of clarifying cause-effect relationships. In relation to all other monitored parameters on these plots, the Institute of Lowland Forestry and Environment is established monitoring of carbon dioxide (CO_2) emission from soil in two sites. Sampling on both sites included two subsites. One subsite is in the level II plot and the other outside the level II plot. Vegetation on one site is represented by pedunculate oak and on the other one with sessile oak. Pedunculate oak (*Quercus robur* L.) forests in lowland are hydrologically related forests. The aim of this research is to determine the soil CO_2 emission in two different oak forest sites at level II monitoring plot. The soil is defined according to the WRB classification. During air sampling, soil temperature was measured, and the moisture content was sampled. The collected air samples were analysed using gas chromatograph. During the research period, we had the opportunity to conduct research under very different climatic conditions. Based on the first data, the first correlations between temperature and CO_2 emission, as well as soil moisture and CO_2 emission were done.

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Pollen deposition in throughfall samples at sixty ICP Forests plots throughout Europe

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Throughfall samples collected in 2018 from 60 ICP Forests Level II plots across 8 countries (Belgium-Flanders, Finland, France, Germany-Bavaria, Italy, Norway, Switzerland, UK), and representing *Abies* (n=6 plots), *Fagus* (n=11 plots), *Larix* (n=1 plot), *Picea* (n=19), *Pinus* (n=13), and *Quercus* (n=10 plots) stands, were considered for the quali-quantitative characterization of pollen deposition. A total of n=196 weekly-to-monthly water sub-samples, previously analysed for the chemical composition, were filtered using 5.0 µm mesh filters that were subsequently dissolved and the pellet was used for the microscopical pollen identification and quantification. Pollen sedimentation rates ($P*cm^{-2}*d^{-1}$) were then calculated and the pollen spectrum of each plot defined, as a proxy of the local plant biodiversity. Overall, 54 (31 woody, 23 non-woody) pollen taxa were identified. The number of pollen taxa ranges from 6 in the *Larix* stand to 22 in the *Pinus* stands. The more frequent pollen types detected in the samples are those of oak, spruce, beech and pine, that correspond to the main tree species (MTS) present in the respective plots. The pollen amount belonging to the MTS represents on average the 26% of the total pollen, ranging from 0.1% in the *Larix* stand to 58% in *Pinus* stands.

In order to optimise the data analysis, and to set the proper sampling design for further studies, the consistency between the temporal coverage and resolution of samples and the flowering time of the correspondent MTS was considered. Overall, in 44 out of 60 plots, samples covered the MTS flowering period; 70 out of 169 samples had a low temporal resolution, referring each one to a 3-5 week period of sampling, thus limiting their informative potential on the time course of flowering.

Further data analysis will aim to verify if a relationship exists between the variations in chemical composition of precipitation along the vegetative season and the concurrent presence and amount of specific pollen, providing new insights on the possible role of pollen on throughfall biochemistry in European temperate and boreal forests (Verstraeten et al., 2023 https://doi.org/10.1007/s10533-023-01082-3).

35 years of monitoring at „Höglwald“ - Documentation of chemical climate change and its impact on the ecosystem

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In 1984, at the forest district “Höglwald”, situated 50 km west of Munich and 70 km north of the Alps at an elevation of 540 m a.s.l., an intensive forest ecosystem research plot was established. The Höglwald is characterized by high nitrogen input dominated by ammonium due to intense agriculture in its surroundings. The investigated Norway spruce stand was 77 years old when measurements started and is characterized by a dense and close canopy, and a high growing stock. For further information about site and stand see Kreutzer and Weiss (1998). In 2010 Höglwald was transferred to a Level 2 site, now operated by the Bavarian State Institue of Forestry.

In 35 years of observation, the input of nitrate-N to the forest floor was relatively constant with values of about 9 kg/ha. The input of ammonium-N, however, was reduced by about one half, from 21 kg/ha in 1985 to 11 kg/ha in 2020. Due to the successful reduction of emissions, the input of sulfur drastically decreased from more than 25 kg per ha in 1985 to less than 2 kg per ha in 2020. The output of sulfate below the main rooting zone in 40 cm depth showed a delay in reduction of more than 20 years. During this time, the sulfate stored in the soil in times of high deposition was remobilised. In the time-span 1985-2020 N leakage was reduced to about one third (11 kg/ha) in 2020. This still high output level is a clear indication for nitrogen saturation of this ecosystem. The proton load of the system mainly results from H production caused by N transformations. In consequence there is a trend towards a slowly decreasing buffer capacity in the upper soil.

The long term monitoring of element fluxes in the Höglwald forest impressively demonstrates a marked change in the chemical environment. Ongoing nitrogen “fertilization” in combination with drastically reduced sulfur inputs lead to the fact that sulfur no longer is an excessive element, but an element which according to Liebig’s law is getting more and more limiting.

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Temporal trends in nitrogen and sulfur throughfall fluxes and soil solution concentrations

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While sulfur (S) deposition has decreased markedly across Europe since the early years of ICP Forests monitoring, nitrogen (N) deposition has only decreased weakly, and not in all forest sites. In Denmark, the intensive agricultural production constitutes a particular challenge to meet aim regarding reduced N deposition and eutrophication of forest ecosystems.

Here we report input fluxes of N in form of nitrate (NO_{3-}-N) and ammonium (NH_4+-N) as well as sulfate (SO_4^{2-}-S) in throughfall at five Level II sites in Denmark during periods of 9-38 years. These data were related to the corresponding concentrations of NO_{3-}-N and SO_4^{2-}-S in the soil solution sampled in 90 cm depth in the mineral soil. The five Level II sites are:

- Ulborg: Norway spruce plantation, planted in 1964, nutrient poor sandy soil, surroundings: conifer forest and heathland, but nearby high-intensive cattle and pig farming may influence the N deposition. Monitoring 1985–2013.
- Tyvkær: Norway spruce plantation, planted in 1962, nutrient poor sandy soil, surroundings: conifer forest. Monitoring 2015–2023.
- Suserup: Beech-dominated semi-natural forest with ash and oak, nutrient-rich loam, surroundings: mainly forest and cropland with few farm animals. Monitoring 2002–2023.
- Vestskoven: Oak afforestation on former cropland, planted in 1970, nutrient rich loam, surroundings: close to several highways and Copenhagen. Monitoring since 2001–2023.
- Frederiksborg: Beech afforestation on former cropland, planted in 1964, nutrient rich loamy soil, surroundings: mainly forest. Monitoring 1985–2023.

The throughfall flux of S decreased over time in all sites, most notably in the beginning of the period from 1985 to 1990s. A parallel decrease was observed in the concentration of S in the soil solution. Fivefold decreases in the flux of SO_4^{2-}-S in throughfall as well as in the soil solution SO_4^{2-}-S concentration were seen during the 38 years of monitoring at the Frederiksborg site. In general, we also observed a decrease in NO_{3-}-N and NH_4^+-N fluxes, however, much less pronounced with larger year-to year variation. The proportions of NO_{3-}-N and NH_4+-N in the total throughfall N fluxes will be discussed relative to the different N emission sources at the five sites.

Changes in soil phosphorus availability in unmanaged spruce forest after bark beetle attack – from dieback to recovery

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We studied the effect of tree mortality on phosphorus availability in soils of two unmanaged mountain forest catchments of similar altitude, vegetation, and soil chemistry (Plešné, PL; and Čertovo, CT; Šumava National park; Czech Republic). Bark beetle infestation caused widespread dieback of the Norway spruce trees in PL (2004 – 2008) and all dead plant biomass remained on the forest floor. CT catchment remained unaffected till 2017 and served as a control.

To evaluate changes in soil chemistry during the forest dieback and following recovery, we performed three soil sampling surveys in 2010, 2015, and 2020. Soil samples were taken from 0.25 m^2 pits (50 × 50 cm) in the PL and CT catchments at elevations between 1028 and 1320 m in the spring to early summer, the sampling grid covered whole catchments (20 pits in each catchment).

The concentration of mobile P form (water-extractable reactive P; SRP) in the forest floor exhibited high spatial variability from 0.01–0.02 mmol kg^{-1} to more than 4 mmol kg^{-1}. The average pools of SRP in the forest floor decreased gradually from 9.3 to 2.4 mmol m^{-2} during 2010–2020, as a result of increased P assimilation due to forest recovery. No significant changes were observed in CT catchment.

(For temporal variations in P concentrations in soils sampled in 9-week interval during 2008–2022 at research plots situated in catchments of PL and CT see poster presentation by Damnjanović et al.)

Investigate the effect of soil water depth on ozone-induced visual foliar injury

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Tropospheric ozone (O_3) is a secondary photochemical air pollutant with the potential to adversely affect forest health and ecosystem functioning. Since O_3 is taken up through stomata, stomatal O_3 uptake affects the extent of O_3 damage to plants. Soil Water Content (SWC) is currently one of the main drivers of stomatal conductance in Mediterranean area. This study aims to assess the influence of different SWC depths on calculating stomatal O_3 uptake as phytotoxic ozone dose (PODy) and the subsequent visible foliar O_3 injury (VFI) in different tree species. The study was conducted over a five-year period (2018-2022) at two Italian forest sites (ABR1 [Collelongo, Abruzzo region] and LAZ1 [Monte Rufeno, Lazio region]). Correlation analysis was conducted to determine the relationship between VFI and PODy, and the results were compared between the forest edge (LESS, Light Exposed Sampling Site) and inside the forest (ITP, In The Plot) sites. The POD_1 was calculated using meteorological and SWC data with different soil depths (10 cm, 30 cm, and 60 cm) and examined the correlations between POD_1 and visible foliar ozone injury (VFI) in the selected tree species. The VFI was investigated in dominant deciduous tree species in the ITP and woody species in the LESS in late summer according to the methodology by ICP-Forests manual. The forest dominant tree species analysed at the ITP in ABR1 and LAZ1 were *Fagus sylvatica* and *Quercus cerris*, respectively. In the LESS *Rosa canina, Rubus ulmifolius* and *Sorbus aucuparia* were found and examined. The 10 and 30 cm depth exhibited a higher correlation between POD_1 and VFI compared to the other depth. The results support the hypothesis that a dried soil surface triggers stomatal closure, limiting stomatal O_3 absorption, regardless of water availability in deeper soil layers, leading to reduced visible leaf damage. This result demonstrates the importance of considering SWC depth when calculating the PODy in European cool-temperate deciduous tree species. Additionally, investigating the potential interactions between SWC and other environmental factors, such as temperature and humidity, could further enhance our understanding of the O_3 effects on forests.

On the relationship between forest status following bark-beetle disturbance and mineral nitrogen in soils of unmanaged mountain catchments: long-term in situ monitoring

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The spruce forests in the Czech Republic are severely affected by bark beetle infestation. Forest dieback reduces the nitrogen uptake of the trees. In unmanaged forests, large amounts of organic plant material end up in the soil, where it undergoes a transformation by microbes. Varying N availability, associated with the vegetation status and microbially mediated transformation of litter, determines the effectiveness of mountain forest soils to retain N and produce nitrates. N availability also affects leaching of other elements from the soil and the chemistry of lakes. From 2005 to 2023, we measured mineral N fluxes in the soils of two spruce forest catchments (Plešné (PL) and Čertovo (CT) lakes in Šumava National Park, CZ, without intervention, above 1000 m a.s.l.) using ion exchangers during forest dieback and subsequent regeneration. Forest dieback in PL increased the flux of mineral N through the soil after five years by up to 400% (2100 mmol N m^{-2} $year^{-1}$), compared to a nearly intact control catchment CT (500-1000 mmol N m^{-2} $year^{-1}$). During forest dieback, the ratio of nitrates to ammonium ions in the soil was 1:1, indicating a high rate of N mineralization. In the regeneration phase and in the control catchment throughout whole study period, soil nitrates dominated (~80-85%). Compared to the runoff of mineral N from the catchment into the lake, mineral N fluxes through the soil were ten times higher at the onset of disturbance culmination (2100 vs. 210 mmol N $m^{-2}year^{-1}$), indicating a relatively effective use of N in the soils despite minimal N immobilizations by the trees. The measured fluxes represent the maximum potential of such an ecosystem to supply a new generation of trees with available N if all biomass is left on site. This potential should be considered when defining management measures following disturbances in production forests. Finally, we discuss the extent to which soil N fluxes are driven by relevant environmental variables.

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Measured vs modelled: ozone concentrations in the Romanian forest plots (ICP-Forests Level II and LTER)

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Ozone is a secondary pollutant, being formed as a result of complex photochemical reactions involving precursors (NOx and VOCs). When present in elevated concentrations can have significant impacts on vegetation and act as a stressor with various ecological consequences. In Romania, ozone is measured in the ICP Forests Level II and LTER sites using both passive samplers and active monitors. Although direct measurements have the advantage to provide accurate and real-time information about the actual ozone levels in the atmosphere at a specific location, in analysing its long term effects on vegetation often longer timeseries are necessary, thus using modelled data. Our study aims to compare measured and modelled ozone concentrations in Romanian forest plots. We use measured data (both passive and active sampling) from Romanian ICP Forests Level II and Romanian Forest LTER sites plots and modelled data obtained from EMEP and CAMS European air quality reanalyses models. Preliminary results show that there are significant differences between measured (using passive samplers) and modelled data (EMEP) in all 4 core plots of the Romanian ICP Forests Level II network. More plots will be analysed and results presented.

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Intra-annual tree growth patterns in level II ICP Forests plots from Romania

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Under the climate change framework, with a continuous warming trend and an increasing frequency and intensity of drought, it is mandatory to understand how forest ecosystems react. Long-term monitoring of tree growth represents a valuable source of information about tree's capacity to react and adapt to environmental changes. In this study, we investigate intra-annual tree growth patterns of the fourth most common tree species (Norway spruce, European beech, English oak, and sessile oak) at the Romanian level over a 15-year span (2009 to 2023). The tree growth was assessed by band dendrometers with bi-monthly readings during the growing season and monthly readings during the dormancy season in Level II ICP Forests plots. Cumulative radial increments were modeled through a Gompertz function, and the day of the year featuring the maximum growth rate was determined using the first derivative of the function. Using a threshold of 5% and 95% from the maximum growth rate the start and the end of the growing season were defined. A Generalized Additive Mixed Model (GAMM) was used to analyze the daily growth rate at yearly and species levels. Preliminary results showed that English oak has the earliest start of growth while European beech exhibits the latest start. In terms of maximum radial growth, Norway spruce showed the highest values. For a better assessment of how climate influences radial growth, the Pearson correlations between the cumulative climate of 5, 10, 15, 20, and 30 days and daily growth were assessed. Preliminary results showed that precipitation from spring have a strong influence on oak growth while beech growth is limited by summer temperature. Our study provides valuable insights into the intra-annual growth patterns of the main tree species in Romania.

Development of mortality rates in Carpathian temperate forests

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Tree mortality is a key indicator of forest vitality. In current forestry practices, alongside quantifying forest production, understanding and measuring tree mortality is indispensable for assessing forest health. Moreover, tree mortality serves as a key indicator for forecasting forest carbon balance, metric of crucial importance in the context of climate change mitigation and sustainable forest management. Drawing on long-term observations (1992-2023) from a total of 130 ICP Forests Level I monitoring plots in Slovakia, this research investigated the tree mortality rates in temperate forests, predominately composed by main Carpathian tree species such as *Fagus sylvatica*, *Picea abies*, *Abies alba*, *Quercus petraea*, and *Pinus sylvestris*. Our study addressed tree mortality resulting from direct management-related human impact as well as other contributing factors. We analysed mortality rates in the context of climate extremes and other damaging factors (such as fungi, and insects) and their simultaneous effects on various tree community strata. The findings underscore that, despite the major impact of climate extremes, common natural processes such as competition in interplay with other damaging factors play a substantial role in influencing mortality rates over the observed three-decade period. This study confirmed the multifaceted nature of tree mortality phenomenon, highlighting the interplay between environmental stressors and intrinsic forest dynamics. Furthermore, our observations indicate a substantial level of uncertainty in the mortality evaluation process and challenges in isolating specific causes of mortality. For more accurate predictions, future research should aim to unravel the complex interplay of environmental, biological, and anthropogenic factors, enhancing our understanding and quantification of dynamic processes related to tree mortality.

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Fifty years of change across forest ecosystems in Britain: a story of interacting drivers and historical legacy effects

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We report an analysis of 50 years of change across British broadleaved woodlands based on ecological (vegetation, tree canopy and soils) observations in 103 broadleaved forest sites first sampled in 1971 and again in 2001 and 2021. Additional data were used as explanatory variables.

There were clear signals of historical timber extraction, pollutant deposition, climate change, deer herbivory and tree disease. Most sites saw tree populations age as stand development progressed from relatively youthful cohorts of trees in 1971 toward older and fewer larger stems by 2021. This was a cross-site pattern related to decline in broadleaved woodland management and an atypically open starting point reflecting widepread timber extraction at the end of World War II. These changes in the canopy have driven shading at ground level and reduced plant species richness by 22% in the 50 year interval. However, in the last 20 years shade-tolerant plants have shown a modest recovery. Against this backdrop of reduced disturbance, new agents of change have occurred. Dutch elm disease reduced *Ulmus* sp. over the entire period but in 2021, 21% of plots were also infected by ash dieback (*Chalara*). Defoliation admitted light into the understorey increasing plant species richness but only where high deer herbivory had debilitated *Rubus fruticosus* agg., a potential dominant that can suppress the ground flora.

Deer herbivory also increased markedly and was associated with reduced tree regeneration. In parallel sulphur deposition reduced driving an increase in soil pH. Nitrogen deposition remains high at many sites and we suspect that change in these two pollutatts coupled with ongoing reduction in offtake of nutrients has also driven a eutrophication signal in the understorey but this tends to be suppressed where soil pH remains naturally low and where the understrey is shaded.

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Response of soil microbes to long-term nitrogen input in spruce forest: results from Gårdsjön whole catchment N-addition experiment

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Chronic nitrogen input disrupts plant-microbe interactions in originally N-poor forests, based on a symbiosis of plants with ectomycorrhizal (ECM) fungi. ECM fungi that are capable of efficient nutrient mining from complex organics and their long-distance transport play a major role in controlling soil N mineralization and immobilization, and eventual nitrate leaching. The functioning of N-poor and N-overloaded (N-saturated) forests is well understood, while the transient stages are much less explored. We therefore focussed on the spruce-dominated catchment at Gårdsjön (Sweden, G2-NITREX) that at the time of our study received an N input of 40 kg N $ha^{-1}yr^{-1}$ over 24 years (a cumulative N input of 1,200 kg N ha^{-1}), but still lost via runoff only <20% of annual N input (deposition + addition) as NO_3^-. We found that the N addition catchment had a much larger soil microbial biomass compared to the control. The N did not change the fungi/ bacteria ratio, but a larger share of the bacterial community was made up of copiotrophs ("feast-and-famine" lifestyle). Fungal community composition shifted to more nitrophilic ECM fungi and saprotrophs. Such a restructured community has been more active, possessed a higher specific respiration rate, enhanced organic P and C mining through enzymatic production and provided faster net N mineralization and nitrification. These may be early indications of alleviation of N limitation of the system. We did not observe any signs of soil acidification related to N addition. These results suggest that a microbial community can contribute to effective soil N retention despite the partial relative retreat (20–30%) of nitrophobic ECM fungi with large external mycelia, provided the biomass remains high because of replacement by other ECM and saprotrophs. We conclude that microbial biomass and its metabolic activity is not necessarily threatened by a high cumulative N dose, provided N is added at a moderate rate, does not cause acidification and the persistent soil microbial community has time to adapt through structural and functional changes. This is likely one of the explanations for low nitrate leaching that have stabilized in the last decade. When fertilising commercial forests with nitrogen, it is therefore important to consider not only the quantity applied, but also the rate at which it is added.

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Transformation of forest humus forms in northwest Germany across three decades

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The classification of humus forms can serve as a valuable diagnostic instrument for evaluating the state of forest ecosystems and for monitoring changes in ecological processes like mineralisation and carbon sequestration over the time. Specifically, humus forms provide insights into the environmental factors and ecosystem dynamics occurring over extended time periods, giving valuable information on how anthropogenic influences have affected nutrient cycling, microbial activity, and the overall health of the forest soil. The classification of humus forms is made based on a composition, morphology, structure, and decomposition stage of the accumulated organic matter. In Germany, the humus forms classification adopts a morphogenetic systematic approach, utilizing diagnostic horizons and properties to infer the processes and pathways involved in its origin and development. As in other classification systems, aeromorphic and aero-hydromorphic humus forms range from Mull to Moder to Mor. This classification gradient not only reflects an increase in the thickness of the forest floor layer but also decreases in nutrient cycling rates.

In this study we investigated how forest humus forms have evolved and changed in northwest Germany over the past 30 years. Employing the German humus form reference base, we classified the humus types of 360 forested sampling sites located on an 8 x 8 km raster across four German states (Schleswig-Holstein, Lower Saxony, Saxony-Anhalt and Hesse). Sampling was conducted within the framework of the German National Forest Soil Inventory, known as the Bodenzustandserhebung im Wald (BZE), which was carried out every 16 years (namely in 1989/1990, 2006/2007, and 2023/2024).

Results show that based on these three BZE inventories, there was a general shift towards Mull and Moder humus forms. More specifically, the proportion of BZE points with Mull humus forms rose from 23% in BZE I to 31% in BZE II to 35% in BZE III. At the other end of the spectrum, the proportion of sites with Mor humus forms decreased from 26% in BZE I to 20% in BZE II and finally to only 9% in BZE III. The general trend toward these “better” humus forms indicates that various external factors have contributed to increased organic matter decomposition rates. This has led to, among other outcomes, an overall reduction in the thickness of the organic matter layer and improved nutrient cycling. There are several factors driving this change, including: (1) persistently high nitrogen deposition, (2) decreased acid deposition, (3) rising temperatures, (4) forest liming activities, (5) a shift towards more broadleaf forests instead of coniferous forests, (6) increased light reaching the forest floor, and (7) more understory rejuvenation.

While this general trajectory towards “better” humus forms might enhance the productivity of forest ecosystems, alterations in the morphology and chemistry of the forest floor layer may trigger a cascade effect on other ecosystem functions, impacting the carbon storage, nitrate leaching, and greenhouse gas fluxes within the ecosystem.

Environmental impacts on foliar nutrient trends of ICP Forests Level II data

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Foliar nutrient status represents an important tree health indicator. Nutrient availability to trees is regulated by environmental conditions and is affected by anthropogenic impacts like surplus deposition of reactive nitrogen (N) to forest ecosystems.

Here, we investigate >59k measurements of foliar nutrient concentrations from ICP Forests Level II plots within the scope of trend analysis for the planned Ecological Studies Book using linear mixed models. For the abundant European forest tree species pine, spruce, beech, and oak, we find that overall concentrations of foliar phosphorous (P) and sulphur (S) significantly declined in the past decades by a range of -6% to -3% and around -6% respectively averaged over 10 years relative to 2012. Further declines in foliar P concentrations could exacerbate nutritional P deficiencies, which we evaluated in 40–60% of foliage samples of the main tree species in 2017–2019.

In a follow-up analysis, we investigate the relative importance of multiple environmental factors on foliar nutrient concentrations including temporal changes in N and S deposition and interannual variations of water stress represented by the Standardized Precipitation Evaporation Index (SPEI) and long-term deviations from volumetric soil water content. Calculation of relative importance metrics is performed separately for forests of high and low nutrient availability in order to take different nutrient dynamics into account.

Analysis of the effects of soil parameters on radial stem growth for four spruce stands in Austria

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Climate change and as consequence, more intense drought spells and an increase in disturbances are major challenges for forest conservation and management in the future. Carbon uptake and storage is limited by cambial activity, which in turn is controlled by environmental conditions, in particular water shortage. To capture the immediate tree response, high frequency measurements are required which permit to analyse the timing, rate and dynamics of tree growth. It is the aim of this study to unravel details of tree growth response to water shortage.

The data of four intensively monitored *Picea abies* plots, collected as part of the ICP Forests Monitoring Programme over the period 2010-2020 were used. On these plots dendrometers installed on 10 trees each, capture hourly diameter increment in the micrometer range and contemporaneously also climate and soil moisture were monitored. Data were analysed using generalised additive mixed models.

Intra-annual growth was predicted by the day of the year, soil moisture, soil temperature, the interaction of soil moisture and soil temperature, the 24-hour moving average of temperature and precipitation, and tree ID as random effect to account for the hierarchical study design.

Diameter increment differed by site almost twice as high on the youngest plot Mondsee in comparison to the older plots, while beginning, culmination and cessation of the growing season were similar across sites. Diameter increment increased with soil temperature and soil moisture, at summer solstice effects were more pronounced than in autumn. With increasing soil moisture the positive effect of temperature decreased. The results of our study highlight the importance soil measurements within monitoring programmes.

Posters

Session 2: Novel monitoring approaches to support the development of resilient forests

Identification of the decline of individual trees due to the impact of drought using a database (Defoliation) as a „health card“ of previous events

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Long-term droughts have long been proven to have a major negative impact on individual trees and entire forest ecosystems. One of the first signs of these impacts is seen as an increase in defoliation. Defoliation, as a term referring to missing leaf mass, aims to indicate changes in tree metabolism, which over time can prove to be an excellent „health card“ of a tree. By looking at the chronology (database), we can accurately determine the „trigger“, i.e. time of onset of increased defoliation through follow-up years. By continuously monitoring certain trees, we saw the appearance of three different groups of defoliation and classified them all into the category with the final result of decline due to the impact of drought. Group I - Defoliation that gradually increased during the drought, and after a few years that decline occurred. Group II - Defoliation as a sudden phenomenon with complete loss of assimilation organs and the final outcome of decline. Group III - Defoliation in trees that for many years had higher percentages of defoliation and after a number of years stimulated by drought, decline occurred. These three groups of recorded defoliations are intended to show the different effects of the dry period on the trees. Each tree is an individual by itself and most often reacts in relation to its current condition, which in the drought period usually refers to the inability to absorb the necessary water from the soil. If the final result of decline, regardless of the separated group, occurs in the same time interval, we can come to the conclusion that the drought was the one that started and ended this phenomenon. Also, if a large number of decline trees (defoliation 100%) is registered during or after recorded extreme climatic events, then this is another excellent indicator of the effect of drought on defoliation and the ultimate cause of decline. Therefore, continuous monitoring of defoliation can be a key tool for understanding the processes occurring in forest ecosystems.

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Can silviculture foster forest genetic evolution? A demo-genetic modelling approach accounting for within-stand individual variability estimated from ICP forest data

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For naturally regenerated forests, which constitute the majority of forested areas worldwide, our understanding of the rate at which these forests can naturally evolve towards adaptation and the extent to which silviculture can influence this natural adaptation remain limited. To address these questions, we developed an eco-evolutionary approach using a demo-genetic individual-based model, Luberon2, that integrates forest dynamics processes, silviculture interventions and genetic diversity of tree growth and sensitivity to disturbances.

The adaptive potential of forest populations heavily relies on their intra-population genetic diversity. Therefore, meaningful predictions require careful consideration of plausible values for genetic parameters for the studied quantitative traits. We used dendrochronological data collected within stands of the French RENECOFOR network (ICP Forests Level II network) to estimate within-stand phenotypic variance of two fitness-related traits, vigour and sensitivity to drought stress. Then, from these empirical estimates, we derived genetic variance parameters using realistic heritability assumptions. Based on these genetic parameters, the predicted evolutionary rates from Luberon2 for both traits align with the observed microevolutionary rates documented for wild plant and animal populations, providing double validation for both the model and input data.

We propose to illustrate our approach through two simulation experiment conducted with Luberon2:

1. In forest ecosystems, natural selection depends on inter-individual competition which is manifested in particular by self-thinning, i.e. the death of the smallest trees when the density is high. We show a rapid increase in vigour and growth performance in monospecific cedar stands in response to selective competition. We also show that non-selective thinnings limits the evolution of stands by reducing competition.
2. A classic strategy for adapting to climate change is to maintain a low stand density to reduce water stress level during droughts. We show that reduction in stand density reduces or even eliminates natural selective mortality due to competition and drought stress in monospecific Douglas-fir stands. We also show that introducing anthropogenic selection (selective thinning) can lead to higher evolutionary rates than natural selection alone. Finaly, we show that a strategy designed to foster genetic evolution by avoiding early and non-selective thinnings, thereby promoting both natural and anthropogenic selection successively, can ultimately result in better stand performance than a strategy only focused on drought stress reduction, all while maintaining long-term evolvability.

Comparison of open land precipitation regimes with forest stand precipitation regimes and calculation of interception rates on the ICP-forest core plot "Klausenleopoldsdorf"

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The intensive monitoring plots of the ICP-forest program (Level II plots) provide high-quality data for tree vitality, adaptability of trees, nutrient cycles, critical load rates and the water balance since 1995. Based on this data, essential statements about climate change, air pollution, biodiversity and the condition of the forest can be made. In Austria forest condition monitoring has been implemented by the Federal Research Centre for Forests (BFW) in 1999. In this study the impacts of the dry years 2021 and 2022 on the precipitation regime of a beech stand are compared and interpreted based on long-term monitoring data of the Level II plot Klausen-Leopoldsdorf. The data sets (i.e. precipitation, interception rates) were evaluated over a period of 13 years (2010-2023). The used data come from a free land weather station, 15 forest stand precipitation collectors, 3 free land precipitation collectors within the forest stand and a station of the Austrian weather service (GEOSPHERE Austria) located near the investigated area. In addition, 3 stem flow collector are installed on the observed plot.

The precipitation data of this station were used as a reference and for the validation of the observed long-term precipitation data. The obtained results correspond to already published values in the literature.

In forest ecosystems, rainfall is partitioned by forest canopies into throughfall, stemflow and interception loss. All these parameters could be measured by our equipment or could be calculated from the measurement results. For this reason, we got a detailed long-term insight into the partitioning of the precipitation amounts within the forest stand.

Due to a predicted increase in the mean annual temperature and consequently higher water demand of the forests, the observation and interpretation of climate data of forest sites near large cities is of great importance (e.g. the Vienna Woods for Vienna). This will contribute to better fitted management practices to get climatic resilient forest stands near urban agglomerations.

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Ambient ozone behaviour near the ground: Insight into seven-year continuous measurements at a rural Central European site tall tower

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In contrast to horizontal representativeness of ambient air quality measuring sites, the vertical representativeness of ambient air pollutant concentration measurement in fixed point is explored rarely though it is an important aspect affecting the use and correct interpretation of measured data. In this study we analyse the measurements from the tall tower monitoring the levels of green-house gases and other atmospheric substances including ozone (O_3). Spare studies on the vertical distribution of air pollutants are aimed at urban areas, where in built-up spaces the dispersion of air pollutants differs substantially from rural regions. For rural site, however, such a study is – to our best knowledge – currently unique. Hereby we present the analysis of the daily mean O_3 concentrations measured at four heights above the ground (i.e. 2, 8, 50 and 230 m) at the rural Central European site Košetice in 2015–2021 (Hůnová et al., 2023). We apply the semiparametric GAM (generalised additive model) approach to analyse the data, using their decomposition into annual trend and seasonality. We found consistently increasing O_3 concentrations with increasing height above the ground. The vertical O_3 concentration gradient in 2–230 m is not uniform, however, but changes substantially with increasing height and shows by far the highest dynamics near the ground between 2 and 8 m, differing in both the seasonal and annual aspects for all the air columns inspected. Study of O_3 concentrations at one site at several different heights above the ground brings useful results complementing ground-based ambient air quality monitoring, provides a deeper insight into the 3D structure of the atmosphere and the pollution, and provides valuable information for environmental studies exploring processes above the ground. Knowledge on vertical distribution of O_3 concentrations near ground is, besides other things, an important input to ecological and environmental studies associating the air pollution with its impact on ecosystems.

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Chlorophyll contents and their relationships with nutrients and δ13C

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The chlorophyll contents of the evergreen endangered species *Juniperus drupacea* Labill. were assessed in the tree needles derived from 30 trees in the area Parnon Mountain, southern Greece. It was found that the averages of chlorophyll concentrations were 1.307 for the chlorophyll a, 0.538 for the chlorophyll b and 0.448 mg g^{-1} for the total carotenoids. The coefficients of variation were not high (around 23% for the chlorophylls and 16% for the total carotenoids). Significant and positive correlations were found between the concentrations of both chlorophylls, carotenoids and Fe in plant tissues. In addition, N concentrations in needles were significantly correlated with the chlorophyll a content. The $\delta^{13}C$ correlated significantly and negatively with all the chlorophyll and carotenoids concentrations. High concentrations of $\delta^{13}C$ mean drought stress and that stress can affect the chlorophyll contents and as a result the photosynthesis rate.

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Monitoring of the European mistletoe distribution based on remote sensing data

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Mistletoes, hemiparasitic aerial plants, play a controversial role in ecosystems, creating uncertainty for foresters and conservationists. They are among the major biotic stressors of host trees, along with other pathogenic organisms that can affect their vitality and longevity, causing significant losses in wood production. However, mistletoes are rich biodiversity hotspots in forests, contributing as shelter and food source for diverse organisms. In the Czech Republic, mistletoe is represented by two species – yellow-berried mistletoe (*Loranthus europaeus*; Loranthaceae), predominantly parasitizing oaks, and the European mistletoe (*Viscum album*; Viscaceae) with a broad host range. There has been a significant increase of an infestation of all *V. album* subspecies on both forest and non-forest trees in recent decades, probably, due to the steady climate warming. The monitoring of mistletoe occurrence in forest stands is carried out within the ICP Forests plots in the Czech Republic as part of field measurements for the National Forest Inventory (NIL), and at the local level in frames of an independent research projects.

The study demonstrates the contribution of remote sensing airborne and UAV (Unmanned Aerial Vehicle) data to detect and characterize the European mistletoe distribution on two deciduous forest sites in the Czech Republic. To map mistletoe infestations in the floodplain deciduous forest site and detect mistletoes on the top of a tree canopy, the airborne hyperspectral data in near-infrared and shortwave infrared regions were acquired by Flight Laboratory of Imaging Systems (FLIS, CzechGlobe) several times during a vegetation season. The accuracy of mistletoe detection was distinguished up to 92%, using the automatic algorithm for airborne data processing acquired at the end of March.

Using the combination of SfM (structure of motion) and LiDAR (Light Detection and Ranging) methods, a poplar windbreak heavily infested with *V. album* was scanned by UAV in the southeast of the Czech Republic (Mohelnice city environs) and the primary data were further analyzed by machine learning algorithms. Based on the studies of mistletoe topology in individual tree canopies, it was found that SfM detects the peripherally located mistletoes with higher resolution as compared to those located close to the host tree stems and branches, while LiDAR can resolve much better the “hidden mistletoes”, which can be done also during the vegetation period.

Detection and sampling of mistletoe remain challenging for plant biologists, arborists, dendrologists, forest ecologists, and other experts due to the limited access to the upper canopy of host trees. Airborne remote sensing and UAV data have a developing potential to provide quick, precise, and cost-effective detection and research on mistletoe at the tree level and over the large areas.

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AI-assisted time-series analysis

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We focus on developing a nowcasting framework for dendrometer data across Europe. The data used is collected through the EU-funded FORWARDS project and the TreeNet research and monitoring network. The main objective is to create a fully automated pipeline that processes and cleans a continuous stream of raw data obtained from field sensors in near real-time. This includes the removal of outliers, noise and artefacts, and gap-filling using different approaches. We also focus on short-term predictions based on dendrometer readings of neighbouring trees together with soil and atmospheric conditions.

Most of the data processing methods adopted are based on machine learning techniques, principally deep neural networks. We explored the state-of-the-art algorithms available in the literature, adapting them for use with dendrometer signals. As a result, we created a scalable software framework that allows different data sources and an increasing volume of data.

We developed an automated machine-learning module capable of gap-filling dendrometer time series across time scales up to at least 10 days. We also evaluated the feasibility of dendrometer signal reconstruction from multiple dendrometer signals originating from trees different from the one being examined together with site and tree characteristics.

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TreeNet project web page: https://treenet.info/

Investigating the relationship between crown defoliation and remote sensing indicators of vitality at the single tree level

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To observe ongoing changes in forest health status, national and international monitoring programs like the “Visual Assessment of Crown Condition and Damaging Agents” as part of ICP forest were established. Germany monitors 410 sample plots with almost 10,000 trees on a Level I grid 16 km x 16 km. The main indicator is crown defoliation, defined as the loss of needles/leaves in the assessed crown compared to a healthy reference tree. However, remote sensing products derived from multispectral imagery or airborne laser scanning (ALS) are not yet included in the WZE assessment process. Remote sensing products allow for large-scale analysis at different temporal and spatial resolutions and can support field data collection by providing structural information. In order to fill the gap between tree-based field surveys and area-based remote sensing products, the project “Ground truth for remote sensing based on crown condition survey (WZE)” has been initiated. The main objective of the project is to investigate the relationships between the vitality indicators crown defoliation and other biophysical parameters with vegetation, vitality indices from remote sensing. This analysis will be conducted at single tree level with the help of accurate GNSS measurements and ALS data.

Positional data for all points of the four-point cross-cluster design for each sample plot are being recorded using a high-precession GNSS receiver with the universal real-time kinematic (RTK) method. Information about tree positions is being recorded in the form of polar coordinates. Additional field data collection includes individual tree measurements such as diameter at breast height, tree height, crown base height. The data is used to provide the ground truth for remote sensing products of tree vitality at single tree precision. Further datasets for analysis include the digital twin high-resolution ALS data to create an individual tree crown dataset resulting from the segmentation of 3D point clouds. Each ALS-derived tree crown will be assigned to a stem from the ground-based inventory. Based on this, the relationship between the crown defoliation and the different vegetation indices of existing remote sensing products will be investigated. Subsequently, different spatially explicit and implicit competition indices will be derived to analyse the effect of competition on defoliation for each WZE tree. In addition to the statistical data analyses, a mechanistic approach will be tested by calculating the leaf area density per sample tree from the ALS point clouds and relating it to its crown defoliation values. By providing all this spatially explicit information at single tree crown level, the project will help to bridge the gap between the ground-based crown condition survey and satellite remote sensing.

How water isotopes can improve predictions of the water balance

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Forests influence and greatly rely on water fluxes from soils to the atmosphere. This water partitioning becomes particularly relevant in the context of climate change, where reduced precipitation and increased atmospheric demand pose challenges to forest ecosystem resilience. In this regard, Soil-vegetation-atmosphere transfer models (SVAT) are helpful for inferring water partitioning and water balance. However, a large unknown in these models is the root water uptake. For instance, do different species access different water pools, and which species have the plasticity to switch to deeper soil water pools during a drought? Stable water isotopes can provide valuable insights to answer those questions, ideally combined within an SVAT model framework.

This study focused on advancing the SVAT model LWF-Brook90 by water isotope transport – the LWFBrook90.jl. We fitted the model at 10 Swiss ICP-Forests Level II plots. In addition to hydrometric data, we used water isotope composition to constrain the model. For this purpose, we collected xylem and soil samples in 2021 and 2022. These samples were cryogenically extracted at WSL and analyzed on a Picarro 2140 laser spectrometer. In addition, we analyzed the isotope composition of water samples from precipitation samplers outside the forest and below the canopy (from 2017-2022) and soil solution from suction cup lysimeters in three soil depths of the forest soil.

The water isotope signatures of xylem samples varied across the season and between tree species. They indicated that oak, followed by beech and maple, are more efficient than fir and spruce in accessing deeper water pools in periods of drought. Even though this temporary shift to deeper water pools may be decisive for the trees‘ survival, the overall reduction of total root water uptake indicates that deeper root water uptake may not entirely release drought stress.

In conclusion, this study contributes to understanding species-specific abilities to cope with scarce water resources. We will further show the combined potential of stable water isotopes and advanced modelling techniques in assessing species-specific drought resilience.

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Arsenic and cadmium in the hydrological cycle and soil in a maquis broadleaved evergreen forest stand in Greece. Sources of some Uncertainties

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The concentrations and fluxes of arsenic (As) and cadmium (Cd) were examined in the hydrological cycle (bulk, throughfall deposition and percolation water), litterfall and soils in a maquis broadleaved evergreen forest stand in western Greece. The concentrations of the metals in the hydrological cycle ranged from 0.076 to 0.306 μg L^{-1} and 0.040-0.050 μg L^{-1} for As and Cd, respectively. These concentrations were far below the alarm limits set by the World Health Organization for waters regarding these two elements. It was found that the enrichment of As in the atmosphere was both due to suspended geogenic material and long range transfer, whereas for Cd the long range transfer was the predominant way for deposition in the ecosystem. This finding was expected for Cd but not for As for which the geogenic material was not considered important. Two models were assessed to find the volumes of percolation water and therefore the fluxes of As and Cd in the water that leave the ecosystem permanently, which were compared with the estimated values derived from soil moisture measurements. The WBS3 model was found to perform better than the other models. When calculating the total amounts of the heavy metals in soils, the statistical uncertainty derived from every soil layer has to be taken into account. This is useful when calculating the ranges of the total elemental amounts in soils. The residence time of Cd in the forest floor (L+FH) of the soils was found 6.4 years, whereas that of As 36.3 years. This difference shows the mobility of Cd in comparison to As in the soils of the area.

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Impacts of ground-level ozone on vegetation in Czechia – assessment using visible foliar symptoms, AOT40F and MDA

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Eight plots of intensive forest monitoring established within the UN-ICP Forests programme have been selected in different regions of the Czechia, at altitudes ranging from 350 to 1300 m. These sites are suitable for our study because of the possibility to assess visible foliar O_3 injury on nearby forest edges with a suitable composition of plant species. They are also fully equipped for meteorological and soil moisture measuring and there is also a historical connection with older ground-level ozone studies. Norway spruce (*Picea abies*, (L.) Karst) and European beech (*Fagus sylvatica*, L.) are main species evaluated, but also other woody species as well as shrubs and herbs are evaluated. The evaluation is carried out twice a year – in the late spring (June) and late summer (August-September) before natural leaf discoloration sets in.

Our results to date are complemented by the content of MDA (i.e., malondialdehyde, a product of peroxidation of the cell-membrane lipids and subsequently, a biomarker of oxidative stress) and AOT40 analysis for forests (AOT40F).

The aim of our work is to evaluate the impact of ground-level ozone on forest stands in Czechia. Our hypothesis is that current O_3 levels result in forest tree impacts demonstrated by visible symptoms on leaves. Our preliminary evaluation is based on results obtained in two growing seasons (2021 and 2022) out of five planned in total (2021–2025). To this end we explore the visible foliar O_3 symptoms, MDA content, AOT40F levels and environmental conditions at individual sites. In the next two years, in addition to the above-mentioned indicators of ozone impact on vegetation, we will focus on the evaluation of POD_1 for beech and spruce on the sites.

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Underestimation of potassium in forest dry deposition? – A simulation experiment in rural Germany

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Combined measurements of throughfall (TF) and wet deposition (WD) are a common method to assess nitrogen (N) and base cation (BC) deposition to forests. Using TF and WD, dry deposition (DD) and total deposition (TD) are usually calculated with a canopy budget model (CBM) assuming similar BC to Na^+ ratios in WD and DD. This assumption is especially uncertain for K^+, since K^+ is often bound to smaller particles compared to Na^+. Here we asses this assumption by comparing the DD of K^+ estimated with the CBM () to the DD of K^+ simulated with a process-oriented DD model ("inferential model"). We performed simulation experiments at two indicator forest stands ("virtual" broadleaved (BL) and coniferous (CF) forest) based on six years of daily $PM_{2.5}$ and PM_{10} concentrations and weekly WD observations measured at the rural background research station Melpitz, Germany. On average, the K^+:Na^+ ratio in WD was 0.24 while the K^+:Na^+ ratio in DD^{INF} was 0.33 (CF) and 0.31 (BL), respectively. Accordingly, would need to be mutiplied by a correction factor of 1.37 (CF) and 1.29 (BL) to match , with substantial variation between years. Applying the correction factors in CBM calculations at nearby ICP Forests monitoring sites had only little effect on TD rates of N and BC. The results were robust against changes in the meteorological data used for the inferential model. However, considerable uncertainty arises from periods affected by presence of particles larger than 10 µm diameter, not covered by local measurements. Excluding periods potentially affected by large K^+ containing particles (e.g from soil dust) resulted in higher correction factors (1.77 for CF and 1.66 for BL). More work is required to assess to what extet the observed underestimation of is confirmed by other methods and at sites with different atmospheric conditions.

Monitoring of tree growth with different types of dendrometers

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Dendrometers are used to continuously monitor tree growth and its intra-annual variation. They capture not only growth processes, but also temporary shrinkage and swelling due to dehydration and subsequent tissue rehydration. Simple manually read permanent girth bands or electronic circumference or point dendrometers with a high frequency of recording are used. Girth bands, depending on the frequency of readings, record stem size variation in weekly, biweekly or monthly intervals. They can be used for reliable permanent measurement of the annual radial increment. Electronic dendrometers record stem size variation with high time resolution in intervals between several minutes to hours and thus monitor continuously the growth and physiological response of trees to climatic factors, especially water availability. Automatic dendrometers, like other electronic devices, are prone to measurement errors e.g. sudden jumps in measurement series, outages in data storage etc. Therefore it is recommended that manually read girth bands are also installed along with electronical dendrometers in the event of damage or failure of equipment.

In the Czech Republic continuous monitoring of growth on ICP Forests Level II plots has been established in 2010. Girth bands DB20 and electronic circumference dendrometers DR26 manufactured by EMS Brno have been used since the beginning. Long-term monitoring by both types of dendrometers placed on the same tree allows to verify the measurements of electronic dendrometers. The results show that growth curves from manual and automatic band dendrometers correspond very well, however, after 4-6 years from the beginning of the measurement, the curves start to diverge, with electronic dendrometers recording consistently lower values of radial growth than girth bands. This indicates the need for calibration of electronic dendrometers after 4 years at the latest.

Recently low-cost point dendrometers D1 (TOMST) were installed on selected ICP Level I and Level II plots. To verify the measurements of new equipment, both types of electronic dendrometers were mounted on selected trees. After two years of joint measurement, it is clear that there is a close correlation between the measured series, however, in absolute values there are significant differences between circumference and point dendrometers, while the values of radial increment recorded by point dendrometers are several times higher than those from circumference dendrometers.

The results of the comparison show that the selection of dendrometer type must be made primarily with regard to the research objectives. Implications for data interpretation and pooling of datasets from different types of dendrometers are discussed.

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The International Soil Moisture Network (ISMN): providing a permanent service for environmental assessments

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Soil moisture is recognized as an Essential Climate Variable (ECV), because it is crucial to assess water availability for plants and hence food production. Having long time series of freely available and interoperable soil moisture data with global coverage enables scientists, practitioners (like farmers) and decision makers to detect trends, assess the impacts of climate change and develop adaptation strategies.

This presentation is going to showcase the International Soil Moisture Network (ISMN) that is hosted by International Centre for Water Resources and Global Change (ICWRGC) and the German Federal Institute of Hydrology (BfG) in Koblenz (Germany). Beyond offering comprehensive in situ soil moisture data, ISMN freely disseminates additional environmental variables, including soil temperature, snow depth, snow water equivalent, precipitation, air temperature, surface temperature and soil water potential if they are available from our data providers. With a global reach, ISMN has already accumulated 3000 stations with observations at various depths, while about 1000 stations are updated on a daily basis. These observations are harmonized and automatically quality checked before they are made accessible to our various users. ISMN served its 2000 users with more than 5500 data downloads in 2024 alone.

Ongoing efforts are concentrated on expanding the database by incorporating additional stations and networks from institutional or governmental sources. Substantial resources are directed towards fortifying the operational system and improve usability to better serve our users. Additional efforts are undertaken to include ISMN in the data-to-value chain by contributing to international initiatives like WMO, FAO and GCOS. One example is the contribution to WMO's yearly Global State of the Water Resources report.