BOOK OF ABSTRACTS

TRACE 2024 – Tree Rings in Archaeology, Climatology and Ecology

BRAȘOV, ROMANIA, 3 - 8 JUNE 2024

TRACE 2024 – Tree Rings in Archaeology, Climatology and Ecology

the annual meeting and international conference of the Association for Tree-Ring Research (ATR)

BRAȘOV, ROMANIA, 3 - 8 JUNE 2024

Local organizing committee:

Ana-Maria Hereş, Ion Catalin Petritan, Elena Ciocîrlan, Mihai Daniel Niță

Faculty of Silviculture and Forest Engineering, Transilvania University of Braşov

TRACE 2024 – Tree Rings in Archaeology, Climatology and Ecology

SCIENTIFIC COMMITTEE*

- **Ana-Maria Hereş**, Transilvania University of Braşov, **RO**
- **Ion Catalin Petritan**, Transilvania University of Braşov, **RO**
- **Any Mary Petritan**, National Institute for Research and Development in Forestry Marin Dracea, **RO**
- **Isabel Dorado-Liñan**, Universidad Politécnica de Madrid, **ES**
- **Stefan Klesse**, Swiss Federal Institute for Forest, Snow and Landscape Research (WSL), **CH**
- **Neil Loader**, Prifysgol Abertawe / Swansea University, **UK**
- **Martin Häusser**, Friedrich-Alexander-Universität Erlangen-Nürnberg, Institut für Geographie, **DE**
- **Eunice Romero**, Charles University in Prague, **CZ**
- **Peter Prislan**, Slovenian Forestry Institute, **SI**
- **Valentina Vitali**, Swiss Federal Institute for Forest, Snow and Landscape Research (WSL), **CH**
- **Montana Puscas**, Terra Analitic SRL, **RO**
- **Guillermo Gea-Izquierdo**, ICIFOR-INIA, CSIC, **ES**
- **Dario Martin-Benito**, ICIFOR, INIA-CSIC, **ES**
- **Roberta D'Andrea**, Université Toulouse - Jean Jaurès, CNRS Délégation Occitanie Ouest, **FR**
- **Ania Cedro**, University of Szczecin, **PL**
- **Achim Bräuning**, Institute of Geography, Friedrich-Alexander-University Erlangen-Nuremberg, **DE**
- **Michal Bosela**, Technical University in Zvolen, **SK**

***** screened and selected all the abstracts for oral and poster presentations

TRACE 2024 – Tree Rings in Archaeology, Climatology and Ecology

SUMMARY

The programme of the TRACE2024 includes:

5 WORKSHOPS:

- **Blue Intensity for Historical Dating**, led by **Rob Wilson** (University of St. Andrews, UK);
- **Diagnosing the Technological Quality of Wood by Means of Tree Rings**, led by **Mariana Domnica Stanciu** (Faculty of Mechanical Engineering, Transilvania University of Braşov, RO) & **Florin Dinulică** (Faculty of Silviculture and Forest Engineering, Transilvania University of Braşov, RO);
- **Dendro-Statistics**, led by **Jernej Jevšenak** (Technical University of Munich, DE; Department for Forest and Landscape Planning and Monitoring, Slovenian Forestry Institute, SI) & **Ernst van der Maaten** (Chair of Forest Growth and Woody Biomass Production, TU Dresden, DE);
- **The Use of Dendrometers for Monitoring Intra-Annual Growth Patterns and Drought Stress**, led by **Roberto L. Salomón** (Departamento de Sistemas y Recursos Naturales, Research Group FORESCENT, Universidad Politécnica de Madrid, ES) & **Antonio Gazol** (Instituto Pirenaico de Ecología (IPE-CSIC), ES);
- **Design and Deliver Effective Scientific Presentations**, led by **Alan Crivellaro** (Department of Agricultural, Forest and Food Sciences, DISAFA, University of Torino, IT).

8 SESSIONS:

- **Climate sensitivity of tree growth**, Session chairs: **Isabel Dorado-Liñan** (Universidad Politécnica de Madrid, **ES**), **Evrim A. Sahan** (Universidad Politécnica de Madrid, **ES**) & **Stefan Klesse** (Swiss Federal Institute for Forest, Snow and Landscape Research (WSL), CH);

- **Developments in Dendro Methods**, Session chairs: **Neil Loader** (Prifysgol Abertawe / Swansea University, UK) & **Martin Häusser** (Friedrich-Alexander-Universität Erlangen-Nürnberg, Institut für Geographie, DE);
- **Wood Anatomy**, Session chairs: **Eunice Romero** (Charles University in Prague, CZ) & **Peter Prislan** (Slovenian Forestry Institute, SI);
- **Stable Isotope Applications**, Session chairs: **Valentina Vitali** (Swiss Federal Institute for Forest, Snow and Landscape Research (WSL), CH) & **Montana Puscas** (Terra Analitic SRL, RO);
- **Miscellaneous Dendroecology**, Session chairs: **Guillermo Gea-Izquierdo** (ICIFOR-INIA, CSIC, ES) & **Dario Martin-Benito** (ICIFOR-INIA, CSIC, ES);
- **Forest ecosystems**, human activities, and climate change dynamics, Session chairs: **Roberta D'Andrea** (Université Toulouse - Jean Jaurès, CNRS Délégation Occitanie Ouest, FR) & **Ania Cedro** (University of Szczecin, PL);
- **Functional DendroEcology**, Session chairs: **Guillermo Gea-Izquierdo** (ICIFOR-INIA, CSIC, ES) & **Dario Martin-Benito** (ICIFOR-INIA, CSIC, ES);
- **Past Climate Reconstructions**, Session chairs: **Achim Bräuning** (Institute of Geography, Friedrich-Alexander-University Erlangen-Nuremberg, DE) & **Michal Bosela** (Technical University in Zvolen, SK).

2 KEYNOTE SPEAKERS:

- **Katarina Čufar**, University of Ljubljana, Biotechnical Faculty, SI;
- **Jesús Julio Camarero Martínez**, Instituto Pirenaico de Ecología (IPE, CSIC), ES

57 ORAL PRESENTATIONS

80 POSTER PRESENTATIONS

PROGRAMME

WORKSHOPS: MONDAY, 03 OF JUNE 2024

PLACE: Faculty of Silviculture and Forest Engineering, Transilvania University of Braşov

ADDRESS: Sirul Beethoven, nr. 1, corpul "S", 500123 Brasov. If you get lost, just ask for **Poarta Ecaterina** (see the *TRACE2024_Brasov_Locations* document) … we will be there waiting for you.

Schedule	Workshop title / Led by	Workshop title / Led by
08:30 –10:00 **10:00 – 10:30 (coffee break)** **10:30 – 12:00**	**Blue Intensity for Historical Dating** / **Rob Wilson** (University of St. Andrews, UK)	**Diagnosing the Technological Quality of Wood by Means of Tree Rings** / **Mariana Domnica Stanciu** (Faculty of Mechanical Engineering, Transilvania University of Braşov, Romania) & **Florin Dinulică** (Faculty of Silviculture and Forest Engineering, Transilvania University of Braşov, Romania)
12:00 – 14:30	**LUNCH BREAK**	
14:30 – 16:00 **16:00 – 16:30 (coffee break)** **16:30 – 18:00**	**Blue Intensity for Historical Dating** / **Rob Wilson** (University of St. Andrews, UK)	**Diagnosing the Technological Quality of Wood by Means of Tree Rings** / **Mariana Domnica Stanciu** (Faculty of Mechanical Engineering, Transilvania University of Braşov, Romania) & **Florin Dinulică** (Faculty of Silviculture and Forest Engineering, Transilvania University of Braşov, Romania)

WORKSHOPS: TUESDAY, 04 OF JUNE 2024

PLACE: Faculty of Silviculture and Forest Engineering, Transilvania University of Braşov

ADDRESS: Sirul Beethoven, nr. 1, corpul "S", 500123 Brasov. If you get lost, just ask for **Poarta Ecaterina** (see the *TRACE2024_Brasov_Locations* document) … we will be there waiting for you.

Schedule	Workshop title / Led by	Workshop title / Led by
08:30 –10:00 **10:00 – 10:30 (coffee break)** **10:30 – 12:00**	**Dendro-Statistics /** **Jernej Jevšenak** (Technical University of Munich, Germany; Department for Forest and Landscape Planning and Monitoring, Slovenian Forestry Institute, Slovenia)	**The Use of Dendrometers for Monitoring Intra-Annual Growth Patterns and Drought Stress /** **Roberto L. Salomón** (Departamento de Sistemas y Recursos Naturales, Research Group FORESCENT, Universidad Politécnica de Madrid, Spain) & **Antonio Gazol** (Instituto Pirenaico de Ecología (IPE-CSIC), Spain)
12:00 – 14:30	**LUNCH BREAK**	
14:30 – 16:00 **16:00 – 16:30 (coffee break)** **16:30 – 18:00**	**Dendro-Statistics /** **Ernst van der Maaten** (Chair of Forest Growth and Woody Biomass Production, TU Dresden, Germany)	**Design and Deliver Effective Scientific Presentations /** **Alan Crivellaro** (Department of Agricultural, Forest and Food Sciences – DISAFA, University of Torino, Italy)
19:00	**ICE-BREAKER (JUNO Wine Garden; După Ziduri, Brașov 500026;** see the *TRACE2024_Brasov_Locations* document**)** **& REGISTRATION**	

WEDNESDAY, 05 OF JUNE 2024

CONFERENCE VENUE: Aula Sergiu Chiriacescu

ADDRESS: 41 A Iuliu Maniu Street, Brasov, 500091 (see the *TRACE2024_Brasov_Locations* document)

08:00 – 09:00	**REGISTRATION & HANGING of POSTERS**	
09:00 – 09:30	**CONFERENCE OPENING – Alexandru Lucian Curtu, dean of the Faculty of Silviculture and Forest Engineering, Transilvania University of Braşov**	
Climate sensitivity of tree growth (first part) Session chairs: Isabel Dorado-Liñan, Evrim A. Sahan & Stefan Klesse		
09:30 – 09:42	Andrei Popa	Divergent temporal shifts in climate sensitivity of Norway spruce along an elevational and continentality gradient in the Carpathians (**O1; student**)
09:42 – 09:54	Inga K. Homfeld	Assessment of climate signal of multiple tree growth parameters in *Pinus sylvestris* (**O2; student**)
09:54 – 10:06	Enrico Tonelli	Variation in radial growth sensitivity to drought among fine-scale gene pools of common yew (*Taxus baccata* L.) in central Italy (**O3; professional**)
10:06 – 10:18	Rupesh Dhyani	Deciphering climate and disturbance impact on tree growth in the Lesser Caucasus: Insights from a tree ring blue intensity network (**O4; student**)
10:18 – 10:30	Samresh Rai	Contrasting impacts of climate warming on Himalayan hemlock growth: Seasonal and elevational variations (**O5; student**)
10:30 – 10:42	Liangjun Zhu	Permafrost melting enhances growth but leads to less intra-annual density fluctuations in boreal *Larix gmelinii* forests (**O6; professional**)
10:42 – 11:00	*Summary and discussion*	
11:00 – 11:30	**Coffee break**	
Climate sensitivity of tree growth (second part) Session chairs: Isabel Dorado-Liñan, Evrim A. Sahan & Stefan Klesse		
11:30 – 11:42	Martin Šenfeldr	Variable climate-growth relationships of quaking aspen (*Populus tremuloides*) among Sky Island mountain ranges in the Great Basin, Nevada, USA (**O7; professional**)

11:42 – 11:54	Karen Uribe	Relationship between climate factors and tree growth of *Tachigali colombiana* in an ever-wet tropical forest (**O8; student**)
11:54 – 12:06	Ricardo Tejada-Arango	Phenology and multitemporal tree growth of Spanish elm Cordia alliodora from tropical Andes (**O9; student**)
12:06 – 12:18	Ernesto J. Reiter	From stable slow-grown to vulnerable fast-growing: the divergent pathway of north Patagonian tree species under climate change (**O10; student**)
12:18 – 12:30	Isabella Aguilera-Betti	Growth patterns of the southernmost conifer, *Pilgerodendron uviferum*, in Patagonia (**O11; student**)
12:30 – 12:42	Jan Tumajer	Using the VS-Lite model to understand an interplay between the extension of growing season and increasing summer drought stress toward the end of the 21st century (**O12; professional**)
12:42 – 13:00	*Summary and discussion*	
13:00 – 14:30	**Lunch break**	
Developments in Dendro Methods Session chairs: Neil Loader & Martin Häusser		
14:30 – 14:42	Martin Häusser	A Novel approach to date intra-annual tree-ring isotopes (**O13; professional**)
14:42 – 14:54	Krešimir Begović	Scratching the surface" of the novel reflected-light QWA methodological approach (**O14; professional**)
14:54 – 15:06	Elina Sahlstedt	A novel method for analyzing $\delta^{18}O$ by laser ablation IRMS (**O15; professional**)
15:06 – 15:18	Tito Arosio	Potential and limitations of different tree-ring stable isotope chronology development techniques (**O16; professional**)
15:18 – 15:30	Stefan Klesse	Reclaiming data integrity compromised by cell wall degradation in multi-millennial MXD data using tree-ring anatomy (**O17; professional**)
15:30 – 15:42	Elisabetta Dixon	The importance of maintaining uncertainty: a Bayesian approach to constraining error and variation in chronology building (**O18; student**)
15:42 – 16:00	*Summary and discussion*	
16:00	**Group photo**	
16:15 – 18:00	**Coffee break & POSTER SESSION** (for the complete list of posters, see the last page of the programme)	
18:00 – 19:00	**ATR MEETING**	

THURSDAY, 06 OF JUNE 2024

CONFERENCE VENUE: Aula Sergiu Chiriacescu

ADDRESS: 41 A Iuliu Maniu Street, Brasov, 500091 (see the *TRACE2024_Brasov_Locations* document)

08:30 – 09:00	**KEYNOTE SPEAKER: Katarina Čufar** Long reference chronologies and chronology networks – why do we need them?	
Wood Anatomy **Session chairs: Eunice Romero & Peter Prislan**		
09:00 – 09:12	Giovanni Bicego	A simple experiment designed to challenge the idea that xylem characteristics are determined by cambial age (**O19; student**)
09:12 – 09:24	Danyang Yuan	Radial growth and xylem adjustment of Mongolia oak to recent warming in the dry and wet areas of northeast China (**O20; student**)
09:24 – 09:36	Ismael J. Borreguero	Reduced precipitation alters xylogenesis of two Mediterranean oak species (**O21; professional**)
09:36 – 09:48	Antonia Kölzer	Assessing European beech responses to climate variability and ecological disturbances using Quantitative Wood Anatomy (**O22; student**)
09:48 – 10:00	Marek Fajstavr	Cell-wall Matters! Sap Flow as an Explanatory Power Indicating How Trees Allocate Carbon into Cell-walls in Temporal Resolution (**O23; professional**)
10:00 – 10:12	Silvia Piccinelli	Xylem traits of peatland Scots pine reveal complex intra-seasonal hydro-climate signals (**O24; professional**)
10:12 – 10:30	*Summary and discussion*	
10:30 – 11:00	**Coffee break**	
Stable Isotope Applications **Session chairs: Valentina Vitali & Montana Puscas**		
11:00 – 11:12	Andrew P. Weitz	Stable isotopes reveal contrasting physiological responses to climate change in Great Basin bristlecone pine (*Pinus longaeva*) (**O25; professional**)
11:12 – 11:24	Jerzy Piotr Kabala	Climate change signals in two low elevation Fagus sylvatica L. forests in southern Italy (**O26; student**)

11:24 – 11:36	Pavel Mezei	Impact of climate and insect outbreaks on isotope ratios in Norway spruce trees in the Western Tatra Mts., Slovakia (Central Europe) (**O27; professional**)
11:36 – 11:48	Sugam Aryal	Tree-ring oxygen isotope variations of two Himalayan pine species under the influence of regional drought (**O28; student**)
11:48 – 12:00	Valentina Vitali	Assessing forest acclimation dynamics: insights from a tree-ring multi-proxy approach (**O29; professional**)
12:00 – 12:12	Katja T. Rinne-Garmston	Drivers of intra-seasonal δ13C signal in tree-rings of *Pinus sylvestris* as indicated by compound-specific and laser ablation isotope analysis (**O30; professional**)
12:12 – 12:30	*Summary and discussion*	
12:30 – 14:00	**Lunch break**	
Miscellaneous Dendroecology Session chairs: Guillermo Gea-Izquierdo & Dario Martin-Benito		
14:00 – 14:12	Jitang Li	Phylogeny and climate explain drought resistance and resilience in arid regions (**O31; student**)
14:12 – 14:24	Evrim A. Şahan	Advancing Forest Carbon Flux Estimation through Fusion of Tree-Ring and National Forest Inventory Data (**O32; professional**)
14:24 – 14:36	Marta Pardos	Carbon storage potentiality of old-growth forests under climate warming (**O33; professional**)
14:36 – 14:48	Jakub Kašpar	Major tree species of Central European forests differ in their proportion of positive, negative and non-stationary growth trends (**O34; professional**)
14:48 – 15:00	Soham Basu	Ecological responses of pedunculate oak and narrow-leaved ash to varying groundwater levels in a South Moravian floodplain forest (**O35; student**)
15:00 – 15:18	*Summary and discussion*	
16:00 – 18:00	**OPTIONAL MID-TERM EXCURSION: Brasov city tour Meeting point:** Livada Postei, in front of the rectorate of the Transilvania University of Brasov (Bulevardul Eroilor 31, Brașov 500036; see the TRACE2024_Brasov_Locations document)	
20:00 – 23:00	**CONFERENCE DINNER at HOTEL ARO PALACE** (Bulevardul Eroilor 27; see the TRACE2024_Brasov_Locations document)	

FRIDAY, 07 OF JUNE 2024

CONFERENCE VENUE: Aula Sergiu Chiriacescu

ADDRESS: 41 A Iuliu Maniu Street, Brasov, 500091 (see the *TRACE2024_Brasov_Locations* document)

08:30 – 09:00	**KEYNOTE SPEAKER: Jesús Julio Camarero Martínez** Drought, forest dieback and tree growth resilience	
Forest ecosystems, human activities, and climate change dynamics (first part) **Session chairs: Roberta D'Andrea & Ania Cedro**		
09:00 – 09:12	István Botár	Cultural heritage and dendrochronology in Transylvania (**O36; professional**)
09:12 – 09:24	Johannes Edvardsson	New South Scandinavian Tree-Ring Records from Subfossil Oak and Pine as Proxies for Long-Term Climate Dynamics and Ecosystem Changes (**O37; professional**)
09:24 – 09:36	Kärt Erikson	Effect of water level change and weather on radial increment of Scots pine (*Pinus sylvestris* L.) in Estonian peatland ecosystems (**O38; student**)
09:36 – 09:48	Mateusz Telążka	Tree ring record of spatial temporal arsenic pollution in old mining area in Sudetes Mountains (SW Poland) (**O39; student**)
09:48 – 10:00	Lena Vilà-Vilardell	Does prescribed burning increase the resistance of pine species to drought and bark beetles? (**O40; student**)
10:00 – 10:12	Daniela Robles	Modelling historical fire dynamics in Sweden: Integrating anthropogenic and climatic predictors (**O41; student**)
10:12 – 10:30	*Summary and discussion*	
10:30 – 11:00	**Coffee break**	
Forest ecosystems, human activities, and climate change dynamics (second part) **Session chairs: Roberta D'Andrea & Ania Cedro**		
11:00 – 11:12	Patrick Chiroiu	Treelines in the Southern Carpathians: a tree-ring based approach to evaluate the impact of climate change and human activities on trees and shrubs growing at the treeline (**O42; professional**)

11:12 – 11:24	Renata Feher	Dendrogeomorphic assessment of rockfall activity and its potential triggers in Outer Western Carpathians: a case study under structural escarpment (**O43; student**)
11:24 – 11:36	Paolo Cherubini	Tree-dating of Stradivari's violins (**O44; professional**)
11:36 – 11:48	Dario Martin-Benito	Low xylem conductivity and plasticity of Mediterranean conifers contribute to drought induce decline and mortality (**O45; professional**)
11:48 – 12:00	Francesco Niccoli	Continuous Monitoring Approach to Unveil the Link Between Tree Hydraulic Function and IADFs: A Study Case on Pinus pinaster Aiton Forest in Drought-prone Mediterranean Ecosystem (**O46; professional**)
12:00 – 12:12	Audrey Salerno	Evaluating Leaf Trait Variation and Cambial Growth in High Elevation Bristlecone Pine (*Pinus longaeva*) (**O47; student**)
12:12 – 12:30	*Summary and discussion*	
12:30 – 14:00	**Lunch break**	
Functional DendroEcology Session chairs: Guillermo Gea-Izquierdo & Dario Martin-Benito		
14:00 – 14:12	Guillermo Gea-Izquierdo	Functional dendroecology: integrating ecophysiological processes and dendrochronological proxies (**O48; professional**)
14:12 – 14:24	Paulina F. Puchi	Integrating tree-ring anatomical traits and carbon fluxes to unravel carbon allocation using 3D-CMCC-FEM model (**O49; professional**)
14:24 – 14:36	Sophie A. Zwartsenberg	Rising CO_2 increases photosynthetic efficiency of tropical forest canopy trees at the centennial scale (**O50; student**)
14:36 – 14:48	Kelly Swarts	Memory in trees (and how to model it) (**O51; professional**)
14:48 – 15:00	Mélanie Saulnier	Growth patterns, climate sensitivity and resilience of silver fir trees (*Abies alba* Mill.) differ along a gradient of time since the last harvest in the Central Pyrenees (**O52; professional**)
15:00 – 15:12	Eva Dafčik Močnik	Impact of climate change on radial growth of silver fir (*Abies alba* Mill.) along the Dinaric Mountains in Croatia (**O53; student**)
15:12 – 15:30	*Summary and discussion*	
15:30 – 16:00	**Coffee break**	
Past Climate Reconstructions Session chairs: Achim Bräuning & Michal Bosela		

16:00 – 16:12	Rob Wilson	Significant volcanic cooling expressed in tree-ring summer temperature reconstruction from Northern Patagonia, Argentina (**O54; professional**)
16:12 – 16:24	Lea Schneider	The East Atlantic/Western Russia Pattern: A 300-Year Climate Dynamics Reconstruction from Tree-Ring Analyses (**O55; professional**)
16:24 – 16:36	Miloš Rydval	Reflected-light quantitative wood anatomy temperature reconstruction from the Romanian Carpathians (**O56; professional**)
16:36 – 16:48	Tatiana Bebchuk	*Taxus* ring width network from southern England reflects western European hydroclimate extremes over the past three centuries (**O57; student**)
16:48 – 17:06	*Summary and discussion*	
17:15	**TRACE2024 - CLOSING & AWARDS CEREMONY**	

SATURDAY, 08 OF JUNE 2024

Schedule	OPTIONAL Excursion – for those that registered for them
08:00 – 17:00	Şinca virgin forest – contact person: Ion Catalin Petritan
09:00 – 17:00	Bran castle – contact person: Ana-Maria Hereş
The meeting points for the two excursions will be announced during the conference days.	

POSTER SESSION

WEDNESDAY, 05 OF JUNE 2024

CONFERENCE VENUE: Aula Sergiu Chiriacescu

ADDRESS: 41 A Iuliu Maniu Street, Brasov, 500091 (see the *TRACE2024_Brasov_Locations* document)

First author's name & surname	Title of the poster	Order (professional / student)
Achim Bräuning	The dual isotope approach in tropical tree rings: how homogeneous is the relationship between carbon and oxygen isotopes?	**P1 (professional)**
Agata Buchwal	Trees and shrubs from northern Norway exhibit distinct Blue Rings in 1877 and 1902	**P2 (professional)**
Agnese Anta Liepiņa	Radial Growth Reference models: Evaluating Oak Growth Response to Removal of Adjacent Trees	**P3 (student)**
Alessia Bono	Exploring wood density as a proxy of carbon stock across northern hemisphere conifers in relation to global warming and tree age variability	**P4 (student)**
Alessio Giovannelli	Can acclimation strategies under drought and warming be explained by changes in cambium sugar metabolism?	**P5 (professional)**
Alma Piermattei	First Record of Blue Ring in a Dicotyledonous Angiosperm	**P6 (professional)**
Andrea Fabiánová	Three-dimensional distribution of mass movement signals in disturbed *Picea abies* (L.) Karst.	**P7 (student)**
Ángela Sánchez-Miranda	Anatomical Response of Cork Oak (*Quercus suber* L.) to Cork Stripping	**P8 (professional)**

Anna Cedro	A birch tree as witness in a murder and cannibalism case	**P9 (professional)**
Annette Debel	Tree-ring stable carbon isotopes indicate increased drought stress for conifers in southeast Germany over the past 50 years	**P10 (student)**
Anni Nurmisto	Comparing sampling strategies for quantifying adaption on tree growth on Norway Spruce	**P11 (student)**
Any Mary Petritan	Do past management legacies modulate climate-growth relationships?	**P12 (professional)**
Bency David Chinthala	Climate reconstruction and geohazard analysis using tree ring data from western Himalaya	**P13 (student)**
Candice C. Power	Willow recruitment patterns along an elevation gradient on Disko Island, Greenland	**P14 (professional)**
Catalin C. Roibu	Comparative analysis of beech and oak resilience and adaptation to past and present extreme climatic events	**P15 (professional)**
Charlotte Angove	Driving factors of seasonal trends in tree-ring cellulose δ^2H in a boreal forest	**P16 (professional)**
Chenxi Xu	High-latitude tree-ring oxygen isotopes from Northwestern Russia record summer relative humidity	**P17 (professional)**
Ciara Greaves	Quantifying lignin in Scots pine blue rings	**P18 (student)**
Ciprian C. Stremțan	$\boldsymbol{\delta}^{13}C$ variations in creep affected *Picea abies* (Făgăraș Mountains, Romania) analysed via laser ablation IRMS	**P19 (professional)**
Colin McFadden	Building Robots with Robots	**P20 (professional)**
Cosmin Ilie Cuciurean	Heavy metal concentrations in growth rings of broad-leaved reflect changes in industrial pollution but depend on analysis type	**P21 (student)**
Daniela Maria Llanos-Campana	Stable carbon and oxygen isotope ratios in Norway spruce (*Picea abies* (L.) Karst.) tree rings along an elevation gradient in the Rarău Mountains (Romania)	**P22 (student)**
Diāna Jansone	Introduced *Pinus contorta* provenances: insights into radial growth variability	**P23 (student)**

Dominik Polťák	The 2022 Heatwave and Drought Led to a Severe Tree Water Deficit but not to Consistent Growth Reduction of Silver Fir and European Beech in Primary Forests	**P24 (student)**
Elisabet Martínez-Sancho	Evolutionary drivers of phenotypic traits in two European tree species – evidence from common garden networks	**P25 (professional)**
Emeka Vitalis Nwonu	Tracheid Anatomy Reveals Temperature-Driven Structural Adaptations in Alpine Norway Spruce	**P26 (student)**
Enrico Tonelli	Tree-ring traits of a silver birch (*Betula pendula* Roth) glacial relict population in Central Italy	**P27 (professional)**
Eunice Romero	Using blue intensity, CooRecorder and BIcounter to estimate whole cross section proportion of compression wood, latewood and earlywood in treeline seedlings	**P28 (professional)**
Fabio Natalini	Declining trends in long-term *Pinus pinea* L. growth forecasts in Southwestern Spain	**P29 (professional)**
Gheorghe Stefan	The influence of forest management on the radial growth of Norway spruce (*Picea abies* L.) trees in the north of the Eastern Carpathians	**P30 (student)**
Henry Marichal	CS-TRD: A Cross Section Tree Ring Detection method	**P31 (student)**
Ionel Popa	The response of *Quercus robur* and *Quercus pedunculiflora* to climate in the forest-steppe area of southeastern Romania	**P32 (professional)**
Iqra Liyaqat	Integrating Dendrochronology and Isotopic analysis to evaluate prolonged drought effect on *Quercus ilex* L. forest	**P33 (student)**
Irena Sochová	Stable carbon isotopes of oak rings reflect a strong drought signal independently of elevation in eastern Slovakia	**P34 (student)**
Ivana Vašíčková	A half-millennium record of disturbance history in the Bohemian Forest	**P35 (professional)**
Jakub Kašpar	Exploring climate growth limitations of European beech and silver fir along the gradient of Carpathian arc.	**P36 (professional)**

Javier Vázquez-Piqué	Old and young *Pinus pinea* and *Pinus nigra* trees show a different response to drought events in a mediterranean environment	**P37 (professional)**
Jelena Lange	Quantitative wood anatomy suggests spatially diverse climatic controls on white spruce growth across the North American treeline ecotone	**P38 (professional)**
Jernej Jevšenak	Non-stationary climate-growth responses in trees: A global dendroecological perspective	**P39 (professional)**
Johannes Edvardsson	Old Wood in a New Light – A dendrochronological database	**P40 (professional)**
Jonathan M. Kormann	Intraspecific differences in wood anatomical traits of northern red oak (*Quercus rubra* L.) provenances provide opportunities for forest management	**P41 (student)**
Jorge A. Giraldo	Annual tree rings in the ever-wet tropical forest of the Americas	**P42 (professional)**
Katarzyna Oblińska	Climate-Growth Relationship Analysis of Trees and Shrubs in the Sub-Arctic - Comparative Study from Øvre Pasvik, NE Norway	**P43 (student)**
Katrien Boonen	The effect of ring width on mercury concentration in conifer tree rings	**P44 (student)**
Kayleigh Letherbarrow	Elucidating the dynamics and drivers of the Scottish mid-Holocene pine-decline using subfossil *Pinus sylvestris* dendrochronology and peat palaeoecology	**P45 (student)**
Lisa Jourdain	A quantitative analysis of the effect of sample size on dendroecological signal in earlywood vessels of ring-porous species	**P46 (student)**
Louis Verschuren	A 242-year beech (*Fagus sylvatica* L.) latewood density chronology as a proxy for summer temperature in Western Europe	**P47 (student)**
Lucie Polášková	Exploring Mining Subsidence: Insights from Dendrogeomorphic Analysis	**P48 (student)**
Lucrezia Unterholzner	Exploring the potential of assisted migration for European beech based on its wood anatomy	**P49 (professional)**
Luis Matías	Introducing the Power Borer: an automated sampling solution for efficient dendrochronological sampling	**P50 (professional)**

Marcel Kunz	Assessing temporal stability of temperature signals in NW North American density records	**P51 (student)**
Marian-Ionut Stirbu	Unprecedented warming captured by the first Carpathian summer temperature reconstruction using quantitative wood anatomy chronologies	**P52 (student)**
Marie Duerinck-Grévy	Oxygen and carbon isotope patterns in tree rings from vital and non-vital beech trees in the Valais, Switzerland	**P53 (student)**
Maris Hordo	Growth-climate response at different stem heights of larch trees in Estonia	**P54 (professional)**
Matej Ferenčík	Conservation of beta-diversity helps guard against the loss of multiple environmentally sensitive species in European primary forests	**P55 (student)**
Michal Bosela	Effects of drought and disturbance on the soil CO_2 and CH_4 fluxes and tree growth in a mixed forest and spruce monoculture	**P56 (professional)**
Mikael Moura	The impact of growth and climate on the resin production of *Pinus pinea* and *Pinus pinaster*	**P57 (student)**
Mirela Beloiu Schwenke	Early successional species show higher tolerance to drought across Europe than late successional species	**P58 (professional)**
Mohammad Hossein Mazaherifar	Tree-Ring Widths and Stable Isotope Records of Juniper Tree Rings as Climate Indicators in Hezar Masjed Mountain, Northeastern Iran	**P59 (student)**
Mohsen Arsalani	Ecological impacts of abrupt climate changes on oak dieback in the Zagros oak woodlands, Iran	**P60 (professional)**
Momchil Panayotov	Avalanche effect on *Pinus peuce* forests on the Northwestern slope of Todorka peak in Pirin Mountains	**P61 (professional)**
Na Li	Herbaceous encroachment altered the climatic sensitivity of the growth of *Rhododendron chrysanthum* in an alpine tundra	**P62 (student)**
Negar Rezaie	Are there any discrepancies between root and stem intra annual growth?	**P63 (professional)**

Nikolaus Obojes	Quantifying drought impact on conifer growth using dendrometer and sap flow data	**P64 (professional)**
Oleksandr Sylenko	Site conditions drive *Quercus robur* climatic sensitivity in urban forests	**P65 (student)**
Osvaldo Pericolo	Dendro-ecological traits as predictive indicators of oak decline	**P66 (professional)**
Paweł Matulewski	Exploring Peatland Dynamics: Dendrochronological and Palaeoecological Insights into Climate Change and Forestry Impacts	**P67 (professional)**
Peter Marcis	Growth Responses of Temperate Forest Tree Species to Climatic Extremes in the Western Carpathians: A Comparative Analysis of Primary and Managed Forests	**P68 (student)**
Peter Prislan	Tree-ring widths and quantitative wood anatomy in beech trees from common garden experiments in Slovenia and Hungary	**P69 (professional)**
Petter Stridbeck	A Millennium-Long Hydroclimate Reconstruction for a Northern Swedish Site	**P70 (student)**
Rob Wilson	Enhanced crossdating using multi-tree-ring parameters	**P71 (professional)**
Roberta D'Andrea	Insights from living trees: dendroecology as a tool to investigate timber exploitation and management throughout medieval and modern Occitania (France)	**P72 (professional)**
Roberts Matisons	Are weather-growth relationships heritable?	**P73 (professional)**
Rory Abernethy	Exploring the climatic responses of several Australasian conifer species and elucidating evidence for volcanic responses through a novel image capture system	**P74 (professional)**
Sajad Sajad	The response of Norway spruce intra-seasonal chronologies to weather variability depicts the impact of extreme drought on growth reduction in 2022 in the Western Carpathians	**P75 (student)**
Viktória Pipíšková	Is the Effect of Drought on Stem Radial Increment Less Intense in Spruce-Larch-Beech Mixed Stands than in Monocultures?	**P76 (student)**
Wenling An	Enhanced Land-Atmosphere coupling has caused strong climate signal in tree-ring oxygen record—a case study from Serbia	**P77 (professional)**

Yulia Prokopuk	Growth-limiting climatic factors of historic *Sorbus torminalis* trees in Kyiv, Ukraine	**P78 (professional)**
Zeynab Foroozan	Growing Through Dry Spells: Unveiling Tolerance Thresholds in Broadleaved and Coniferous Tree Species During Soil Water Scarcity	**P79 (professional)**
Rob Wilson	Applied Examples of "MultiXdateR	**P80 (professional)**

ABSTRACTS – ORAL PRESENTATIONS

Climate sensitivity of tree growth session

Session chairs: Isabel Dorado-Liñan, Evrim A. Sahan & Stefan Klesse

Divergent temporal shifts in climate sensitivity of Norway spruce along an elevational and continentality gradient in the Carpathians

Andrei Popa[1,2], Jernej Jevšenak[3,4], Ionel Popa[1,5], Ovidiu Badea[1,2], Allan Buras[3]

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The impacts of climate change on forest ecosystems are visible worldwide. Rising temperatures and intensified droughts are the main challenges. While large parts of Europe have experienced substantial dieback of Norway spruce (*Picea abies* L.) as a result of climate change, the southeastern edge of this tree species – the Eastern Carpathians – has not yet suffered large-scale dieback. In recent decades, temporal shifts of climate sensitivity (TSCS) have been observed on a global scale. Thus, studying TSCS over time may elucidate the extent to which Norway spruce may be vulnerable to climate-change-induced decline in the upcoming decades. In this study, we analysed a regional tree-ring network comprising more than 3,000 trees to quantify TSCS since 1950. We mathematically defined TSCS as the slope parameter of the regression of climate sensitivity (the correlation coefficient) over time. Given the frequently observed contrasting shift of climate sensitivity at low and high elevations, we were particularly interested in studying potentially divergent TSCS along elevational and spatial gradients. Our results revealed several indications of TSCS for Norway spruce in the Eastern Carpathians. Firstly, we observed a decrease in the positive relationship between summer temperature and Norway spruce growth at higher elevations (>1,100 m) over the study period. In turn, these trees featured an increasing positive relationship with late winter temperatures over time. At low elevations (<800 m), the signal of positive summer Standardised Precipitation-Evapotranspiration Index (SPEI) correlation became more frequent among sites. Our findings demonstrated TSCS were significantly impacted by elevational and climatic factors, alongside a distinct continental gradient. In conclusion, our findings suggest that Norway spruce is increasingly affected by water limitations under climate change at low elevations, indicating a potentially increasing risk of decline of this species in the Eastern Carpathians.

Assessment of climate signal of multiple tree growth parameters in *Pinus sylvestris*

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As one of the most widely distributed conifer species in Eurasia *Pinus sylvestris* L. is frequently used in dendroclimatological reconstructions based on tree-ring width and density. However, the climatic response of additional measured parameters such as early-/latewood width and density or minimum density is often neglected leaving their potential unexplored. Here, we investigate multiple measurement parameters of *P. sylvestris* L. ring width and density to ongoing climate change at three different sites in north-western Europe. The application of different detrending and age band decompositioning methods to unique datasets of 100 samples (50 mixed-aged trees) at each site allows for optimal low frequency preservation. Trees from Torneträsk, Sweden, grow near the species' northern distribution limit, while the two sites from Scotland originate from the north-western boundary resulting in a close relationship of growth and temperature which can be used to reconstruct local climate. Across all three sites correlations with mean, minimum and maximum temperatures are highest for latewood width, latewood density and maximum latewood density with coefficients ranging between 0.5 and 0.7 ($p < 0.01$). Correlation patterns of the earlywood parameters differ between sites and are further analysed for precipitation and drought influences.

Variation in radial growth sensitivity to drought among fine-scale gene pools of common yew (*Taxus baccata* L.) in central Italy

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European yew (*Taxus baccata*, 1753) is an extremely long-living dioecious tree native to most of Europe. Yew has a high ecological importance and most of the forests harbouring yew have been designated as special protection areas in Europe. Intense drought can potentially cause a reduction in yew growth, increasing the tree susceptibility to pathogens and pests. The effects of climate change are likely to increase the frequency of droughts events, thus leading to drastic changes in the dynamics of forest ecosystems. Preserving genetic diversity, among others, is a valuable tool to ensure healthy and resilient forests. However, the assessment and monitoring of such genetic resources are still lacking, especially in forest tree species not considered to be a commercial crop. Here we aim to combine genetic and tree rings data to study the radial growth sensitivity to drought of yew among different genetic groups. We analysed radial growth trends in the period 1950-2018 of yew trees in two areas of central Italy characterized by different rainfall regimes. We assessed relationships between tree growth and droughts using the Standardized Precipitation Evapotranspiration Index (SPEI). The genetic information and tree-ring cores were globally collected from 298 trees. The studied individuals clustered in two distinct genetic groups. In the populations of the most xeric site, it is possible to identify two further subgroups that show similar sensitivity and resilience to periods of moderate and severe droughts. As expected in the rainiest site, growth is less limited by evapotranspiration rates in the 1950-2018 period. However, climate-growth analysis on moving windows shows an increasing impact of the August three-month SPEI in recent times. Combining dendroecology and genetics can be a valid approach to identify trees which are putatively able to better react to changing conditions, thus posing the bases for an informed collection of reafforestation material.

Deciphering climate and disturbance impact on tree growth in the Lesser Caucasus: Insights from a tree ring blue intensity network

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Dendroclimatic information from the Caucasus region is still very limited, especially regarding past temperature variability. A long history of human activity and animal husbandry has left relatively few undisturbed forests in the Caucasus mountains. Together with short instrumental recordings hamper the establishment of robust chronologies and only few tree species and sites exhibit a robust climate signal in their tree-ring widths (TRW). Density-related parameters from coniferous tree-rings can enhance the climatic information and potentially provide more reliable estimates of climate variations than TRW. Here, we present a network of 8 tree ring blue intensity (BI) chronologies from high elevation (1700-2200 masl) sites in the Lesser Caucasus region. Over 300 years of tree growth from three predominant coniferous species (*Picea orientalis*, *Abies nordmanniana* and *Pinus sylvestris*) are analyzed. Correlations between mean temperature and individual site chronologies exhibit mostly stronger positive correlations with BI data than with TRW. We find a difference in correlation of up to 0.38 (r_{BI}=0.78, $p<0.001$ vs. r_{TRW}=0.40, $p<0.01$). Considering regional variability in the tree-ring network, BI data reflect more site-related components in their chronologies compared to TRW, potentially related to a stronger impact of local disturbance events. This is evident from the results of a principal component analysis which reveals a clear and robust regional common signal in the BI. Specifically, the BI chronologies exhibit a strong loading on Principal Component 1 (PC1), explaining 56% of the overall variance, while the TRW data loads less prominently on PC1, accounting for just 46% of the variance. Correlation ($_{rBI\ vs\ TRW}$=0.25, n=310) between PC1 from both TRW and BI indicated that common variability is mainly governed by climate. Incorporating additional BI sites holds the potential to develop a broad-scale and long-term temperature reconstruction across the Caucasus region.

Contrasting impacts of climate warming on Himalayan hemlock growth: Seasonal and elevational variations

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Ongoing climate change can have varying impacts on tree growth within the growing season and across their elevation ranges, with important implications for forest ecosystem functions and services. However, our knowledge of these effects on climate-sensitive Himalayan forests is still limited. Here, we explore the elevational changes in climatic factors driving long-term changes in the radial growth of Himalayan Hemlock (*Tsuga dumosa*), including recent responses to unprecedented climate warming in the central Himalayas. We evaluated several growth parameters, including total ring width, earlywood width, adjusted latewood width, and maximum latewood density, in unique > 400-year-old forests along an elevational gradient of 2500–3100 m on the southern slopes of Dhaulagiri, Nepal. Our findings show that changing climatic conditions, characterized by increasing temperatures and variable precipitation patterns, had a more detrimental effect on *Tsuga* growth at the edge of its elevation range compared to the optimal mid-elevation zone. Specifically, at lower elevations, the combination of spring and preceding autumn warming restricted earlywood growth, while warmer late summer temperatures stimulated growth at the mid-elevation site by alleviating the cool growth-limiting conditions caused by high monsoonal precipitation. Furthermore, increased spring temperatures enhance latewood density, while summer warming promotes latewood growth at higher elevations. Additionally, we observed that the recent rise in autumn temperatures has begun to impede *Tsuga* growth across all elevations. In conclusion, our study reveals that the growth of *Tsuga* trees is influenced by multiple climatic factors that vary within the growing season and across different parts of its elevation range. Recent spring warming has constrained growth in lower elevations, while higher previous autumn temperatures have reduced growth at both higher and lower boundaries of the species' range. These findings contribute to a better understanding of the complex relationship between climate change and tree growth dynamics, particularly in vulnerable Himalayan forests.

Permafrost melting enhances growth but leads to less intra-annual density fluctuations in boreal *Larix gmelinii* forests

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Permafrost melting due to climate warming in recent decades has produced significant effects on forest ecosystems, especially the boreal biome. How it affects wood formation of trees at intra-annual resolution is unclear, yet is crucial for assessing the impact of permafrost melting on boreal forest growth. We compared the radial growth and intra-annual wood density fluctuations (IADFs) of Dahurian larch (*Larix gmelinii*) at a permafrost (PF) and a non-permafrost (NPF) site at the southernmost permafrost limit in northeast China and quantified their relationships with climate factors. Drought in early summer was the main factor limiting growth of larch. The basal area increment (BAI) of trees at both sites increased initially and then decreased in the 1980s, probably in response to warm-dry climate conditions. The earlywood type IADF (IADF-E) occurred in 14.0% and 9.3% of dated rings at the NPF and PF sites, while the frequency of latewood type IADF (IADF-L) was 6.8% and 2.7% at the two sites. The frequency of IADF-E in trees at both sites was positively and negatively related to June temperatures and precipitation, suggesting drought stress in early summer triggered the formation of IADF-E. The IADF-Ls were probably formed in response to warm temperatures in the late growing season. A higher BAI and a lower frequency of IADFs of trees at the PF site than at the NPF site indicated that permafrost melting could alleviate drought stress in early summer and promote radial growth of larch. This greatly improved forest carbon sequestration and wood quality of some northeastern Asian boreal forests and offset to some extent the adverse effects of warming-drying climates. Larch IADF-Es recorded extreme droughts in early summer, giving us a new sight for reconstructing high-frequency extreme climate events. Our findings provide valuable information for boreal forest management and conservation under future global warming.

Variable climate-growth relationships of quaking aspen (*Populus tremuloides*) among Sky Island mountain ranges in the Great Basin, Nevada, USA

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The Great Basin is an arid province located in the interior western United States. The montane aspen (*Populus tremuloides*) forests play a key role in providing ecosystem services in the region. With ongoing climate change, the future of aspen has become a critical concern. Using dendroecological approaches, we assessed growth patterns of 20 aspen stands across three geographically isolated "sky island" mountain ranges in the north-central Great Basin. We anticipated that growth of Great Basin aspen would be strongly influenced by regional climatic patterns and largely in synchrony. Results revealed a more complex growth dynamic that varied among mountain ranges and across environmental gradients. In particular, aspen climate-growth relationships in the slightly dryer Ruby Mountains were strongly and positively correlated ($r > 0.5$) with previous fall to winter moisture availability. The Jarbidge Mountains had a positive but modest relationship with previous fall to winter moisture availability ($r > 0.3$). Climate-growth response in the Santa Rosa Mountains, the wettest range, showed no significant response to moisture availability during any time period examined but had greater tree-ring growth with warmer May temperatures. Although tree-ring centennial (1910 – 2010) growth trends were positive for all three mountain ranges, only the Santa Rosa Mountains maintained a positive recent growth trend (1970 – 2010). Moreover, distinct temporal shifts in growth-climate relationships in each mountain range suggest potentially unique aspen population adaptations to climate variability. A better understanding of biogeographic variation and causality in aspen growth could provide multiple management pathways governed by resilience characteristics in the face of future anthropogenic and climatic threats. Note: This work has been published as Šenfeldr, M., Shinneman, D.J., McIlroy, S.K., Rogers, P.C, DeRose, R.J. (2024). Variable climate-growth relationships of quaking aspen (*Populus tremuloides*) among Sky Island mountain ranges in the Great Basin, Nevada, USA. Forest Ecology and Management, 554, 121664. https://doi.org/10.1016/j.foreco.2023.121664.

Relationship between climate factors and tree growth of *Tachigali colombiana* in an ever-wet tropical forest

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Understanding how tropical trees growth and develop is understand how they sink carbon through wood incorporation. Growth rhythms in plants, such as tree rings, are crucial indicators of environmental dynamics and rhythmic accumulation of wood. In the ever-wet tropical forest of Buenaventura, Colombia, where *Tachigali colombiana* – Fabaceae, thrives amidst annual rainfall exceeding 7200 mm, understanding the drivers of its growth is essential. While prior studies have predominantly focused on water deficit, this research shifts attention to the roles of precipitation, light availability, and soil moisture determining growth rhythms. This study investigates how radiation, temperature, and precipitation influence *T. colombiana* growth patterns. Using cross sections and cores from eight trees and employing CooRecorder, CDendro, and R for analysis, we developed a robust tree-ring chronology (1967-2019). Findings reveal a positive correlation with precipitation in February (least rainy month - higher light availability). Conversely, a negative correlation is observed in September, the wettest month (lower light availability), indicating potential saturation effects. Radiation exhibits a similar pattern, with positive correlations in February due to reduced cloudiness and negative correlations towards the year's end as cloud cover intensifies. Despite expectations, no significant temperature correlation was found. These results underscore the predominant influence of light deficits, driven by high cloudiness and precipitation levels, on *T. colombiana* growth in an ever-wet tropical forest. This study not only contributes to our understanding of growth dynamics in hyper-humid environments but also highlights the importance of considering multiple environmental factors in elucidating plant responses to climate variability. Further research could delve into the physiological mechanisms underlying *T. colombiana* sensitivity to light and precipitation and explore broader implications for forest management and climate modelling.

Phenology and multitemporal tree growth of Spanish elm *Cordia alliodora* from tropical Andes

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Wood layer accumulation in woody plants is determined by vascular cambium activity. Combining dendrochronology with phenology monitoring at fine scales offers a unique opportunity for a deep understanding for tree growth drivers; however, such an approach has rarely been applied in tropical trees. Our aim is to achieve a better understanding of the multi-temporal tree growth of Spanish elm (*Cordia alliodora* – Cordiaceae) growing on the campus of the National University of Colombia in Medellín city (Tropical Andes, with precipitation and annual temperature averaging 2066 mm and 21.7°C respectively). We analyzed weekly phenological stem observations using dendrometers with a precision of 0.01 mm across 22 individuals over a period of 12 months (from 10/01/2022 to 11/30/2023). Additionally, following standard dendrochronological techniques, we sampled cores from 12 monitored individuals. Using the collected data, we performed correlative analyses with local precipitation and temperature. Dendrometers indicated greater activity of the vascular cambium (i.e., stem growth) during the second peak of rainfall (October-December), which coincides with the least rainy period of the year (January-March). Successful cross-dating of tree ring series (correlation coefficient 0.51, $p < 0.05$) led to the establishment of a chronology spanning 53 years (1959-2022), which showed a positive correlation with precipitation and a negative correlation with temperature in some, but not all, months of the observed growth season using dendrometers. These findings, previously unpublished, represent important information regarding the multi-temporal understanding of growth rhythms and wood accumulation in a tropical tree, with great potential for establishment in silvicultural systems.

From stable slow-grown to vulnerable fast-growing: the divergent pathway of north Patagonian tree species under climate change

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Rapid climate change is stressing forests species worldwide. The northern Patagonian Forests, east of the Andes Mountain chain (Argentina), have been experiencing stand-level decline and tree mortality linked to recent warmer and drier climate. We investigated 24 stands across a steep precipitation gradient (1900–700mm year^{-1} over <80km) of three native tree species: the evergreen broadleaf *Nothofagus dombeyi* (humid-mesic forests), the evergreen conifer *Austrocedrus chilensis* (dry-mesic forests), and the deciduous broadleaf *Nothofagus pumilio* (subalpine belt). We compared radial growth trends, within-stand growth synchrony and growth sensitivity to climate, examining their relationship with temperature and precipitation variability since the late 1970s. Our findings revealed declining basal area increment (BAI) in *A. chilensis* across the entire precipitation gradient, linked to increasing within-stand growth synchrony and sensitivity. The BAI of *N. dombeyi* remained stable or increased towards the dry-mesic and xeric sites at the east, while in the moister, western sites, BAI decline was associated to an increase in growth sensitivity; still, growth synchrony has generally increased. Both evergreen species showed growth limitations to high temperature and low precipitation in late spring/early summer. At the subalpine belt, overall increasing BAI of *N. pumilio* since the mid-20th century reached a tipping point during the last four decades: BAI continued to increase in humid-mesic and high elevation sites, while either remained stable or declined in dry-mesic, xeric and lower elevation sites, linked to an overall growth synchrony decrease and apparently shifting from cold- to drought- (and heat-) sensitive stands. Across all species, we observed a negative relation between growth rates during the first 30 cambial years (at ~1.3m) and BAI during the last four decades, indicating that fast growing stands are predisposed to significant BAI decline at higher age. The divergent growth responses in this mountainous landscape warn of species vulnerability to future climate change.

Growth patterns of the southernmost conifer, *Pilgerodendron uviferum,* in Patagonia

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The temperate forests of southern Chile are unique and complex ecosystems, threatened by climate change and anthropogenic activities. One of the long-lived and endemic species of these forests is the Guaitecas Cypress (*Pilgerodendron uviferum*), the southernmost conifer in the world, with a latitudinal distribution between 39-55°S, from temperate rainy to Subantarctic climates, being an ideal model for studying the response of tree species to climate in high latitudes. The objective of this study is to determine the growth patterns of *P. uviferum* forests in Chilean regions of Aysén (~47-48°S) and Magallanes (~53°S) using ring-width chronologies of four and six forests in Aysén and Magallanes, respectively. A Principal Component Analysis (PCA) was used to identify two dominant growth patterns: PC1 dominated by Magellan chronologies (43.10%) and PC2 dominated by Aysén chronologies (20.90%). Using Singular Spectral (SSA) and Multitaper (MTM) analysis, we found periodicities of 70, 37 and 2.9 to 6.5 years for PC1, and 89, 30 and 10 to 15 years for PC2. The 10–37-year periods of these oscillation modes are analogous to the 20–30-year periodicities observed in the Pacific Decadal Oscillation (PDO) Index; while the high-frequency oscillations between 2.9 and 6.5 years are similar to the broad 3-to-6-year period spectral peak recorded in ENSO index. In addition, PC1 is negatively correlated with the PDO and Southern Annular Mode (SAM, or Antarctic Oscillation Index; AAO), and positively correlated with Southern Oscillation Index (SOI); while PC2 is positively correlated with PDO, SAM/AAO, and negatively with SOI. This suggests that regional growth patterns of *P. uviferum* are influenced by large-scale modes of climate variability affecting southern South America climates. These results highlight the potential of *P. uviferum* chronologies to represent the large-scale climate variability of southern South America and to recover the low-frequency signal in climate reconstructions developed from this species.

Using the VS-Lite model to understand an interplay between the extension of growing season and increasing summer drought stress toward the end of the 21st century

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Radial growth in central European forests significantly responds to ongoing climate change. However, growth responses show a prominent variation across space and between species. To understand past and future growth patterns, we calibrated the VS-Lite process-based model of wood formation for 925 tree-ring width chronologies distributed across the Czech Republic. The VS-Lite captured the non-linear response of wood formation to climate during the 1961-2010/2020 baseline period. Using the model outputs, we determined variables characterizing climatic limitation of growth (growth deficit due to dry or cold conditions) and growth phenology (start and end of growing season, growth unimodality vs. bimodality) for each site. Next, we used calibrated model parameters to predict growth until the end of the 21st century under climatic conditions forecasted by the SSP5-8.5 scenario. We assessed shifts in climate-growth responses and growth phenology by comparing simulations in forecasting mode with the 1961-2010/2020 baseline. Currently, the unimodal growth pattern with significant winter cold limitation prevails throughout the Czech Republic. Moderate intensity of summer drought stress was simulated only at low elevations during the 1961-2010/2020 period. By 2050, the increase in summer drought stress will be compensated by a significant extension of the growing season, resulting in overall positive growth trends. However, simulations suggest that the second half of the 21st century will be characterized by a significant drop in summer growth rates not further compensated by phenology. Consequently, a bimodal intra-annual growth pattern with a long growing season but significantly reduced summer growth kinetics might prevail in elevations below 800 m by the end of the century. Our results suggest that intra-annual growth plasticity, i.e., the ability of radial growth to profit from autumn precipitation, might become an important trait of Central European tree species under future climatic conditions.

Developments in Dendro Methods session

Session chairs: Neil Loader & Martin Häusser

A Novel approach to date intra-annual tree-ring isotopes

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Tree-ring stable isotope ratios have been successfully used to reconstruct past climates and investigate ecophysiological responses of trees to changing environments. While most studies study tree-ring isotopes in annual resolution, the resolution of isotopic changes in tree ring can also be analyzed with intra-annual resolution. These intra-annual isotope analyses are especially useful to obtain deeper insights into the dependencies of trees on seasonally varying water sources. However, due to lacking information of when exactly a specific section of a tree ring was formed, it is challenging to assign a calendar date for the respective isotope value and to correlate them with contemporaneous environmental factors. Furthermore, varying ring widths can lead to different numbers of isotope samples per year. This complicates the comparability between growing seasons. The approach we present utilizes xylogenesis data to date intra-annual isotope samples. We collected wood samples of pine on Corsica in biweekly intervals using a Trephor microcorer. First, xylem cells were counted and categorized into different cell differentiation phases for each microcore thin section. Then, Gompertz models were calculated for cells in the wall-thickening and mature phase. The modelled maximum cell count was divided by the number of measured isotope samples in the respective year to obtain a modelled number of cells per isotope sample within the annual growth curve. This yields a time window for each isotope sample in which the wood was formed. The proposed method enables better comparability between intra-annual isotope samples from different years, more reliable correlations with the environmental factors controlling isotope values in the respective tree ring sections, and allows deeper insight in fractionation processes within trees.

"Scratching the surface" of the novel reflected-light QWA methodological approach

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Quantitative wood anatomy (QWA) has been widely recognized as a valuable tool for extracting a range of anatomical and environmental information from tree-rings. Despite the well-documented potential of QWA parameters for dendrochronological research, producing anatomical slides remains a time-consuming, costly, and technically challenging process. Recent advancements in sample preparation techniques and image capturing and processing protocols at the Czech University of Life Sciences Prague have enabled the development of a new surrogate for tree-ring density called Binary Surface Intensity (BSI; Rydval et al., 2024). By using reflected-light microscopy to capture ultra-high-resolution (UHR) images (~74 700 dpi), we were able to overcome the limitations of scanner-based Blue Intensity parameters (BI), including issues with image resolution and colour/light aberration biases, and measure density information from the anatomical structure. Our next goal was to obtain cellular-level anatomical information from tree-ring samples without the limitations and requirements of conventional anatomical slide preparation, by using the methodological concepts of UHR imaging and the BSI technique. Thus, we introduce the methodological and sample surfacing protocols of the novel sample processing technique termed "surface quantitative wood anatomy" (sQWA). Furthermore, we compare the cell feature outputs from the ROXAS software of corresponding conifer samples from the Romanian Carpathians prepared using the QWA and sQWA techniques. Our results, based on the ROXAS output, demonstrate that samples prepared using the novel sQWA technique exhibit anatomical traits of high quality comparable to those measured from anatomical thin-section slides. Additionally, we highlight the economic and ergonomic advantages of adopting sQWA protocols for producing and capturing high-quality images of anatomical traits, utilizing less labour-intensive and more cost-effective methodological principles that require basic-to-advanced level of expertise in microtome and microscope use. Finally, we illustrate the potential utility of applying sQWA protocols in other woody species, including hardwoods, tropical and commercial species (*e.g.*, grapevine).

A novel method for analyzing $\delta^{18}O$ by laser ablation IRMS

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The oxygen isotope composition ($\delta^{18}O$) of sequentially growing organic tissues, such as tree rings, can respond to changes in environmental conditions in relatively short time spans. As a result, $\delta^{18}O$ in these tissues can vary significantly at small spatial scales, storing valuable information of growth conditions that may be useful for studying plant physiology and palaeoclimate. However, there are practical issues in obtaining high resolution oxygen isotope data from tree rings due complicated sample handling and analytical processes, which have limited the routine production of such data. We have developed a novel method for analysing $\delta^{18}O$ in organic matrices using laser ablation mass spectrometry. The method couples a UV laser ablation unit with an isotope ratio mass spectrometer (IRMS). We conduct measurements on the carbon monoxide (CO) gas produced in the laser ablation process, which is directed into the IRMS operated in continuous flow mode. This streamlined analysis procedure sidesteps the time-consuming sample cutting and weighing steps. A single analysis run takes approximately 15 min, which is comparable to conventional thermal conversion IRMS, and, together with the reduced sample preparation time allows for increased sample throughput for high resolution analysis of $\delta^{18}O$. Further, the analysis consumes only small fraction of the sample thus saving valuable research material for further analysis. Preliminary results indicate a typical measurement precision of better than 0.5 ‰ at spatial resolution of 100µm (spot size) based on tests conducted on woody materials. The new method is expected to provide a valuable tool for investigating fine-scale variation of $\delta^{18}O$ in organic matrices.

Potential and limitations of different tree-ring stable isotope chronology development techniques

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Tree-ring stable isotope (TRSI) chronologies that combine information from living and relict wood hold the potential of capturing long-term trends that might be missing when using measurements of traditional tree-ring parameters, such as tree-ring width and maximum latewood density. A comprehensive assessment of different TRSI chronology development techniques is, however, missing. Here, we compare five different chronology development techniques to three multi-millennial TRSI datasets from central Europe, the European Alps and Japan: *(i)* raw data, *(ii)* cohort correction, *(iii)* interactive correction, *(iv)* outlier correction, and *(v)* series normalisation. We show that the different techniques not only produce chronologies of varying multi-decadal variability and long-term trends, but that the preserved frequency domains also depend on the input data. Method *(i)* is particularly prone to outliers if overall sample size is low. Method (*ii)* can create artificial step functions and long-term trends when individual series share start dates and when end and start dates are systematically skewed. Methods *(iii)* and *(iv)* yield similar results for annually resolved data, though *(iv)* is more suitable for lower resolution series and less sensitive to age trend effects. Method *(v)* removes any low-frequency signal. Our comparative study shows the importance and risks of applying different TRSI chronology development techniques.

Reclaiming data integrity compromised by cell wall degradation in multi-millennial MXD data using tree-ring anatomy

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Tree rings are a great paleo-environmental archive and are prominently used to reconstruct past summer temperatures using maximum latewood density (MXD). However, the availability of material and the reliability of climate reconstructions using densitometric measurements diminishes back in time due to natural decomposition processes. Consequently, few MXD chronologies extend >2000 years to the past. Sapwood degradation in subfossil material is usually easily visible and can be expertly flagged and removed from analysis. However, the extent to which other types of degradation like brown rot might affect densitometric or anatomical measurements is unknown. In this study, we investigated whether wood anatomical measurements in *Larix sibirica* are less affected by brown rot compared to densitometric measurements as they are based on the dimensions instead of the composition of the cell walls. We measured X-ray-based density and performed quantitative wood anatomical analyses on living trees and trees that grew 4700 years ago (relict) and were since buried in riverbank sediments in the Yamal peninsula. Additionally, we measured the bulk density and cellulose-to-wood ratio of these samples. Both the bulk density and the cellulose-to-wood ratio of the relict material on average showed lower values than the living material (24% and 20%, respectively). This coincided with 8% lower MXD values compared to the living material. However, the mean radial cell wall thickness of the latewood of the relict material was 5% wider than in the living material. In a reconstruction, the MXD data would suggest 1.8°C colder June-August temperatures 4700 years ago, whereas QWA-based estimates would suggest 0.8°C warmer temperatures than the 20th century mean. Here, we show two simple laboratory measurements to determine if densitometric measurements can be performed on degraded samples, and highlight the potential for QWA to alleviate decay-related limitations of X-ray-based densitometry to produce high-quality multi-millennia-long chronologies of late summer temperatures.

The importance of maintaining uncertainty: a Bayesian approach to constraining error and variation in chronology building

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The absolute, single-year dating potential of tree-ring sequences has enabled unprecedented high precision dating across multiple disciplines such as radiocarbon calibration. This precision relies on the accuracy of the master- or site-chronology of tree-ring sequences, the formation of which attempts to recover the environmental growth signal on ring-widths of a given species on an annual scale. Natural variability within the climatic signal will be witnessed, but traditional frequentist statistical approaches 'smooth' out this variation to form an averaged signal. Certain species can also exhibit missing, false, or merging rings (non-annual ring formation), particularly during environmentally stressful periods. To identify the occurrence and placement of these features within a sequence requires the analysis of multiple cross-sections and cross-referencing of other sequences. Although effective at successfully dating sequences, frequentist approaches used to form tree-ring chronologies do not allow for uncertainty to be preserved. When ring-width indices are averaged, or non-annual ring formations identified along a sequence, the resulting chronology is the statistically most likely climatic signal; all the variation and uncertainty that went into forming this signal is 'thrown away'. Variation and uncertainty, however, provide information on possibility: the least statistically probable answer is not an impossible one and removing it completely from a chronology risks losing important environmental information. What if these 'possibilities' could then be quantified, maintained, and used in subsequent applications of the chronology? Here, we introduce Chowder, a new Bayesian statistical model that can uphold variation and possibilities of non-annual ring formation when cross-dating sequences. The Bayesian framework also means that the resulting chronology is independent of the order in which our sequences are added. We demonstrate that the software is valuable for comparison of environmental signals across different geographical regions and potential applications of the uncertainty produced within chronologies, such as in single-year radiocarbon calibration.

KEYNOTE SPEAKER: Katarina Čufar

Long reference chronologies and chronology networks – why do we need them?

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We will review and discuss some examples of the past and current development of reference chronologies, chronology networks, their importance and use, and the challenges for the future. The recent review of the bibliography and the impact of Dieter Eckstein's work on development of dendrochronology have shown that the construction of chronologies and their improvement is the main activity especially of the newly established laboratories. In addition to long regional chronologies of oak (*Quercus* sp.), which were first constructed for Western Europe, the activities of constructing regional chronologies showed good results also in Southeast Europe, including Slovenia, Romania and the surrounding countries. We will discuss the enormous potential of chronologies for answering biological, ecological and social questions. In Slovenia, despite three decades of systematic work, the longest oak chronologies cover the last five centuries and the period 3771–3330 BC. The length of about 500 years and the high replication enabled teleconnection with chronologies from areas within a radius of 500 kilometres, so that they can be used to answer questions of local and international interest. We will discuss the gaps in the chronologies, the reasons for them and the possibilities to fill them. In addition to composed regional chronologies, we also need networks of local chronologies for different species and time periods to address the needs of local environments and to compile large databases and networks to address issues of global importance. Networks of oak and European beech (*Fagus sylvatica*) chronologies are especially important to address the questions of current negative effect of climate change to performance of trees, wood formation and its quality. The chronologies need to be constantly improved for their use in combination with other data sources.

Wood Anatomy session

Session chairs: Eunice Romero & Peter Prislan

A simple experiment designed to challenge the idea that xylem characteristics are determined by cambial age

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There is a prevailing belief that cambial age influences xylem properties such as conduit size. Typically, xylem conduits in the inner rings of a tree are narrower than those in the outermost rings. However, there is no established causal relationship between cambial age and conduit size. Instead, it is well known that the hydraulic path length (leaf-to-root) primarily influences conduit diameter variation along the stem axis, given the unavoidable tip-to-base conduit widening. The study aimed at disentangling the effects of path length and cambial age on conduit size. We exploited a phenomenon common in coppice-with-standards forest stands: after harvesting, isolated non-coppiced trees produce numerous low epicormic branches, significantly altering crown structure and reducing hydraulic path length, while cambial age continues to increase. This setup provided a unique opportunity to test if hydraulic path length, rather than cambial age, dictates conduit diameter at the stem base. Wood cores were collected from the stem base of seven broadleaved trees across four species, particularly focusing on those exhibiting significant epicormic branching, alongside two control trees from a non-coppiced area. Median vessel area was measured in several (3-4) annual rings before and after coppicing. Across all analyzed samples, median vessel area consistently decreased 2-3 years after coppicing ($P<0.0001$), with reductions ranging from -7% to -44% compared to pre-coppicing values, despite a greater width of the tree rings. Conversely, trees under constant canopy cover did not exhibit significant changes in vessel size. The study effectively challenges the misconception that cambial age dictates conduit size, highlighting instead the pivotal role of hydraulic path length.

Radial growth and xylem adjustment of Mongolia oak to recent warming in the dry and wet areas of northeast China

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Climate changes greatly affect tree growth, community succession and forest productivity, which determines the global carbon cycle patterns. Mongolian oak (*Quercus mongolica*) is a widely distributed tree species in broadleaf forests of Northeast China, which are susceptible to increasing drought. Accurately estimating how *Q. mongolica* responds to climate is vital for understanding the impacts of climate changes on the development and productivity oaks forest ecosystem. Here, we use the dendrochronological and wood anatomical methods to evaluate the response and adaptive mechanism of *Q. mongolica* from 28 sites in two contrasting areas (dry and wet) of northeast China, the plasticity response and adaptation strategies of radial growth, earlywood vessels (EWV), and hydraulic features of *Q. mongolica* to climate change were studied. Results showed that compared with the wet area, *Q. mongolica* in dry area had wider rings, larger vessel area, higher number of vessels (VN), larger hydraulic diameters (Dh), and higher theoretical tree-ring hydraulic conductivity (Kh). On the contrary, the vessel densities (VD) were lower than those in wet region. Water availability (moisture factors) more than temperature played a decisive role in the xylem formation of *Q. mongolica* in both dry and wet regions. Moisture factors affect its growth mainly by changing its vessel density. *Q. mongolica* is more restricted by drought in dry regions. Our results suggest that oaks in the study area will place more emphasis on hydraulic safety than hydraulic efficiency, especially in drier sites. If climate warming continues or intensifies, *Q. mongolica* in the dry regions will show an obvious decline caused by warming, and the distribution of *Q. mongolica* will likely shift to regions with more water availability.

Reduced precipitation alters xylogenesis of two Mediterranean oak species

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Recent changes in climate have induced growth alterations, affecting many oak forests worldwide. However, and despite the ecological importance of these ecosystems, there is scarce information regarding the seasonal pattern of wood formation (xylogenesis) in oaks under an increasing drought scenario. *Quercus canariensis* (Willd.) and *Q. suber* (L.) form a mixed oak forest at "Los Alcornocales" Natural Park, one of the largest oak forests in Spain, but currently are showing growth decline and defoliation or mortality episodes. Here, we investigated how drought conditions affect vessels formation. We related the xylogenesis phases (cambial onset, radial enlargement) with 15-day temporal windows under natural conditions and experimentally reduced precipitation. Moreover, we measured how drought affect water conductivity through the number and area of vessels. Both species are susceptible to drought, advancing the cambial onset and reducing area of early-wood vessels with respect to control trees, assuming safe and continuous water transport. These results allow us to assess the role of drought in wood formation in order to predict changes in wood anatomy in the coming decades and the response of oak species to drier climate. Identifying this process represents an important tool for the future development of management plans aimed to preserve one of the most important economic resources of the area.

Assessing European beech responses to climate variability and ecological disturbances using Quantitative Wood Anatomy

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European beech (*Fagus sylvatica* L.) is one of the most drought-sensitive tree species and thereby most threatened by projected climate change. Beech productivity is strongly influenced by summer climate anomalies and model simulations forecast growth declines and widespread mortality throughout the 21st century due to rising temperatures across Europe. Xylem functional traits derived from Quantitative Wood Anatomy allow to retrospectively evaluate species adaptations to environmental conditions, including their short-term response to past ecological disturbances, and to predict their vulnerability under future climatic scenarios. Here we introduce a new dendro-anatomical dataset spanning the period 1778-2022 from the old growth beech forest of Serrahn – Müritz National Park (Germany), an unmanaged forest listed as UNESCO world heritage site. The goal of this study was to 1) identify the main climatic signals encoded in xylem anatomical parameters and 2) explore the variability of xylem anatomical and functional traits during major canopy disturbance events. Mean vessel area and hydraulic diameter were the most signal-rich anatomical parameters, showing negative correlations with late spring to early summer maximum temperature. Xylem traits generally responded to seasonal climate during the current year, while ring-widths were more frequently affected by previous-year conditions. Functional traits associated with xylem hydraulic efficiency showed high plasticity in response to major canopy disturbances. Our findings highlight the crucial contribution that wood anatomical parameters may provide to clarify mechanisms driving climate-growth relationships and determining species vulnerability to climate change.

Cell-wall Matters! Sap Flow as an Explanatory Power Indicating How Trees Allocate Carbon into Cell-walls in Temporal Resolution

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Facing a dieback of pine stands across their European ecotype distribution, we still don't have sufficient evidence of their acclimation to water shortage both in the soil and in the atmosphere. Despite having the high-temporal resolution of stem radial growth using dendrometer sensing, it is not possible to isolate the radial increment (or swelling) from periodically depositing "key bio-message" into cell-walls. Considering the soil-plant-atmosphere continuum, the tree represents a bridge-segment balancing the water availability difference between soil water potential (SWP) and air water potential (AWP) gradient. Using weekly micro-core examination of cell differentiation (cambial activity – CA, cell enlargement – CE, wall-thickening– SW), we managed to prove how xylem morphogenesis responds a negative tree-water balance (TWB) throughout heat waves in the three consecutive growing seasons (2014–2016). The transpiration was monitored by trunk heat balance as a sap flow level (SF) to express the relation: SF ≈ AWP – SWP originated from Darcy's law validity. To demonstrate the temporal carbon allocation, we used the spectrophotometric determination of soluble carbohydrate concentration via wood mass methanolic extractions from the periodical micro-coring. Within the SWP-SF-AWP interplay, we found in which range of those hydro-limits the xylem conduits could adjust their morphological parameters exposing to water depletion. The SWP was confirmed as a main driver determining the whole CA, CE and SW (both rate and duration), including the final cell dimensions (tracheid radial diameter - TRD and cell-wall thickness - CWT), while the SF directly affected the cell-wall thickening process. The thresholds of SWP (< -0.5 MPa), SF (< 20 kg day-1) and AWP (80 MPa) triggered the dimensional abrupt changes associated with SW significantly reacting to TWB improvement after heat waves. Consequently, the SF fluctuation becomes an explanatory factor that captures the course of cell-wall material deposition, indicating the carbon-sink allocation in temporal resolution.

Xylem traits of peatland Scots pine reveal complex intra-seasonal hydro-climate signals

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Peatland dynamics, influenced by climatic and hydrological fluctuations, play a crucial role in regulating carbon storage capacity and methane emissions, thereby affecting feedback processes on climate change. Persistent draining conditions driven by increasing air temperature, drought and evapotranspiration, promote soil aeration and peat mineralization boosting tree establishment, which further lower water-table levels, and eventually cause an increase in greenhouse gas emissions. Conversely, peatland tree growth is hindered by either excessively dry or waterlogged conditions, which lead to water stress in trees or limit nutrient uptake due to anoxia and soil acidity, respectively. Despite recent research efforts, dendroecological studies focused on peatland trees remain scarce, impairing a successful application in hydro-climatic reconstructions. To address this gap, we sampled and analyzed 13 *Pinus sylvestris* trees at Mycklemossen peatland in southern Sweden, selecting three 63-year-long chronologies: ring width (RW), radial cell-wall thickness (CWTrad) and radial diameter (Drad). While daily air temperature, precipitation and estimated water-table data were correlated with RW, xylem traits were assessed at an intra-seasonal resolution, by dividing each ring into five equal-width sectors and computing five chronologies per trait. Our results provide significant, albeit variable, hydro-climatic responses among wood parameters, with the strongest signal detected for temperature in CWTrad and Drad, resulting in *i)* a positive correlation during the beginning of the growing season for CWTrad (March-May, S3-4), and *ii)* a negative correlation during spring and summer for Drad (March-August, S4). While growth responses to water-table were absent in RW chronologies, a significant influence was observed in the earlywood formation of both Drad and CWTrad during summer of the previous year of ring formation (July-August, S1-3), with negative and positive correlations, respectively. Moreover, a variable but significant positive effect of precipitation was detected in CWTrad, though not visible in RW. Our novel findings offer a crucial advancement in dendroecological research, confirming the value of QWA analyses over RW, allowing for more accurate hydro-climatic reconstruction models in peatland environments, extremely needed in the actual context of global change.

Stable Isotope Applications session

Session chairs: Valentina Vitali & Montana Puscas

Stable isotopes reveal contrasting physiological responses to climate change in Great Basin bristlecone pine (*Pinus longaeva*)

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Great Basin bristlecone pine is among the most influential tree species in the field of dendroclimatology due to its extremely long life span and its physiological sensitivity to changes in climate. Tree ring chronologies assembled across this species' geographic range extend beyond 5,000 years, but can be difficult to interpret when individual trees exhibit growth responses to variability in both temperature and soil moisture. This is complicated further by the large degrees of seasonal topoclimatic variation that individual trees are exposed to. Additional physiological data that characterizes the annual responses of individual trees to localized changes in topoclimate is needed to better understand the key drivers of xylogenesis, and will improve our understanding of the physiological capacity of this species to perform in a warmer, drier future. To address this, we collected branches from 11 bristlecone pines along an elevation gradient near Great Basin National Park, NV, USA. Using the unique phyllotaxy of this species, we isolated annual needle samples from every available growth year of every branch we collected. We then measured their carbon and nitrogen content and their stable carbon and nitrogen isotope composition, and paired these data to each tree's annual growth. We found that annual growth has declined significantly at upper treeline over the last 55 years, and that this decline was significantly associated with increases in ${}_{i}$WUE, foliar nitrogen content, and isotopic enrichment in ^{15}N, and decreases in foliar c_i/c_a and Δ^{13}C. Conversely, annual growth towards lower treeline was much more variable, and was decoupled from these physiological proxies. These trees all still exhibited significant temporal increases in ${}_{i}$WUE and nitrogen content, and significant decreases in c_i/c_a and Δ^{13}C. Here, we discuss the implications of these contrasting physiological responses for interpreting this species' tree ring chronologies and predicting its physiological performance under future climate scenarios.

Climate change signals in two low elevation *Fagus sylvatica* L. forests in southern Italy

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The European beech *Fagus sylvatica* L. is one of the most important forest species in Europe, and the most abundant one in Italy. It is commonly regarded as a drought sensitive species, and water scarcity and climate change are strongly affecting its productivity. However, there are still few studies and its responses to drought are poorly understood. This study aims at assessing the growth trends of two *Fagus* forests located in the Matese mountains (Campo Braca and Falode), in response to climate, and to provide insights into their ecophysiological responses by investigating the drivers of intrinsic Water Use Efficiency (hereafter WUE_i) variability. Wood cores were sampled for dendrochronological analysis and Stable Isotope Analysis. The $\delta^{13}C$ was used for computing the WUE_i. The two forests were located on mountain slopes with S aspect, and there was no difference in tree density. However, they showed different sensitivity of growth to climate, while the WUE_i responded in a similar way in both sites. WUE_i was negatively affected by early summer precipitation, highlighting the optimization of the water resource by the trees during drought. An important part of the WUE_i variability was explained by CO_2 concentration in the atmosphere, however, increased WUE_i was not linked to increased growth. Moreover, the Campo Braca site growth was negatively affected by high summer Vapour Pressure Deficit and showed a positive correlation with summer precipitation. Overall, our results suggest that the studied forests respond to reduced water availability by increasing their Water Use Efficiency, however this compensating behaviour is not sufficient to improve their growth.

Impact of climate and insect outbreaks on isotope ratios in Norway spruce trees in the Western Tatra Mts., Slovakia (Central Europe)

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Recent outbreaks of the European spruce bark beetle (*Ips typographus*) in Norway spruce (*Picea abies*) forests in Central Europe highlight the importance of studying forest health in complex ways. Drivers such as increased temperatures and decreased water availability (droughts) linked to climate change can weaken tree vitality and promote insect activity. This study provides quantitative evidence on tree physiology in two periods in the 20-th century (1940-1960 and 2000-2020). During the second period a windstorm occurred (2014) followed by a bark beetle outbreak which caused the death of trees. We analyzed the tree-ring O and C isotopic composition of three dead and three living trees. Meteorological data (monthly average temperatures and monthly precipitation sums) were used to analyze the impact of climate on tree physiological processes. Although the stable isotope variability was overall similar for dead and surviving trees, some clear temporal patterns were identified and differences in the climate correlations for dead and surviving trees. Carbon isotopes increased in the second period (but not oxygen isotopes) as well as annual temperature. Average annual temperature showed more "hot years" in the second period (2000-2020) whereas we did not observe any trend for precipitation. In the first period (1940-1960), oxygen isotopes positively correlated ($r>0.5$) with average temperature in August whereas carbon isotopes in dead trees positively correlated with temperature in June. Carbon isotopes did not show the same pattern in the trees which survived the outbreak. In the second period (2000-2020) neither the oxygen isotopes nor the carbon isotopes showed any correlations with temperatures but higher correlations with precipitation were found, particularly for surviving trees. These changes in climate sensitivity indicate increasing physiological stress for Norway spruce in recent decades. Acknowledgment: this work was supported by VEGA 1/0606/22.

Tree-ring oxygen isotope variations of two Himalayan pine species under the influence of regional drought

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The Himalayan region, including Nepal, has experienced a rapid increase in temperature, leading to a shift in hydroclimate and changes in the frequency and severity of extreme precipitation events. Tree-ring oxygen isotope variations ($\delta^{18}O_{TR}$) can provide insights into plant physiological and ecological responses to changing climate at different scales. $\delta^{18}O_{TR}$ depends on the isotopic composition of source water, which is further modified by local temperature and precipitation amount. Several studies have focused on high-elevation conifers to understand their adaptation to long-term and seasonal environmental changes. However, studies focusing on lower-elevation conifer species are still underrepresented, indicating the demand for further studies focusing on elevation gradients to understand changes in monsoon dynamics and ecosystem responses coupled with plant physiological effects. In this study, we have developed the first $\delta^{18}O_{TR}$ chronologies of two pine species native to Himalaya. The $\delta^{18}O_{TR}$ chronology of low-elevation red pine (*Pinus roxburghii* C. S. Sarg.) and high-elevation blue pine (*Pinus wallichiana* A. B. Jacks.) showed moderate correlation (r=0.51). However, the correlation was inconsistent over time, resulting in a divergence between the two species. In contrast, we observed convergent relationships between the tree-ring width chronologies for the same period. A further detailed investigation revealed that the divergence resulted from a severe drought event during 1993-1995 in both sites, with a more pronounced impact in blue pine. The weakening of the inter-series correlation of $\delta^{18}O_{TR}$ chronology of blue pine growing on a mountain slope indicated the adaptation of individual trees to localised available moisture resources during the drought. This adaptation was indicated by the weakening influence of the source water signal and, simultaneously, the strengthening of the leaf water signal.

Assessing forest acclimation dynamics: insights from a tree-ring multi-proxy approach

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Understanding forest acclimation to changing environmental conditions is crucial for predicting ecosystem resilience in the face of climate change. We propose a multi-proxy approach to assess the acclimation of trees to changing growing conditions by investigating the relationship between stable isotopes and growth patterns in tree rings. We applied this approach to a long-term irrigation experiment in the dry forest of Pfynwald and found distinct acclimation phases in response to altered water availability. Initially, irrigated trees exhibited increased growth, reflecting a temporary overyielding. After ten years of irrigation, growth trends stabilized, indicating a new equilibrium state adapted to the ecosystem carrying capacity. Our hypothesis posits that a strong relationship between $\delta^{18}O$ and $\delta^{2}H$ indicates trees operating near equilibrium, while perturbed states lead to increased metabolic variability, thus an OH-relationship decoupling. Indeed, results showed a coupled OH relationship indicative of equilibrium in irrigated trees after the growth plateaued, and in control trees, although their $\delta^{13}C$ values showed significantly different drought-stress levels. On the contrary, the trees for which irrigation was stopped after ten years showed an OH-decoupling and low growth, suggesting increased stress and physiological imbalance. Tree vitality, measured by crown transparency, further modulated responses to environmental changes. High-vitality trees suffered steeper declines post-irrigation due to overbuilding, while low-vitality trees maintained a conservative strategy, showing more constant growth under irrigation and following the irrigation interruption. Our findings provide quantitative indicators for assessing physiological imbalance and tree acclimation after environmental stresses. The multi-proxy approach offers insights into complex acclimation dynamics, essential for early detection of ecosystem imbalances and decline under climate change. This research underscores the significance of long-term monitoring and whole-stand investigations to fully grasp forest acclimation processes and inform effective management strategies for maintaining ecosystem resilience in a changing climate.

Drivers of intra-seasonal $\delta^{13}C$ signal in tree-rings of *Pinus sylvestris* as indicated by compound-specific and laser ablation isotope analysis

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Carbon isotope composition of tree-ring ($\delta^{13}C_{Ring}$) is a commonly used proxy for environmental change and ecophysiology. $\delta^{13}C_{Ring}$ reconstructions are based on a solid knowledge of isotope fractionations during formation of primary photosynthates ($\delta^{13}C_P$), such as sucrose. However, $\delta^{13}C_{Ring}$ is not merely a record of $\delta^{13}C_P$. Isotope fractionation processes, which are not yet fully understood, modify $\delta^{13}C_P$ during sucrose transport. We traced, how the environmental intra-seasonal $\delta^{13}C_P$ signal changes from leaves to phloem, tree-ring and roots, for 7-year-old *Pinus sylvestris*, using $\delta^{13}C$ analysis of individual carbohydrates, $\delta^{13}C_{Ring}$ laser ablation, leaf gas exchange and enzyme activity measurements. The intra-seasonal $\delta^{13}C_P$ dynamics was clearly reflected by δ $\delta^{13}C_{Ring}$, suggesting negligible impact of reserve use on $\delta^{13}C_{Ring}$. However, $\delta^{13}C_P$ became increasingly ^{13}C-enriched during down-stem transport, probably due to post-photosynthetic fractionations such as sink organ catabolism. In contrast, $\delta^{13}C$ of water-soluble carbohydrates, analysed for the same extracts, did not reflect the same isotope dynamics and fractionations as $\delta^{13}C_P$, but recorded intra-seasonal $\delta^{13}C_P$ variability. The impact of environmental signals on $\delta^{13}C_{Ring}$, and the 0.5 and 1.7‰ depletion in photosynthates compared ring organic matter and tree-ring cellulose, respectively, are useful pieces of information for studies exploiting $\delta^{13}C_{Ring}$.

Miscellaneous Dendroecology session

Session chairs: Guillermo Gea-Izquierdo & Dario Martin-Benito

Phylogeny and climate explain drought resistance and resilience in arid regions

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Repeated droughts have proved more harmful to forest growth than single extreme droughts. Given an increase of global-warming induced future with intensified drought severity and unpredictable frequency, how forests respond to drought episodes in different climatic regions is a key question to understand current and potential forest growth status. Here, we investigated the spatiotemporal changes of resilience indices under three typical drought episodes (i.e., 1-year single extreme drought, 2-year and multiyear repeated droughts) and revealed phylogenetic signals, environmental, and trait-based factors of resilience indices. Specifically, globally measurement-based 4374 chronologies obtained from three main databases were used to reveal divergent drought response patterns. The main findings illustrated that repeated droughts poured worse impacts on resilience (R_s), while resistance (R_t) showed no significant difference in arid regions under drought episodes. Clade-wise, significant higher R_t and R_s were observed in humid regions, but not in R_s of deciduous species. Temporally, R_s of evergreen in repeated droughts in humid regions decreased overtime from 1950 to 2020, while R_t of deciduous increased significantly in contrast. Surprisingly, R_t of species in arid regions showed phylogenetic conservation and was importantly controlled by economic and hydraulic traits, while environmental conditions attributed more on R_s. Furthermore, humid tropical forests were more threatened than in dry regions, particularly after repeated droughts. Our findings compensate for the drought response patterns under different drought episodes, providing new knowledge for global model simulations, uncertainty assessment, and future forest conservation. Besides, we emphasis considering phylogeny in resilience analysis in future drought episodes.

Advancing Forest Carbon Flux Estimation through Fusion of Tree-Ring and National Forest Inventory Data

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Forests play a crucial role in the terrestrial carbon cycle by capturing and storing more than 30% of annual anthropogenic CO_2 emissions into biomass. However, current projections on the capacity of forests to remain as a carbon sink through the century are highly uncertain due to the limitations in the parameterisation of biological responses in dynamical global vegetation (DGVM) and land surface models (LSM). These models have been developed using only short-term observations, resulting in highly uncertain long-term responses and projections of biomass growth and forest carbon balance. Consequently, long-term records on forest carbon uptake and storage are needed to reduce the uncertainties in modelled terrestrial carbon dynamics. To address this objective, we integrate a network of plots of National Forest Inventory (NFI) at the Iberian Peninsula dominated by European beech (*Fagus sylvatica*) with tree-ring data derived from the same plots. The NFI data provide comprehensive forest structure information at tree and stand level at approximately 10-year intervals. However, annual biomass accumulation rates are unknown and usually interpolated using linear growth models. Tree-ring data provide a reliable measure of annual tree growth that could improve the quantitative estimations of annual carbon storage in biomass. We applied frequentist modelling approaches to retrospectively interpolate annual estimates of diameter at breast height (DBH) in trees from NFI plots based on climate, stand variables and tree-ring width measurements. The preliminary results suggest that models including the cumulative tree-ring width and dominant height lead to more accurate estimations of annual DBH in the NFI plots. We will also show the effect of the different approaches used to interpolate DBH values on the calculation of carbon uptake during severe climatic events. A more accurate long-term forest carbon accumulation estimations may provide a benchmark to reduce uncertainties in the simulated terrestrial carbon fluxes by DGVMs and LSMs.

Carbon storage potentiality of old-growth forests under climate warming

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As the capacity of old-growth forests to store carbon until very old ages has been proved, their conservation has become a mitigation strategy to reduce net CO_2 emissions and moderate climate warming. We investigated the effect of tree age, competition and climate on aboveground standing biomass and C stocks over a 50-years period in two Spanish old-growth forest pine stands (OGFS) (*Pinus pinea* and *Pinus nigra*), combining dendroecological methods with forest inventory data and using semiparametric modeling. *P. nigra* OGFS stored 69.9 t C.ha^{-1} in standing volume, while *P. pinea* OGFS stored 58.2 t C.ha^{-1}. Carbon stored during the last 50 years increased in both OGFS, with a steeper increase in *P. pinea* OGFS. Annual C stored by the oldest trees was 20-25% in *P. nigra* OGFS and 17-23% in *P. pinea* OGFS. The different patterns of biomass growth increment in the two OGFS were explained by different biophysical environments, climate and history effects. The response to contrasted climate events was species-specific. Results for *P. nigra* showed a similar response to climate irrespective of tree age, while biomass growth in *P. pinea* increased in humid periods compared to dry periods in trees older than 40 100-years. The negative effect of drought is evidenced in *P. pinea* trees over 100-years old, while *P. nigra* showed a cumulative negative effect of drought for all ages. A lower effect of competition was recorded in the oldest trees in both OGFS. The interaction of competition with climate and tree age showed attenuated climate-mediated differences when competition was high.

Major tree species of Central European forests differ in their proportion of positive, negative and non-stationary growth trends

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Temperate forests are undergoing significant transformations due to the influence of climate change, including varying responses of different tree species to increasing temperature and drought severity. To comprehensively understand the full range of growth responses, extensive representative datasets spanning site and climatic variability are essential. This study utilizes tree-ring data from 548 sites from the temperate forests of Czechia to assess growth trends of six dominant Central European tree species (*Abies alba*, *Fagus sylvatica*, *Picea abies*, *Pinus sylvestris*, *Quercus petrea* and *Quercus robur*) over 1990-2014. By modelling mean growth series for each species and site, and employing principal component analysis, we identified the predominant growth trends. Over the study period, linear growth trends were evident across most sites (56% increasing, 32% decreasing, and 10% stable). The proportion of sites with stable positive trends increased from low towards high elevations, whereas the opposite was true for the stable negative trends. Notably, within the middle range of their distribution (between 500 and 700 m a.s.l.), *Picea abies* and *Fagus sylvatica* exhibited a mix of positive and negative growth trends. While *Pinus sylvestris* growth trends showed no clear elevation-based pattern, silver fir and oaks displayed consistent positive growth trends regardless of site elevation, indicating resilience to the ongoing warming. We demonstrate divergent growth trajectories across space and among species. These findings are particularly important as recent warming has triggered a gradual shift in the elevation range of optimal growth conditions for most tree species and has also led to a decoupling of growth trends between lowlands and mountain areas. As a result, further future shifts in the elevation range and changes to forest diversity of European temperate forests can be expected.

Ecological responses of pedunculate oak and narrow-leaved ash to varying groundwater levels in a South Moravian floodplain forest

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Floodplain forests are crucial for maintaining biodiversity and providing ecosystem services. However, they face threats from declining groundwater and climate change. The key tree species in Central European floodplains, pedunculate oak (*Quercus robur* L.) and narrow-leaved ash (*Fraxinus angustifolia* Vahl.), express distinct water usage strategies, and are likely to exhibit divergent vitality and growth patterns in the future. We hypothesize that tree-water coupling varies seasonally due to river runoff patterns. Additionally, we anticipate oak to exhibit greater drought resistance than ash, considering physiological differences such as deeper root systems and a retained stomatal conductivity and thus photosynthesis in oaks under drought. We analyzed ring-widths from four adult sites in southern Czech Republic with comparable climate and site conditions but varying groundwater levels. Monthly correlation analysis assessed the influence of groundwater levels and climate variables. Temporal trends were examined through correlations within a 30-year moving window for more dynamic insight. Resilience components were quantified to gauge the adaptability of both species to extreme drought conditions, offering insight into their plasticity under environmental stress. Our study revealed dynamic relationships between radial growth and hydroclimatic parameters, indicating significant shifts in tree sensitivity over time. Both species exhibit strong correlations at sites with declining water levels (Lanzhot and Soutok), with the pattern being more consistent and pronounced in ash. Conversely, at Lednice, where groundwater levels are higher, a decrease in sensitivity was observed, suggesting that the availability of groundwater might mitigate adverse impacts. Spring precipitation emerged as a crucial growth factor, with increasing correlation trend. Ash radial growth consistently showed strong correlations with groundwater levels, whereas oak exhibited significant relationships, particularly after river modifications. Generally, both species rely on precipitation in the early growing season, shifting to greater reliance on groundwater level from late spring to the end of the vegetation season.

KEYNOTE SPEAKER: Jesús Julio Camarero Martínez

Drought, forest dieback and tree growth resilience

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Worldwide, forests are being more severely impacted by drought stress. More frequent, drier, longer and hotter droughts trigger growth decline and forest dieback or die-off episodes characterized by unusually high mortality rates. Tree rings can be used as ecological tools to uncover when and how severe water shortage leads to irreversible growth decline and loss of resilience. In addition, dendroecological data can also improve our predictive power on when will forest dieback occur. In this tall, I introduce and discuss some issues related to drought, forest dieback and tree rings. These research avenues illustrate how complex is to forecast dieback due to site- and species-specific factors and carryover effects (cumulative stress). Further studies could consider these issues to build a stronger framework of growth resilience in the face of aridification.

Forest ecosystems, human activities, and climate change dynamics session

Session chairs: Roberta D'Andrea & Ania Cedro

Cultural heritage and dendrochronology in Transylvania

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In the last two decades the Anno Domini Dendrolab managed sampling and dating by more than 300 monuments in Transylvania. Due to this systematic working plan, we offered exact building and restoration dates for churches of different confessions (Orthodox, Lutheran, Catholic, Calvinist) and nationalities (Romanian, Hungarian, German/Saxon) and contributed on more research and restoration works in the area. The main focus of this research is a future monography about the history and typology of historical roofs in Transylvania. The presentation will give a short introduction about the beginnings and development of this research which will be completed by some study cases.

New South Scandinavian Tree-Ring Records from Subfossil Oak and Pine as Proxies for Long-Term Climate Dynamics and Ecosystem Changes

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Our understanding of long-term climate dynamics, environmental changes, as well as our possibilities to evaluate climate models predicting future climate scenarios are largely based on proxy records with a high temporal resolution and a wide geographical distribution. This study is an ongoing initiative to develop multimillennial Scandinavian tree-ring width (TRW) chronologies from subfossil oak (*Quercus* spp.) and pine (*Pinus* spp.). About 1000 oak trunks extracted from Danish and South Swedish sites have been analysed, and the material consists of a mixture of absolutely dated, radiocarbon dated, and not yet dated TRW records with a temporal spread over the last 8500 years. Regarding the pine trees, the material consists of remains from about 800 trees from south Swedish peat-extraction sites. The main part of the material covers the period 5200 - 1100 BCE, which corresponds to the Holocene Thermal Maximum (HTM) and the transition period towards a colder and more unstable climate following HTM. Significant long-distance cross-dating statistics between Swedish – Danish – German TRW chronologies proves that there is a (palaeo)climatic signal in the TRW data. Moreover, several oak dying-off and burial events coincide with wet shifts causing expanding peatlands, whereas pine colonization phases correspond to relatively warm and dry periods. The two species are thereby valuable complements to each other. The importance of these TRW chronologies should not be underestimated as (1) climate records of comparable length and resolution are rare for southern Scandinavia, (2) the TRW chronologies can serve as a dating tool for archaeological artefacts, and (3) there is a widespread lack of detailed moisture proxies spanning several millennia. Our data show that a continuous 8000-year oak chronology and multimillennial pine chronologies from South Scandinavia are realistic objectives and being important climate proxies in an ecologically sensitive region located at the interface between the temperate and boreal vegetation zones.

Effect of water level change and weather on radial increment of Scots pine (*Pinus sylvestris* L.) in Estonian peatland ecosystems

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A majority of Estonian peatlands have been under heavy human influence over the last century, primarily by draining. This study focuses on spatial and temporal relationships between anthropogenic changes in water level and annual tree-ring growth of Scots pines (*Pinus sylvestris*) in four historically drained peatlands across Estonia. Core samples from growing pines were extracted, measured and analysed using dendrochronological methods. In each peatland, pine growth at six to seven study plots along a gradient of water table was investigated. Since drainage is a form of disturbance, relative increment methods were applied. Disturbance events were identified from changes in tree growth in unstandardised tree-ring data. We also assessed variations in tree growth both within and between the peatlands. For climate analysis the tree-ring series were standardised. The preliminary results show that trees in three peatlands responded to the lowering of the water lever with a clear increase in tree-ring growth. In one peatland drainage effect was not so visible by the increase of tree-ring widths but by relative increment methods. Our preliminary climate analysis shows that trees sprouted after the drainage event exhibited better response to climatic factors than older trees. It also turns out that the more the peatland is influenced by drainage, the weaker is the effect of climate on tree growth. A certain lag in drainage effect was also detected.

Tree ring record of spatial temporal arsenic pollution in old mining area in Sudetes Mountains (SW Poland)

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Arsenic is a trace element commonly found in soil environments. However, the development of mining activities in the Sudetes has increased As contamination in environment, posing a serious threat to living organisms. This study examined the long-term impact on arsenic accumulation in trees over time, caused by the former gold and arsenic mine in Złoty Stok (Eastern Sudetes, SW Poland) using a dendrochemical approach. The Złoty Stok mine is one of the oldest mining facilities in Europe, thus this area has a long history of arsenic ore exploitation, and consequently contamination of surrounding soils and waters. The aim of our research is to asses of temporally and spatially impact of arsenic on the natural environment and phytoextractive potential of trees for arsenic. Three research sites were selected: Storczykowa Heap (in the vicinity of old mine), floodplain of Poisonous River (below mines and adit), and reference site. Four tree species were selected for the study: *Pinus sylvestris*, *Picea abies*, *Quercus robur*, and *Alnus glutinosa*. From each tree species we selected ten specimens. Cores were taken using Pressler's increment borer, creating chronologies. Additionally, cores from four specimens of each species were taken for chemical analysis of arsenic content using the Atomic Absorption Spectroscopy method (AAS) or/and Laser-Induced Breakdown Spectroscopy (LIBS). No presence of arsenic was found in the increments at reference sites. At the Poisonous River site, with high soil arsenic contamination, arsenic was detected in trees. The Poisonous River is fed by waters from the former gold and arsenic mine shafts in Złoty Stok, where the contamination originates. Lower arsenic concentrations were recorded at the Storczykowa Heap site, which is an ecological site created for calcareous grasslands (*Violetalia calaminariae*). These ecosystems form in post-mining areas with elevated concentrations of heavy elements. Interesting that lower arsenic concentration in trees is associated with the presence of plant species with phytoremediation abilities.

Does prescribed burning increase the resistance of pine species to drought and bark beetles?

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Prescribed burning is mainly used to reduce fuel load and prevent wildfires, but its effects often extend beyond the initial objective. As prescribed burning becomes increasingly used as a fuel management tool, it is important to understand its potential effects on tree vigour, as well as its indirect impacts on tree resistance to other disturbances. The choice of prescribed burning type and timing influence the intensity of the burns and, thus, the severity experienced by the trees. In this work, we review several studies in which we have used dendroecology to understand the effects of prescribed fire on pines of Mediterranean and montane forests, as well as its implications for tree resistance to other disturbances such as droughts and bark beetles. Vulnerability to drought after burning can be studied through changes in growth resistance and resilience, and in the physiological response. Tree-ring measurements show an increase in growth resistance and resilience to drought following prescribed burning; yet, the magnitude of change varies among pine species, burning seasons, the level of crown scorch, and the type of additional treatments implemented alongside prescribed burning. Stable isotopes reveal physiological responses in different directions: a decrease in the photosynthetic capacity caused by needle scorch or an increase in photosynthetic capacity and/or stomatal conductance caused by fire-induced competition release. Additionally, vulnerability to bark beetles after burning can be studied through changes in resin ducts. Our results show a short-term increase in resin ducts following prescribed burning, contributing to tree survival during subsequent bark beetle outbreaks. With this synthesis, we show how dendroecology can assist forest managers in understanding the impacts of prescribed burning beyond mitigating wildfire hazard in moisture-limited environments of Mediterranean and montane pine forests.

Modelling historical fire dynamics in Sweden: Integrating anthropogenic and climatic predictors

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Wildfires play a crucial role in European boreal forests, shaping forest structure and biodiversity while influencing global climate dynamics. However, contemporary Fennoscandian forests have experienced a sharp decline in wildfires due to effective fire suppression and changes in land use practices. Despite this decline, recent mega-fire events in Sweden have highlighted the persistent interplay between climate and human factors in shaping fire dynamics. Addressing this complex relationship is essential for understanding future fire trajectories. In this study, we employed a Generalized Additive Model (GAM) to investigate the influences of anthropogenic and climatic factors on historical fire activity in Sweden from 1550 to 2000. We used dendrochronological fire history reconstructions, independent climate reconstructions and an exceptionally long record of human population data at the municipality level. We further investigated the spatiotemporal patterns of the initiation of the fire-free period across the country by conducting regime shift analyses and mapping the initiation years of the cessation of fire across the country. Our findings revealed significant influence of human population density and drought conditions on fire occurrence with temporal variations. We found a south-north gradient in the initiation of the fire-free period in Sweden that agreed with the shift in human-land use patterns across the country. This study presented the first comprehensive synthesis of dendrochronologically-resolved fire occurrence reconstructions at the national level for Sweden and demonstrated that a model-based approach can be useful in untangling the climatic and anthropogenic effects in historical fire reconstructions.

Treelines in the Southern Carpathians: a tree-ring based approach to evaluate the impact of climate change and human activities on trees and shrubs growing at the treeline

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The global rising trend of temperatures causes various responses in climate-sensitive environments, such as the arctic and the alpine environments. In mountain areas, the growth of trees depends on a complex combination of biotic and abiotic influences, among which air temperature appears as the main limiting factor of tree growth. Increasing temperatures will, thus, allow trees to grow at higher elevations, and studies all over the world confirm that treelines are generally advancing. At local and regional scales, however, significant variability in treeline dynamics is observed, mainly due to site-specific environmental settings. The upward migration of the treeline depends not only on enhanced growing conditions, but it is also limited by seedling establishment and survival at higher elevations. Moreover, species-specific climate-growth relationships are also responsible for the heterogeneity of treeline responses to climate change. Local and regional treeline studies in the Southern Carpathians are generally lacking. The variety of local environmental conditions, tree species and degree of human impact, makes it challenging to characterize a regional treeline behaviour. Consequently, our study aims to assess how local treelines in the Southern Carpathians respond to climate change and reduced anthropogenic impact. We present preliminary results of a dendrochronological approach in different areas of the Southern Carpathians. In this study, we have analysed tree-ring widths (TRW) of five tree and shrub species (*Picea abies, Pinus cembra, Larix decidua, Fagus sylvatica* and *Juniperus communis*) growing at the treeline. A total number of 221 trees and 30 shrubs were sampled in six different locations, from the easternmost to the westernmost parts of the Southern Carpathians. Site-specific and species-specific responses were recorded, generally pointing on enhanced growing conditions in the last decades. In some areas, abandoned pastures are being recolonized by shrubs and trees, while in other locations the position of the treeline seems to be stable.

Dendrogeomorphic assessment of rockfall activity and its potential triggers in Outer Western Carpathians: a case study under structural escarpment

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Rockfalls are unpredictable natural hazards with a high speed and rapid evolution. To predict their occurrence, it is necessary to analyze their dynamics and triggers under natural conditions. The occurrence of rockfalls in space and time can be determined precisely using dendrogeomorphic methods. The aim of this study was to assess the rockfall activity, potential triggers, and key parameters of rock walls predisposed to rockfalls. The study area is located in the Moravskoslezské Beskydy Mountains (Western Outer Carpathians). Rockfalls induced by landslides have already been analyzed on rock walls. The uniqueness of this study lies in the analysis of rockfalls under rock walls induced by natural erosion. A total of 74 trees were sampled from five rock walls separated by an escarpment. Visible tree scars and growth disturbances were identified and analyzed in 296 incremental cores. In general, the rockfall intensity was low compared to landslide-induced sites, and the spatial pattern of rockfall indices indicated that trees farther from the wall were more damaged. The increase in the kinetic energy of falling rocks and the various deformations of their trajectories (due to the specifics of the rock walls) can play an important role. The main trigger for rockfall at the study site appears to be high spring temperatures, which influence the intensity of the freeze-thaw cycles. Therefore, it is the most important regional trigger for rockfalls. The major difference from landslide-induced rockfall sites is the lower frequency and dynamics of erosion-induced sites.

Tree-dating of Stradivari's violins

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The prime factor which affects the market value of a work of art is its authenticity. String instruments are among the most valued works of art, particularly those made by the old violin-making masters of northern Italy in the late 17th and early 18th centuries. Their authenticity is difficult to be verified on the basis of style and design alone, as these were often copied or forged. The only analysis that can objectively indicate, if not the exact year an instrument was made, at least the date before which it certainly was *not* made is a dendrochronological analysis of the wood used to make the instrument. We will review the dendrochronological studies done to assess the authenticity of the instruments made by the old Italian masters, bringing the example of the controversial dating of the famous violin "The Messiah" attributed to Antonio Stradivari. Such studies help to establish the earliest date the tree from which the wood was taken could have been felled, and to determine the source region of the wood. I will present the main achievements and challenges that have arisen in the past 50 years, and discuss the limitations and potential of using dendrochronological methods to establish the provenance and time period in which an instrument was made. Finally, I will describe needs of research in history, wood anatomy, biochemistry and dendrochronology, proposing some new methods that may open up new avenues of research and aid in the assessment of the authenticity of old string instruments.

Low xylem conductivity and plasticity of Mediterranean conifers contribute to drought induce decline and mortality

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Understanding the impacts of global change on forest ecosystems and dynamics requires the analyses of species performance and growth. Different responses to climate stress may lead to decline of some species or shifts in species composition. The adaptation of woody species to changing environmental conditions often relies on the plasticity of their xylem traits. In a Mediterranean landscape where tree species show contrasting mortality and decline rates and patterns, we analyzed the response of xylem traits and water use efficiency to drought and climate variability of three co-occurring conifer species with different drought tolerances (*Pinus pinaster, Pinus pinea and Juniperus oxycedrus*). In the studied landscape, *P. pinaster* shows widely symptoms of decline and accelerated mortality, whereas *P. pinea* only shows scattered mortality and *J. oxycedrus* shows no symptoms of decline. We analyzed annual and intraanual series of xylem anatomical traits, carbon discrimination ($\Delta^{13}C$), and intrinsic water-use efficiency (WUEi) for the period 1978-2017. Tracheids in healthy *P. pinaster* trees had wider lumens, thicker walls in latewood cells and higher resistance to implosion than dead or declining trees. Xylem plasticity in response to drought and climate variability was higher in healthy pines than dead pines, and higher in pines than junipers. Carbon isotopic discrimination and WUEi was similar in pines of all health status suggesting that declining and dead trees did not rely on tighter stomatal control to reduce transpiration under drought stress which may have led to an excessive water loss. In contrast, junipers had the highest WUEi. Our results suggest hydraulic failure as the main cause of tree die-back and the importance of high xylem conductivity to sustain high productivities. Our study highlights that xylem plasticity plays a major role in tree survival during drought events.

Continuous Monitoring Approach to Unveil the Link Between Tree Hydraulic Function and IADFs: A Study Case on *Pinus pinaster* Aiton Forest in Drought-prone Mediterranean Ecosystem

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Climate change significantly impacts the survival and growth of forests globally, leading trees to adapt their wood traits in response to climatic stress. In the Mediterranean, characterized by hot, dry summers and mild, rainy autumns, trees often develop intra-annual density fluctuations (IADFs) in tree rings, to optimize water use during favourable seasons and survive periods of intense water stress. Despite numerous studies on IADFs, our understanding on the relationship between water availability, wood formation dynamics, and xylem hydraulic functioning relies on indirect observations. This study, focuses on *Pinus pinaster* Aiton in a Mediterranean forest, integrates high-frequency sap flow (SF) monitoring with wood anatomy and xylogenesis studies during two growing seasons to shed light on their relationship. We compared a hot, dry season with a subsequent rainy one aiming to identify variations in wood traits and water use dynamics. The study, through an innovative monitoring approach, marks a significant milestone by providing the first direct observation of bimodal dynamics in SF and wood formation. Our results highlight *P. pinaste*r's sensitivity to climatic variations, emphasizing the crucial role of water availability for their physiology. In dry summers with limited autumn rainfall, trees may halt growth and enter a state of early quiescence; however, in wetter years, IADFs are stimulated, extending the growing season into autumn. Our achievements underscore how the capacity to form IADFs with large cells in autumn positively influences the overall xylem hydraulic conductivity, compared to years without IADFs. These results emphasize the need to extend measurements to different species and types of IADF, clarifying the acclimatization and resilience strategies of Mediterranean trees.

Evaluating Leaf Trait Variation and Cambial Growth in High Elevation Bristlecone Pine (*Pinus longaeva*)

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The relationship between foliar traits and tree growth under changing climate conditions remains largely unexplored since many species do not retain leaves for extended, datable periods. Bristlecone pine (*Pinus longaeva*, DK Bailey) is a well-known, long-lived conifer found at high elevations in the cool and dry mountainous region of the American West. The species is extensively used in dendrochronological paleoclimate reconstructions. Fortunately, bristlecone pine needles are annually datable and retained on their branches for an average of 45 years making it the ideal subject for research on foliar traits and growth relationships under contemporary changes in hydroclimate. To explore this relationship, we sampled six individuals on Mt. Washington in Nevada, USA, three from the alpine treeline ecotone and three from the subalpine forest. From each tree, we measured the ring width, needle length, and stomatal density and analyzed results using generalized-least squares regression followed by an ANOVA. For individuals, needle length and ring width had variable growth trajectories over time while stomatal density had an inconsequential response to time. Both stomatal density and ring width increased at the alpine treeline location when grouped by site, potentially explained by a greater number of stomates per needle. Ring width and needle length were positively correlated and had high first-order autocorrelation. Stomatal density, comparatively, had a weak negative relationship to ring width and low first-order autocorrelation, implying a minimally plastic response to climate conditions. Overall, the response of these traits to climate is not uniform and varies between individuals and locations. This is likely due to the specific environmental conditions each tree experiences. By expanding beyond ring width, interannual variation in needle physiology allows us to understand the response of the bristlecone pine to recent climate change and the relationship between these traits.

Functional DendroEcology session

Session chairs: Guillermo Gea-Izquierdo & Dario Martin-Benito

Functional dendroecology: integrating ecophysiological processes and dendrochronological proxies

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Growth rings of woody species serve as long-term records of plant physiological responses to climate and other environmental factors. This has long been explored in dendrochronology at different scales. However, interpretation and models of dendrochronological data have most often been implemented empirically to maximize proxy responsiveness to some environmental forcing of interest. In recent years, it has increased the development of different complementary approaches with a functional goal and models implementing physiological processes that profit from dendrochronological proxies. The combination of anatomical, isotopic and growth dendrochronological data has much potential to investigate the carbon and water dynamics to understand the tree physiology under increased abiotic stress under climate change. However, there is still much to be learned regarding the functional interpretation of dendrochronological proxies, therefore to implement this knowledge in precise process-based models. We would like to encourage discussion on concepts and applications to advance towards a more oriented 'Functional dendroecology'. We briefly discuss the history and applications of physiological interpretations in dendrochronology, complemented with some recent applications of process-based models and dendrochronological data. We need not only to benchmark models with data but also to adapt new dendroecological sampling protocols towards a better understanding of carbon and water dynamics. These approaches have large potential to assess short- and long-term responses and provide functional interpretation, through the combination of observational studies, retrospective analyses or simulation exercises. Integrating empirical dendroecology with ecophysiology is essential to better functional understand of diverse dendrochronological records and ultimately ecosystem functioning under climate change.

Integrating tree-ring anatomical traits and carbon fluxes to unravel carbon allocation using 3D-CMCC-FEM model

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Boreal forests sequester one third of terrestrial carbon, playing a crucial role in mitigating climate change. However, our understanding of the relationship between carbon assimilation and its allocation into woody biomass remains limited. To address this gap, we propose a novel approach that combines eddy covariance (EC), quantitative wood anatomy in tree rings, and forest modelling. This integrated method aims to elucidate the pathways of carbon allocation over short and long-time scales. The study was conducted in a site of *Pinus banksiana* (Lamb.) in Canada (Ameriflux CA-Ojp, Western Boreal, Mature Jack Pine), spanning from 1999 to 2019. Our results revealed notably high correlations between model-predicted and measured Gross Primary Productivity (GPP) ranging from 0.87, 0.91, 0.77 for daily, monthly, and annual scales, respectively. We found a strong correlation between annual tree-ring modeled by the 3D-CMCC-FEM model and measured (r = 0.6). Furthermore, we observed significant inter-annual variability correspondence between measured ring wall area (RWA) and cell wall area (CWA, proxy of total woody biomass at ring and cell level, respectively) and allocated carbon in the stem pool predicted by the model. Tree rings provide high resolution information on forest aboveground biomass growth. In combination with long-term carbon flux measurements, they can significantly enhance our understanding of both inter-and intra-annual variability of carbon fluxes, providing insights into the pathways of carbon in forest.

Rising CO_2 increases photosynthetic efficiency of tropical forest canopy trees at the centennial scale

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The increasing sink capacity of tropical forests in response to rising atmospheric CO_2 (C_a) is expected to help mitigate the negative effects of climate change on forest carbon sink capacity. This assumption is grounded in our current understanding of the C_3 photosynthetic pathway, which is utilized by all tropical forest canopy trees. This photosynthetic pathway is still CO_2-limited under current C_a levels, and therefore increased efficiency is expected with rising C_a. Canopy trees are the main drivers of carbon fluxes in tropical forests, yet studying tropical tree physiology in canopy trees at centennial time scales is challenging. In this study, we use deuterium isotopomers derived from tree rings of *Toona ciliata* trees from three climatically distinct forests in Asia and Australia. Using these isotopomers we study how the ratio between oxygenation and carboxylation changed with C_a, diameter (as a proxy for tree exposure), temperature, and precipitation. We found that C_a increases photosynthetic efficiency, likely due to increased carboxylation and suppression of oxygenation. This effect is consistent across all sites at the centennial scale. Tree exposure changes the ratio in the opposite direction, and asymptotically reduces photosynthetic efficiency as trees grow into the canopy, likely due to increases in the fraction of oxygenation over carboxylation with increasing irradiance. We did not find any effects of temperature or rainfall on photosynthetic efficiency. In short, our research shows that higher C_a levels boost photosynthetic efficiency, potentially increasing net photosynthesis. Yet, understanding C_a effects on trees requires considering the effects of tree size.

Memory in trees (and how to model it)

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Annual rings in trees are not independent and a good year one year can mitigate a bad year that follows. But how long of a memory do trees have? And – given that an annual ring from the same tree or core is a good predictor of other rings from the same tree because they share a genetic basis – how exactly should this be modelled? Using trees sampled from ecological plot designs across Europe, we investigate the extent of interannual buffering in different populations in the context of physiology-informed modelling approaches.

Growth patterns, climate sensitivity and resilience of silver fir trees (*Abies alba* Mill.) differ along a gradient of time since the last harvest in the Central Pyrenees

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Old-growth forests are particularly rare in Europe, even though they fulfil a key role in mitigating climate change and providing numerous ecosystem services (biodiversity). They also offer real inspiration for future forest management. Over the last few years, we have carried out a number of projects in the Pyrenean forests (ANR JCJC BENDYS, OcciGEN project funded by the Occitanie region, Labex DRIIHM FODYNA and TRANSYLVE projects), resulting in the sampling of 244 tree rings series for silver fir (*Abies alba* Mill.). To assess the effect of management on growth, responses to climate, and resilience to major disturbances, we clustered the forest into three groups according to the intensity of practices during the last centuries: *production forests* regularly harvested, mature stands unharvested for about 40-50 years, and old-growth forests characterized by very high maturity and unharvested for at least 100 years. On each core, we measured both ring width (TRW) and late-wood width (LWW) to examine growth patterns. TRW and LWW were correlated with climatic data to identify the main climatic drivers of fir growth in the Pyrenees. On a selection of 75 cores (25 for each stand type), we identified two positive and negative pointer years for which we calculated resilience components (according to Lloret), and isotopic analyses (dc13) were also performed on these four selected rings to estimate drought responses. We used different climatic data to estimate drought indices with the SurEau model. We compared growth rates, tree-ring-climate relationships, as well as resilience and dc13 signatures between stands types to test for the effect of the time since the last logging. The aim of our talk is to present the initial results of this study, as well as the research perspectives that we consider essential to refine our knowledge of possible forest adaptations to future global changes.

Impact of climate change on radial growth of silver fir (*Abies alba* Mill.) along the Dinaric Mountains in Croatia

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According to the IPCC report from 2013, the Europe's climate is becoming warmer and drier. At the same time, we are witnessing more and more frequent and intense extreme climatic events and the associated disturbed habitat conditions which have a significant influence on stability of European forests. With silver fir (*Abies alba* Mill.) representing an important species in Croatian forestry, as it greatly contributes to the biodiversity and the resistance of stands to various biotic and abiotic factors, its future in current natural range is of a crucial question. The potential ecological niche of silver fir, based on its current distribution, suggests a high suitability for wet rather than warm and dry habitats, even though paleoecological studies reveal that this species was widely distributed in Meso-Mediterranean conditions. Previous research indicates potentially significant reduction of the ecological niche of silver fir in Croatia over the next 100 years due to climate change, but only indicates a decrease of habitat suitable for silver fir while its adaptation as a species has not yet been investigated in Croatia. This study investigates the influence of climate change on radial growth dynamic of silver fir along its distribution area in Dinaric Mountains of Croatia. To assess that, three sites representing diverse habitat conditions were selected, ranging from wet stands in optimum to drier stands on the edge of its distribution area in the Croatia. Dendrometer data indicate that silver fir trees growing on the edge of its distribution area suffer from certain amount of drought stress during summer months, while in the optimum this growth stress was not evident. Using dendrochronological methods together with the composition of carbon isotopes ($\delta^{13}C$) in the cellulose of tree-rings gives us the long term evaluation of silver fir response to climate and related stand conditions change.

Past Climate Reconstructions session

Session chairs: Achim Bräuning & Michal Bosela

Tree-ring-based atmospheric dryness reconstruction for northwest Patagonia since 1588

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The dryness of the air, also known as vapor pressure deficit (VPD), plays a crucial role in plants functioning. However, our long-term understanding of how plants respond to increasing VPD is limited and has been largely unexplored. Since trees are the longest-living organisms in nature, dendrochronology offers a unique opportunity to utilize annual tree rings as proxy for expanding climate records. In this study, we utilized tree rings from a dioecious tree species, *Araucaria araucana*, at three sites in Northern Patagonia, to investigate the potential of tree rings as indicators of past VPD variability. By developing a tree-ring width chronology dating back to the 14th century, we reconstructed 431 years of VPD fluctuations, covering the period from 1588 to 2019 AD. Our reconstruction successfully explained 43% of the variance in January-February VPD (summer) between 1969 and 2016. Furthermore, we observed that the sensitivity of tree rings to summer VPD varied depending on the sex ratio. Although female trees exhibited higher sensitivity to summer VPD compared to male trees, the combined population signal (i.e., both sexes) is highlighted over the gender-specific signal. Our chronology matched well with other tree-ring based moisture or drought reconstructions from South America which allows us to improve the knowledge of the atmospheric dryness in a long-term regional context.

Significant volcanic cooling expressed in tree-ring summer temperature reconstruction from Northern Patagonia, Argentina

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No traditional tree-ring (TR) density-based reconstruction of past summer temperatures exists for the Southern Hemisphere. It is therefore no surprise that current published ring-width (RW) based temperature reconstructions provide ambiguous evidence for past volcanic forcing in the Southern Hemisphere. In this study we present a new January-March summer temperature reconstruction (1382-2017) for Northern Patagonia (NPAT) based on RW and Blue Intensity (BI) parameters measured from *Araucaria araucana* trees from 6 locations across the middle to southern end of the species' range. The multi-TR-Parameter reconstruction explains 53% of the summer temperature variance (1903-2017) which is on par with similar TR based reconstructions from the Northern Hemisphere. The reconstruction coheres strongly with surface mean air temperatures for a large region in South America including sea surface temperatures well into the southeastern Pacific for these latitudes. The warmest 10-year period is 2008-2017 while the coldest period is 1455-1464. The coldest reconstructed year, outside the instrumental period, is the late summer of 1460. Superposed Epoch Analysis, focussing on significant tropical eruptions since the 1400s, indicates a significant mean cooling of ca. 0.4 - 1.0 oC, depending on which volcanic events are used. The degree of relative cooling is on par with the cooling represented by individual TR records used in the Northern Hemisphere N-TREND reconstruction suggesting that the volcanic response in northern Patagonia over the last 6 centuries is equivalent, or even more extreme, to what is observed in many Northern Hemisphere locations. Our results indicate that the use of ring-density parameters is of paramount importance for assessing past volcanic forced cooling in the Southern Hemisphere, but the continentality of the tree sites may also be an important factor.

The East Atlantic/Western Russia Pattern: A 300-Year Climate Dynamics Reconstruction from Tree-Ring Analyses

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The East Atlantic Western Russia (EA/WR) pattern explains a significant amount of short-term temperature variability over Eurasia. In summer, the positive phase of this atmospheric mode is associated with a temperature dipole over Europe: cold anomalies covering a broad region over western Russia, the Caucasus and Turkey are accompanied by warmer than average temperatures in France and parts of Spain. Using two clusters of new and existing temperature reconstructions from tree-rings, allows us to reconstruct the high frequency variability of the summer EA/WR pattern 300 years beyond the instrumental records. We explore reasons for a multidecadal decrease in the magnitude of the European temperature dipole during the Little Ice Age and investigate potential spatial changes in the EA/WR pattern. Radiative relevant volcanic eruptions only have limited impact on the EA/WR pattern indicating a weakening of the temperature dipole in response to short-lived, large-scale forcing. Our findings provide new insights in historical climate dynamics across Europe and can be used as a benchmark for investigating the EA/WR pattern in model simulations.

Reflected-light quantitative wood anatomy temperature reconstruction from the Romanian Carpathians

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Dendroclimatic reconstructions are vital to understanding historical climatic variability. However, compared to other regions, eastern Europe remains a spatiotemporal paleoclimatic gap that is underrepresented in terms of robust, high-quality dendroclimatic reconstructions. Chronologies based on quantitative wood anatomical (QWA) parameters typically possess superior climatic signals to other tree-ring datasets. However, although the considerable paleoclimatic potential of QWA datasets has been well-established, temporally-extensive and well-replicated QWA chronologies, and particularly dendroclimatic reconstructions, are still very rare as producing and measuring anatomical thin-section slides remains time-consuming, costly, and methodologically challenging. As an alternative to traditional QWA, we utilized ultra-high-resolution (~75000 dpi) reflected-light binary microscope images of Norway spruce samples from the Făgăraș Mountains in the Romanian Carpathians, initially produced to generate Binary Surface Intensity (BSI) datasets (Rydval et al., 2024). Using ROXAS software, we measured the reflected-light equivalent of QWA parameters, termed "surface-QWA" (sQWA). With this first-of-its-kind dataset, we produced cell-wall thickness (CWT) chronologies from the outermost ring sector and developed a ~300-yr temperature reconstruction for southeastern Europe. After developing additional reconstructions for central and northern Romania using multiple tree-ring parameters, including tree-ring width, latewood Blue Intensity, and latewood Surface Intensity, we compared this unique sQWA-based reconstruction with these and other records in the wider region, along with relevant instrumental temperature datasets. Calibration R^2 of the sQWA reconstruction with April-September CRU TS4.07 mean temperatures over 1901-2010 reached 48.9%, outperforming all other parameters and the reconstructed temperature trends generally agreed with other records. This demonstrates the vast potential of utilizing ultra-high-resolution reflected-light images to develop QWA datasets and their paleoclimatological utility. The advantages of sQWA, which include faster and easier sample preparation with no thin-sectioning or chemical processing requirements, will help facilitate more widespread access and higher-volume QWA dataset production, particularly in combination with emerging AI measurement systems, opening a new frontier in dendrochronological research.

Taxus ring width network from southern England reflects western European hydroclimate extremes over the past three centuries

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Affecting ecological and societal systems across Europe, heatwaves and summer droughts are likely to intensify under anthropogenic global warming. High-quality annually resolved and absolutely dated climate reconstructions are needed to place modern trends and extremes in the context of past natural ranges. Here, we present a network of 153 yew (*Taxus baccata* L.) tree-ring width (TRW) series from 22 sites in southern England. Inter-series and -chronology correlations of 0.60 and 0.67 indicate a high degree of growth coherency between 1710 and 2020 CE. We developed a suite of robust residual and standard TRW chronologies that correlate >0.65 with gridded April–July precipitation totals and July drought indices over western Europe back to 1901 CE (p <0.001). We then reconstructed interannual to multi-decadal spring-summer precipitation and mid-summer drought variability for southern England, northwest France, the Low Countries, and western Germany over the past 310 years. Our pseudo-independent hydroclimatic reconstructions capture all of the observed summer droughts back to 1710 CE, but tend to underestimate the amplitude of pluvial extremes. Using 30-year moving windows and the threshold of 1 standard deviation, with eight severe summer droughts reconstructed between 1762 and 1791 and only six such extremes found in the past three decades, our study suggests that the frequency and intensity of recent western European hydroclimatic extremes are still within the range of past natural variability.

ABSTRACTS – POSTERS

The dual isotope approach in tropical tree rings: how homogeneous is the relationship between carbon and oxygen isotopes?

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Stable carbon and oxygen isotopes in tree-ring cellulose are an important environmental proxy in tree-ring research, especially in tropical environments, where they often provide a much stronger climatic signal than tree-ring width. In combination, carbon and oxygen isotopes have been used in conceptual models to disentangle ecophysiological responses between external drivers (i.e., increasing atmospheric CO2 concentration) versus internal mechanisms (i.e., increasing photosynthetic capacity) in the isotopic fractionation processes. However, dual isotope approaches have not been systematically applied yet in tropical environments. We investigate the relationship of both isotope species in different tropical tree functional types (conifers versus evergreen and deciduous broadleaved species) under seasonally dry and humid climate conditions in Ethiopia and Bangladesh. We found strongly contrasting coherency between the two isotope species in different tree species and provide preliminary interpretations about possible internal and external drivers determining the interplay of both isotope species.

Trees and shrubs from northern Norway exhibit distinct Blue Rings in 1877 and 1902

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Exposed to extreme climate conditions, woody plants in northern Scandinavia provide ideal opportunities to study possible effects of short growing seasons and abrupt summer cooling on xylogenesis. Here, we present combined dendrochronological and wood anatomical investigations of 25 *Pinus sylvestri*s trees and 25 *Juniperus* spp. shrubs that were collected along the slope of Iškoras Mountain in northeastern Norway around 69°N, 25˚E, and 300-400 m asl. The tree and shrub species not only exhibit exceptionally small growth rates, but also a surprisingly large number of Blue Rings over the past 300 years, for which robust ring width chronologies were developed. The highest frequency of Blue Rings in our pine and juniper samples occurred in 1902, whereas another peak in Blue Rings in 1877 was restricted to the tree samples. Taking advantage of daily temperature measurements from the nearby meteorological station in Karasjok, we found the lowest sums of growing degree-days in June 1902 and August 1877, which likely resulted in more uniformly non-lignified Blue Rings in 1902 compared to those in 1877. Our study not only provides first evidence for different impacts of early and late growing season cold spells on cell wall lignification in trees and shrubs, but also demonstrates the potential to refine the temporal resolution of existing summer temperature reconstructions, from northern Scandinavia and elsewhere.

Radial Growth Reference models: Evaluating Oak Growth Response to Removal of Adjacent Trees

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In the Baltics, in order to enhance oak growth, removal of adjacent trees and shrubs is practiced, however, by practicing this specific management method, microclimate within the stand can be significantly altered, causing a contrasting effect on oak growth. Radial increment is known to reflect the impact of changes of various environmental factors on tree growth, consequentially. The development of radial increment reference model could improve the assessment of alterations in oak growth in response to elaborated growth conditions. The aim of the study was to develop a radial growth reference model that would further be implemented in the assessment of radial growth response of oak to environmental changes caused by selective removal of adjacent trees. The measurements were collected from 8 historically planted oak stands, in which no significant thinning of the stand density has been carried out. Data was collected in 2 - 4 circular sample plots, depending on the area of the stand. Tree height and diameter at breast height were measured. From each sample plot, increment cores were obtained for 3 - 5 oak trees of different dimensions, with an obligation that the minimal number of sampled trees was not less than 12 from one stand. Dendrochronological methods were used in data analysis; if necessary, age correction was performed by determining the number of missing years to pit and the cumulative radial increment was calculated. In order to distinguish possible changes in oak radial growth, due to removal of adjacent trees, modelling of reference tree radial growth will be performed by using the *nls* 'Nonlinear Least Squares' function in R software.

Exploring wood density as a proxy of carbon stock across northern hemisphere conifers in relation to global warming and tree age variability

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Wood density is a major determinant in calculating above-ground carbon stock in global forest areas. However, wood density is assumed to be constant, neglecting its inter- and intra-annual variations over time due to tree age and climate, thus attributing uncertainties in carbon stock estimations. To investigate the effect of tree age and temperature-related tree growth response on wood density trends, we analysed more than 5000 conifer time series of earlywood, latewood, total tree-ring width, and X-ray density in the Northern Hemisphere (NH) from 1700 CE to the present and sourced from the International Tree Ring Data Bank (ITRDB). Over this period, we observed a consistent increase in tree-ring widths across all age classes. This trend could suggest higher carbon stock. However, we observed decreased wood density by computing total tree ring wood density, weighted by early- and latewood widths. Despite the reduced numbers of data available beyond the 1990s, our preliminary findings suggest a decreasing trend in wood density and an overall reduction in NH trees' carbon sequestration rate over time. If significant, this decline must be considered in future forest carbon stock calculations and global warming mitigation policies.

Can acclimation strategies under drought and warming be explained by changes in cambium sugar metabolism?

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The ability to restore cambium cell division or cell enlargement after drought or heat waves is a crucial step in overcoming the physiological imbalance and allowing tree growth to recover under new optimal environmental conditions. Water deficit and warming directly affect wood formation by altering the turgor pressure in cambial cells and their derivatives, or by limiting the availability of carbon to support cell construction, respiration and metabolism, and to modulate signalling. In some woody species, the sensitivity of the cambial region to water deficit was found to be a genotype-dependent feature and it was related to the activation of specific metabolic pathways (oxidative scavenging machinery) and osmotic processes, mainly involving soluble sugar metabolism. Such processes have been well characterised in leaves, but rarely in the cambium or phloem, and recent evidence has shown that the cambium responds differently from leaves to water stress and warming. In this framework, we discuss the main results obtained through manipulative experiments on poplar and Norway spruce, showing the main involvement of sugar metabolism in phloem and cambium as osmotics in the tissue response to drought and warming. Furthermore, we present the prospects of using information on sugar metabolism in the cambial zone and phloem to improve our knowledge of the effect of environmental stress on the main morphological traits of the xylem and the putative degree of resilience of woody species/clones/varieties to climate. We discuss these results with a view to understanding how trees will adapt to future environmental conditions.

First Record of Blue Ring in a Dicotyledonous Angiosperm

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Previous analyses of conifer woods have highlighted the formation of a continuous layer of less lignified axial tracheids, the so-called Blue Rings (BRs). Until now, the same anatomical feature has never been described in dicotyledonous angiosperm woods. Here, we report the formation of BRs on two *Populus x canadensis* clones ("Tucano" and "San Martino"), and we discuss potential causal factors related to climate, stem growth and plant hormones. BRs were observed in all 13 poplar cuttings included in the study, with the primary driving factor identified as a lack of hormonal signals due to apical bud and leaf damage after intense warmth. Identifying BRs in angiosperms could refine paleoclimate reconstructions from tree rings and promote studies on plant adaptation to a changing climate. This study was performed under the project Agritech.

Three-dimensional distribution of mass movement signals in disturbed *Picea abies* (L.) Karst.

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Dendrogeomorphologic approaches enable annual absolute dating of various potentially hazardous geomorphic processes. This study tested the dating precision of three commonly used dendrogeomorphic approaches used for the extraction of geomorphic signals from the tree ring series of disturbed trees. The first approach is based on the onset of reaction wood occurrence, and the other two approaches are based on the detection of abrupt changes in tree ring eccentricity. Nine 165 cm long stems of maximally 27 year old Norway spruces (*Picea abies* (L.) Karst.) growing on unstable slope affected by mass movement events of known age were analysed. Several sampling directions on stems were analysed to reveal the best sampling strategy for each tested approach. The relationships between stem curvature and the dating precision of the approaches were also analysed. The results of dating precision showed crucial differences between the tested approaches. Tree stem curvature did not influence dating precision. Overall, we concluded that the approaches based on eccentric increments are less precise than those based on reaction wood analysis when juvenile *P. abies* trees that grow on landslide slope are sampled. The importance of this study is in providing new insight into dating precision by analysing the whole tree stems of trees influenced by mass movements. This is unique since the approaches based on eccentricity increments have not been previously tested in such a detail.

Anatomical Response of Cork Oak (*Quercus suber* L.) to Cork Stripping

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The cork oak (*Quercus suber* L.) is a species of high ecological and economic value found in the western Mediterranean basin. In managed areas, its thick, insulating bark is traditionally harvested every 8-11 years as a source for the cork industry. Some studies suggest a reduction in the vessel size after bark removal, which might affect the hydraulic conductivity of trees and ultimately their growth. Yet, little is known about the size effect of changes in vessel formation after bark removal and the resilience of cork oak trees to recover to previous vessel formation patterns. Here, we quantify the immediate effect of bark removal in vessel size and number in a managed woodland in southern Spain. We used minicore samples from recently debarked and never debarked cork oaks to obtain wood cross sections using a sledge microtome. Stained sections were analysed using image analysis techniques to measure vessel size and number in wood rings from the last year after stripping. We found evident differences in vessel formation between debarked and never debarked trees. Specifically, vessel size diminished immediately after bark removal while vessel number increased. Furthermore, neither the size nor the number of vessels recovered in subsequent years, suggesting a lack or steady recovery of cork oak wood development after bark removal. These changes in the number and size of conductive vessels likely have consequences in the response capacity of these trees to the current increase in temperature and water scarcity in the study area. In this sense, our results provide a piece of the puzzle to the current problem of the viability of cork oak populations from the southern Iberian Peninsula.

A birch tree as witness in a murder and cannibalism case

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Fifteen years after a murder and an act of cannibalism, the police in Szczecin (NW part of Poland) have conducted an investigation, in which neither the time of the murder, nor the victim identity were known, no body was found, and the defendants have not confessed. Due to the circumstantial nature of the investigation and the trial, a number of analyses were performed, and expert opinions were requested as part of the inquiry. A dendrochronological study of a birch tree growing on the shore of Lake Żabie was one of the analyses lending credibility to the testimony of one of the defendants, and pointing to the murder site. The aim of the study was do determine the age and size of the birch tree in the period 1998-2002, and to determine whether the tree was a distinctive feature of the landscape through the period in question. Field work was performed in April 2019, under the supervision of the police. The birch tree was measured, and samples were collected using a Pressler borer. The measurements and observations revealed that the birch tree, due to its size, and the absence of other trees of this species in this segment of the lake shore, may have been a characteristic landscape element in the late 1990s and early 2000s. According to the police officer and the prosecutor in charge of the case, the results of the dendrological analysis have lent strong credibility to the testimony of one of the defendants, and to other findings of the investigation.

Tree-ring stable carbon isotopes indicate increased drought stress for conifers in southeast Germany over the past 50 years

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Stable carbon isotopes in tree-ring cellulose ($\delta^{13}C_{TRC}$) represent a robust proxy reflecting the physiological responses of trees to annual climatic conditions. Carbon isotope ratios, only sparsely influenced by extrinsic factors, provide detailed insights into the drought-induced stress level of a tree and the intrinsic water-use efficiency (iWUE). This study investigated $\delta^{13}C_{TRC}$ of one broadleaved and one coniferous tree species at six study sites in North Bavaria, southeast Germany, differing in altitude and climatic conditions. Site- and species-specific responses to climate conditions are determined over the past 40 to 50 years. Furthermore, direct relations are explored between physiological tree responses and specific weather patterns of the past 30 years. Weather patterns, meaning the distribution, intensity, and characteristics of high- and low-pressure systems over Central Europe, drive the local weather conditions in Bavaria. Since it is possible to predict the occurrence of specific large-scale weather patterns and their local effects very precisely, future $\delta^{13}C_{TRC}$ signatures can be reliably modelled. The $\delta^{13}C_{TRC}$ measurements revealed a steep increase of $\delta^{13}C_{TRC}$ values and increased iWUE for all studied tree species, but the respective manifestations differed regionally. For instance, *Pinus sylvestris* at low-elevation sites indicated the highest rise in drought stress within the last 30 years. Secondly, $\delta^{13}C_{TRC}$-climate correlations identified specific weather patterns, predominantly provoking stress responses (stomatal closure). Weather patterns associated with low precipitation amounts and warm temperatures revealed the highest correlation coefficients. However, especially those are predicted to occur more intensively and frequently until the end of the 21st century. Therefore, the findings suggest that the increase in $\delta^{13}C_{TRC}$-values continues, and longer-lasting drought periods will aggravate drought stress in Bavaria, especially for low-elevation coniferous forests.

Comparing sampling strategies for quantifying adaption on tree growth on Norway Spruce

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Norway Spruce (Picea Abies L Karst) has adapted to environments throughout central Europe, spreading within and beyond its natural range. It has also become a species of great economic importance, resulting in large monocultures. However, the rapidly changing climate makes it more and more difficult for Norway Spruce to adapt quickly enough to environmental changes. Capturing this adaptation correctly is essential in order to quantify the changes in forest growth. In this project, we focus on gaining more insight into the sampling strategy necessary for successfully quantifying this adaptation within tree rings. We sampled approximately 60 trees (>5 cm DBH) per site and took at least two cores per tree. All trees within the site were mapped from a center point and the bearing was recorded to situate the trees precisely. With these measurements the site can be presented in a xyz – coordinate system. For this project, multiple sites in two locations (Šumava, Czechia and Mercantour, France) were used. We compare several sampling strategies commonly used in dendrochronological studies by subsampling the already sampled sites. We investigate the effect of sampling only dominant trees, sampling reduced number of trees, older trees and only using one core per tree. This project contributes understanding to sampling strategies needed in order to effectively quantify ecological adaption on tree growth.

Do past management legacies modulate climate-growth relationships of oak trees?

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Temperate forests are undergoing significant changes due to the effects of global change. Beside climatic factors, the past management legacies influence the tree growth. One of the appropriate approaches to study the effect of management is the comparative analysis between unmanaged old-growth and managed forests. But, due to the scarcity of old-growth forests, little is known about how past management legacies modulate tree responses to climate warming and more frequent droughts. Here, we assess the response of trees basal area increment (BAI) to climatic factors (temperature, precipitation, drought) in one of the best-preserved sessile oak-dominated old-growth forests in Europe compared to a managed forest with similar composition and environmental conditions. A clear rise of the temperature and droughts frequency after 1980s and particularly in the last decade (all annual average SPEI values (12-month scale) were negative) was observed. The BAI long term pattern, with lower values in dry years, was similar in both forests. The temperature rises and changes in atmospheric water demand during growing season let to increasing drought stress during the late 20th and early 21th centuries affecting both managed and unmanaged forests. However, trees in managed forests showed higher correlations between BAI and SPEI values, indicating higher sensitivity to drought compared to old-growth forests. Furthermore, trees in old-growth forest generally shown greater resilience and resistance to past extreme events. Molecular genetic analyses showed greater values of genetic diversity indices (e.g. private allelic richness, average number of alleles per locus, observed heterozygosity) in oak trees in old-growth than in managed forest, but without significant differences. Our results confirm the lower sensitivity to climate in unmanaged old-growth forest found in previous studies and highlight the importance of legacies in growth response to drought in temperate forests, making them more vulnerable to climate-warming related drought in central Europe.

Climate reconstruction and geohazard analysis using tree ring data from western Himalaya

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Under global warming, extreme events such as droughts and floods are becoming the greatest challenge for the societal livelihood. Extreme climate events cause sudden changes in soil moisture conditions, enhance the risk of ground failures leading to geohazards, but also leading to anomalous tree growth. In the Himalayas, winter moisture influx by western disturbances (WDs) is important for tree growth by providing soil moisture during the dry spring and pre-summer monsoon months. To understand the impact of moisture changes on tree growth behaviour, we developed a 463 year-long (1558-2021 CE) tree-ring width chronology (TRWC) of *Cedrus deodara* (cedar) growing in the Kinnaur region, western Himalayas, and established correlations with climate variables. TRWC revealed a significant negative correlation with mean maximum temperature and a significant positive correlation with the standardized precipitation evapotranspiration index (SPEI 04) for the winter and spring months (January-May). A tree-ring based SPEI04 reconstruction showed moderate to extreme wet years between 1600 and 1770 CE, which correspond to the cold and humid Little Ice Age climate anomaly phase recorded from many northern latitude regions. We also assessed the impact of ground moisture changes on the geohazard frequency by developing a weighted index factor (wit) for the twentieth century by analyzing wood anatomical features including traumatic resin ducts, very narrow rings, and injuries in the impacted trees. We found good correspondence between years of high wit index and negative SPEI04 values, indicating that the dry slopes are vulnerable to ground failures. With ongoing climate change, the spring and pre-summer months are becoming more critical for tree growth and ground stability due to unprecedented temperature rise during the last century. Our study is significant for the forest management, species sustainability and ground stability measures under the future warming trend scenario.

Examining Autocorrelation as a Critical Factor of Growth Depensation of Tropical Trees in the Chocó Biogeographic Region

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Growth depensation, the variation of size with age exhibited by populations, is attributed to biologic, ecologic, environmental factors, and autocorrelation. Several studies have focused on the study of diameter growth of tropical trees to obtain information of ontogenic traits and silvicultural metrics of interest for ecology and forest management. However, few studies have considered, in a rigorous and appropriate manner, the autocorrelation as a primary contributing factor of growth depensation. This research aims to investigate the diameter growth of tree species from the Chocó biogeographic region. We used tree-ring data corresponding to 38 trees and 5 species. Our modeling approach included von Bertalanffy-type equations to estimate diameter growth trajectories for each species using mixed-effects models. Additionally, ARIMA specifications were included as part of the residual terms to account for autocorrelation. Estimated parameters were used to calculate ontogenic traits and silvicultural metrics for each species. Results indicate that autocorrelation was a critical factor of growth depensation for all the studied species, and was satisfactorily incorporated by using the proposed modeling approach. Autocorrelation patterns on residuals revealed stochastic tendency, and were examined by correlation structures of ARIMA(1,1,0) and ARIMA(2,1,0). Ontogenic traits and silvicultural metrics obtained for these species were biologically consistent, providing reliable and useful information to understand population ecology of tropical trees and to inform management and conservation strategies of natural forests.

Willow recruitment patterns along an elevation gradient on Disko Island, Greenland

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Rapidly rising Arctic temperatures can influence vegetation dynamics, including shifts in population distributions and community composition. With increasing temperatures, there has been a widespread pattern of shrub populations expanding into areas that were previously absent of woody plants. However, variations in the extent and pace of shrub expansion exist between different locations, and there is still a lack of comprehensive understanding of the drivers and limitations of current and past range shifts. Here we aim to identify recruitment patterns of Salix spp. along an elevation gradient on Disko Island, Greenland, ranging from 160 to 800 m above sea level. We employed stratified random sampling and methods of dendrochronology to assess current and retrospective population structures and potential recruitment pulses related to climate and site characteristics. Our findings will provide comprehensive *in-situ* evidence of long-term Salix spp. population dynamics and contribute to a better understanding of the complexities behind Arctic shrubline expansion, which can play a major role in Arctic nutrient and carbon cycles and plant community composition.

Comparative analysis of beech and oak resilience and adaptation to past and present extreme climatic events

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In this study we assessed the beech (Fagus sylvatica, L.,) and oak (Quercus sp.) resilience and adaptation to past and present climatic extreme based a wide dendrochronological network which covers the Eastern Romania and Republic of Moldova. Using multivariate association methods (PCA and HCA), enabled us to define different growing bioregions, four for beech and three for oak. Both at individual and regional levels the pointer years were computed, being identified 1946, 2003 and 2015 as extreme climatic induced years. By using ecological indices, such as recovery, resilience, and resistance, we assess drought tolerance levels that revealed significant lower resilience, following drought periods, in beech trees in optimal vegetation conditions compared to beech populations at the eastern edge of their range. For oak, populations at the edge of its distribution show higher resistance compared to those in the optimal zones, while growth recovery after an extreme event is higher in optimal conditions, but this relationship has no statistical significance. We pointed out that the variability of resistance (Rt) and recovery (Rc) indices decreases in areas with optimal water supply, this pattern being similar for the two species, but is statistically significant only for beech and only for the resistance indices.

Driving factors of seasonal trends in tree-ring cellulose δ^2H in a boreal forest

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Temporal variability of tree-ring cellulose δ^2H can be a unique tool for understanding tree metabolism and climate interactions. In this study, our aim was to uncover the underlying mechanisms that explain the temporal changes in tree-ring cellulose δ^2H. We utilized a comprehensive dataset from a field survey (ISOBOREAL) of Scots Pine (*Pinus sylvestris*), conducted during 2018-2019 at Hyytiälä forest in central Finland. We analyzed the seasonal δ^2H variability of water, non-structural carbohydrates (i.e., water-soluble carbohydrates and starch) in leaves and in the phloem of branches and stems. Then, we micro-dissected wood sections of five trees, collecting intra-annual data at 5-10 timepoints during the growth periods of both 2018 and 2019. From the wood sections, we extracted α-cellulose for δ^2H analysis, with formation and maturation periods assigned using xylogenesis measurements. Our findings revealed that, while tree identity had a role to α-cellulose offsets and seasonal variability, there was a general seasonal trend α-cellulose δ^2H for both years, with notable variations between the two years. Leaf water δ^2H followed a distinctive seasonal trend that represented an interplay between seasonal variability in evaporative enrichment and source water δ^2H, but water-soluble carbohydrate δ^2H was more closely related modelled evaporative enrichment than bulk leaf water δ^2H, indicating that water compartmentalization in the leaf could have been important to the prevailing information transferred from water δ^2H to water-soluble carbohydrate δ^2H. The seasonal variability of δ^2H in leaf water-soluble carbohydrates was most closely related to time-integrated, measured leaf CO_2 fluxes ($\mu molm^{-2}s^{-1}$). Our findings could help to elucidate whether seasonal variability in tree-ring δ^2H captures a time-integrated signal of such leaf-level carbon fluxes, alongside the role of seasonal variability in source water δ^2H to α-cellulose by hydrogen exchange during cellulose synthesis, and other potential sources of ^2H fractionation.

High-latitude tree-ring oxygen isotopes from Northwestern Russia record summer relative humidity

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High-latitude regions are highly sensitive to climate change, necessitating long-term perspectives for accurate predictions. While meteorological data in these areas is often limited, proxies like tree rings offer valuable insights. Dendrochronological studies of ring widths and density have been explored, the potential of tree-ring oxygen isotopes remains largely unexplored. This study develops an annual-resolved tree-ring oxygen isotope chronology from 1848 to 2016 in the Solovetsky Islands, Russia, based on four cores from pine. Notably, our chronology exhibits strong correlations with summer (JJA) relative humidity. This relationship holds true for both raw data ($r = -0.61$, $p < 0.01$) and first-differenced data ($r = -0.61$, $p < 0.01$) during the period of 1950-2016. The encoded relative humidity signal is demonstrably stable and significant ($p < 0.05$) through 30-year moving correlations. Additionally, spatial correlations confirm the representativeness of this signal. These findings highlight the promising potential of tree-ring oxygen isotopes for reconstructing summer relative humidity fluctuations in high- latitude regions.

Quantifying lignin in Scots pine blue rings

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Blue rings (BRs) are an anatomical anomaly in tree rings, signifying reduced cell wall lignification. BRs are visualised through a double-staining method, whereby thin sections of wood are stained with Safranin and Astra blue. They have been associated with temporary end-of-growing-season cold spells, often following significant volcanic eruptions, and offer potential as a proxy for temperature on the intra-seasonal scale. Multiple qualitative descriptions have been used to distinguish between different BRs visually. However, the lack of cell wall lignin content has never been measured quantitatively in BRs, potentially hindering information collection regarding the temperature conditions related to of their formation. Also, to date, no other method has confirmed the difference in lignin content between BRs and standard rings. Here, we present the first independent evidence to the double-staining method of reduced lignin in blue rings in Scots pine (*Pinus sylvestris* L.) and a framework to quantify lignin changes throughout tree rings, utilising a confocal microscopy approach. Our results confirm a marked reduction of lignin in latewood cells of BRs and demonstrate the changes in lignin throughout the ring.

$\delta^{13}C$ variations in creep affected Picea abies (Făgăraș Mountains, Romania) analysed via laser ablation IRMS

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The study area is situated on an anthropogenic slope in the Bâlea glacial valley (Southern Carpathians, Romania). Trees were selected for sampling based on visible signs of creep movements affecting their growth. Trees with *d*-shaped stems were chosen. Norway spruces (*Picea abies*) were sampled using a 30 or 40 cm Pressler increment borer with a 5.15 mm diameter bore. Two increment cores were extracted from each tree: one in the direction of the slope and the other upslope. Samples were extracted at the point of maximum curvature along the stems. Moreover, *P. abies* growing outside of the creep area but in the same microclimatic conditions were sampled to construct a reference chronology to distinguish climate signals from other land-forming events. The shape of the trees and sudden change in the width of tree ring growth (eccentric growth and reaction wood) were responses to the disturbance recorded in the trees following creep. Summer rains (June and July wettest months in the Bâlea Valley) are the most important factor in triggering creep. Laser ablation isotope ratio mass spectrometry (LA IRMS) was used to measure $\delta^{13}C$ at high spatial resolution to detect metabolic changes in stable isotope signatures and see if there is a perceptible difference within the same growth ring between the creep affected, respectively unaffected sides. We used a CO_2 Fusions Laser (Photon Machines) fitted with an isoScellΔ100 sample chamber (Terra Analitic), a pyrolysis oven, CryoPrep unit and HS2022 IRMS (all three Sercon). In creep affected cores the carbon signature is clearly distinguishable between the normal and abnormal growth areas within the same ring – with Δ13C ratios in some cases higher than 1‰. The more negative δ13C values are consistently downslope, where the tree is depositing thicker rings to straighten its trunk.

Building Robots with Robots

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The development of software and hardware to support research is increasingly feasible for non-developers, thanks to a combination of new development platforms, increased compute capacity, and generative AI tools. In this talk, we'll explore how attendees can get started building their own tools by looking at examples from our tree core research in the Griffin Lab at the University of Minnesota. Our pursuit of high-resolution, high-volume tree ring imaging has required numerous hardware and software innovations, allowing us to build a library of more than ten thousand gigapixel scale specimen images. We've built custom tools for stitching images and performing photo processing, tools for controlling imaging robots, and tools for analyzing the resulting images. In many cases, these tools have been built by undergraduates without prior experience in software development, with guidance from staff developers. Our applications focus on a few key design directives to ensure their functionality and sustainability, while providing a net productivity benefit for the lab. These directives include a focus on iterative design, a clear target audience, and an "ecosystem" approach which keeps tools simple. The advent of generative AI tools like ChatGPT and Mistral now allows research facilities to rapidly build tools to solve local needs. During this talk, we'll build a dedicated tree core image processing program using generative AI tools and free and open-source frameworks. Attendees will gain a strong understanding of how to begin applying these tools tactically in their own work.

Heavy metal concentrations in growth rings of broad-leaved reflect changes in industrial pollution but depend on analysis type

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The development of urban areas, industrialization and increasing traffic intensity pose global threatens on human health and ecosystem services by leading to the pollution of air, soil and water. A good example of forest dieback due to heavy metal pollution is the decline of hardwood forests in Eastern Europe, particularly in regions such as Baia Mare and Copșa Mică, both in Romania. In this study, we aim to find out whether trees in intensively polluted areas accumulate a higher concentration of heavy metals in wood as compared to trees growing in unpolluted areas. We compared the concentrations in tree-ring wood of several elements from two broad-leaved species (European beech-*Fagus sylvatica*, and Sessile oak-*Quercus petraea*). Both regions studied were heavily affected by local industrial pollution. Two methods were used to analyse the dynamics of heavy metals in wood composition: Inductively coupled plasma mass spectrometry (ICP-MS) and X-ray fluorescence spectrometry (XRF). The ICP-MS analyses clearly revealed higher Mn wood concentrations in beech trees from intensively polluted areas from the Baia Mare region, whereas XRF analyses revealed higher Zn wood concentrations in beech and oak trees from intensively polluted areas of the Copșa Mică region. Cu concentrations increased in polluted areas in Sessile oaks from the Copșa Mică region, whereas Mn increased in beech from unpolluted areas of this region according to XRF analyses. The highest Mn concentrations were observed in beech from Baia Mare, where Pb was also detected. In this region Pb concentrations did not differ between polluted and unpolluted areas.

Stable carbon and oxygen isotope ratios in Norway spruce (*Picea abies (L.)* Karst.) tree rings along an elevation gradient in the Rarău Mountains (Romania)

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Carbon ($\delta^{13}C$) and oxygen ($\delta^{18}O$) stable isotope analyses were carried out on Norway Spruce (*Picea abies (L.)* Karst.) tree ring cellulose collected in the Rarău Mountains, (Eastern Carpathians, Romania) at three different elevations (i.e., 906, 1212, and 1519 m. a.s.l.). The objective of this study is to a) analyze the variations of cellulose stable isotope values ($\delta^{13}C$, $\delta^{18}O$) along an altitudinal gradient and b) correlate the long-term isotope variability with the available meteorological parameters (i.e., air temperature, precipitation amount). From each elevation, the samples were three individual trees, using a 1 cm-diameter Pressler driller. Tree rings were separated with a scalpel to obtain annual resolution and α-cellulose was extracted using the modified Jayme-Wise method. Measurement was performed on each individual ring (no pooling). Stable carbon and oxygen isotope ratios were determined simultaneously by pyrolyzing cellulose samples over glassy carbon at 1450 °C using a ThermoQuest TCEA interfaced with a Thermo Delta V Advantage IRMS. Our preliminary results, based on data covering the period AD 1985-2020, show that: *i*). cellulose yield varied between trees, with the mean values slightly decreasing with elevation (from 45.56 %±1.42 % at the lowest point, to 45.41 % ±1.21% at middle one, and finally to 43.21 %±2.49% at the upper point); *ii*). trees from the highest altitude site have the lowest $\delta^{18}O$ while those located at mid-altitude have the lowest $\delta^{13}C$ values. Furthermore, correlation analysis of the mean stable isotope values and the daily meteorological variables indicate that $\delta^{18}O$ is negatively correlated with the precipitation amount during the growing season (~May-August) and positively with winter (~December-March) temperature at each site. Further, $\delta^{13}C$ appears to be positively correlated with the air temperature (growing season) the linear relation becomes stronger with increasing altitude. This study was financially supported by project PN-III-P2-2.1-PED-2019-4102, awarded to AP.

Introduced *Pinus contorta* provenances: insights into radial growth variability

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Climate change is causing significant shifts in weather patterns. To aid tree adaptation, strategies such as assisted migration and gene flow are proposed, alongside the introduction of non-native species. Understanding genetic variations and local adaptation potential through provenance trials is vital for adaptive management strategies. Despite being classified as invasive in some regions, favorable traits of lodgepole pine have led to renewed introduction efforts, with large-scale provenance trial establishment since the 1970s. It demonstrates ecological plasticity and suitability for commercial use in producing high-quality lumber and pulp-wood products. This study aims to assess sensitivity variations among lodgepole pine provenances, hypothesizing that higher-altitude origins may exhibit greater sensitivity. Lodgepole pine plantations were established in Zvirgzde and Kuldiga, Latvia in 1984;1992, and 1993, respectively, with different planting densities. The sampling process occurred in autumn 2022, enclosing 14 provenances from each location. A minimum of eight trees at breast height using a Pressler increment borer were bored for each of the provenances. A total of 362 trees were drilled, cores were sanded gradually, and manually measured for tree ring width using LINTAB 5 with TSAP software. TRW series were assessed for accuracy, detrended, and whitened, with mean chronologies created for each provenance. Bootstrapped Pearson correlation analysis was employed to examine TRW-meteorological factor connections and cluster analysis was performed. The findings revealed that the influence of the study site outweighed that of provenance. A negative correlation between winter temperatures and radial increment was observed specifically at the Kuldiga site. While the study site holds a significant influence on tree growth, certain provenances, like Lacobie Creek, demonstrate consistent superiority in radial increment regardless of location, indicating a possible strong genetic advantage.

The 2022 Heatwave and Drought Led to a Severe Tree Water Deficit but not to Consistent Growth Reduction of Silver Fir and European Beech in Primary Forests

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Within the diverse European ecosystems, mixed mountain forests, primarily consisting of silver fir (*Abies alba* Mill.) and European beech (*Fagus sylvatica* L.), are one of the most ecologically and economically important. These forests form stable ecosystems across Europe, offering valuable sites for investigating the resilience of forest species under climatic stress. The unprecedented heat and drought of 2022 presented a unique opportunity to investigate the adaptive responses of these species in three primary forests in the Western Carpathians. This study aimed to provide a comprehensive assessment of how climatic variables, especially those characterizing extreme conditions, influence tree water deficit and radial growth. Our methodology centred on the estimation of tree water deficit and radial growth of beech and fir trees, employing high-resolution dendrometers. Such measurements directly reflect tree vitality and the ability to withstand environmental variability. By focusing on these indicators, our research offers an in-depth look into the dynamic responses of silver fir and European beech to changing climatic conditions. Preliminary findings indicate that, despite the severe water stress during the 2022 heatwave, there was no consistent pattern of growth reduction across the studied species. The evidence from previous studies suggested a lag in beech growth response, where a decline is usually observed in the year following an extreme event. Similar findings were identified in our study. The varied growth responses suggest that while tree water deficit is a significant stressor, its impact on radial growth can differ markedly between species, reflecting their unique adaptive capacities.

Evolutionary drivers of phenotypic traits in two European tree species – evidence from common garden networks

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Evolutionary processes such as phenotypic plasticity and genetic adaptation are key mechanisms that have enabled tree species to cope with environmental changes and to colonize new areas over millennia. Extremely rapid environmental changes due to anthropogenic climate change are challenging species adaptation and resilience. In this study, we assessed the evolutionary drivers of functional traits of two major European tree species: sessile oak (*Quercus petraea* (Matt.) Liebl.) and European beech (*Fagus sylvatica* L.). We used four common garden experiments established in the 1990s within the distribution area of these two species. We measured the following traits: i) tree growth; ii) specific leaf area; iii) long-term responses to climate; and iv) short-term responses to extreme drought. Individual traits were modelled as a response of environment, genetic identity and genetically based plasticity. To explore the potential influence of climate conditions, both, genetic identity and genetically based plasticity, were correlated with the bioclimatic variables from the seed origin. Associations between the climate of origin and multi-trait genetic effects and genetically based plasticity, as well as associations between the climate of the site and multi-trait plasticity were also explored for both species. At the individual trait level, sessile oak showed evidence for both genetic and plastic causes of trait variation. In contrast, the variability of traits of European beech seemed to have been mostly shaped by environmentally driven responses. The results of the integral multi-trait phenotypes, however, suggested genetically driven differences along a resource-use gradient governed by temperature conditions in both species. The plasticity of coordinated traits also reflects the ability of all provenances to adjust to new environmental conditions by optimizing the integrated phenotype. Our results suggest that mitigation strategies for climate change could be directed towards seeking provenances that are more plastic in their integral phenotype across the resource-use gradient.

Tracheid Anatomy Reveals Temperature-Driven Structural Adaptations in Alpine Norway Spruce

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Norway spruce (*Picea abies*) plays a vital role for Europe's forest ecology and economy; however, it faces growing threats from climate change. Understanding how its tracheids (water-conducting cells) adapt to climatic fluctuations is important for predicting its future in a warming world. We studied the response of Norway spruce tracheids to interannual climate variability during the last 70 years in the Renon forest, central Italian Alps, 1735 m a.s.l. We analyzed tracheid cell number, cell wall area, and ring wall area in earlywood and latewood from ten trees. Anatomical chronologies were correlated with E-OBS climate data for the period 1950-2020. Interestingly, temperature had a greater positive influence on ring wall area in latewood (RWA_LW) and cell wall area in latewood (CWA_LW) than on tracheid cell number (NUM). The May-Sept temperature was highly correlated ($r = 0.44$) with RWA_LW and the August-September temperature correlated significantly with CWA_LW ($r = 0.43$), whereas the correlations between May-Sept and August-Sept temperatures with NUM_LW were marginally significant. This shows that, at this site, Norway spruce prioritizes formation of thick cell walls (cells with high biomass) over cell proliferation during hot summers. In contrast, tracheid number (earlywood and latewood) and ring wall area (earlywood and latewood) showed a positive correlation with the mean annual precipitation from the previous year. This observed tendency could be explained by lagged effects of favourable conditions on growth in the successive year, or recharge of soil water-storage reservoirs. Site-specific investigations are crucial for understanding tree responses to climate change, as broader patterns may miss local nuances. Our study reveals Alpine Norway spruce prioritizes structural stability over cell proliferation in response to rising temperatures, suggesting a trade-off between growth and adaptation. Further research on physiological responses and water use efficiency is needed for a comprehensive understanding of their future under changing climate.

Tree-ring traits of a silver birch (*Betula pendula* Roth) glacial relict population in Central Italy

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The impacts of climate change on tree species at their distribution limits are well-documented, and various species adaptation and conservation strategies have been explored. However, further research is still needed, especially in relevant biogeographic areas such as the Apennines (Italy). The Apennines forests besides providing multiple ecosystem functions are often the rear edge of the distribution of many European tree species, including silver birch (*Betula pendula*). Its current distribution in the Apennines consists of several small and sparse populations considered Pleistocene glacial refugia. In one of these populations located in Central Italy, birch is growing in a mixed beech forest at 1200 m asl, where we wanted to compare the climate sensitivity of a pioneer and a final species. We extracted increment cores from 30 birch and 20 beech trees and processed them for dendroecological analysis. Also, a subsample of birch cores was prepared for a quantitative wood anatomy (QWA). Tree-rings standard chronologies of both species were correlated to monthly climate series; including temperatures, precipitation and the standardized precipitation index (SPI). The mean cambial age of beech samples is around 80 years, whereas birch trees are generally younger (50 years). The birch raw tree-ring series show a negative trend in the last decades, probably due to the canopy closure by the dominant beech layer. Both species positively correlate with May mean temperatures and winter precipitation, i.e. February 3-month SPI for birch and February 6-month SPI for beech. For both species, chilling requirement and the buds dormancy release are well correlated to winter low temperatures and mild late spring conditions, affecting the growing season length and the radial growth rate. QWA are in progress and could provide a better understanding of climate effects on birch growth under the peculiar environmental conditions, occurring in the Apennines region.

Using blue intensity, CooRecorder and BIcounter to estimate whole cross section proportion of compression wood, latewood and earlywood in treeline seedlings

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Low temperatures at high elevations affect tree growth, resulting in the global pattern of high-elevation (forest) treeline. At the treeline, tree seedlings are particularly susceptible to mechanical forces caused by strong winds and snowpacks loads, which may affect the growth direction of their stems, causing eccentricity. Moreover, these forces may affect the wood hydraulic and mechanical properties in the area subject to compression forces (compression wood). Additionally, earlywood and latewood have different properties affecting stem functions, therefore the relative amounts produced in the seedlings may also affect their survival, growth, and reproduction (ecological performance). As part of an ongoing postdoctoral project, we developed a method to assess, at the whole cross section level, in *Picea abies* treeline seedlings, the percentage of: latewood and compression wood (LCW, with high wood density), strong compression wood (SCW) and earlywood, radial parenchyma, plus resin canals (ERW, low wood density). We studied 15 seedlings from five European treelines (Austria, Czech Republic, Italy, and Slovakia). Given that the blue light absorbed by wood (blue intensity, BI) is related to wood density, to assess those percentages we used BI, BIcounter, a new program that counts blue pixels and gives a threshold based on the CooRecorder dark/light segmentation algorithm. We found that LCW occupies 50% of the cross section of treeline tree seedlings, while the rest consists of ERW. Mean SCW varied between 1% and 47% (mean = 21 ± 12%). Eccentricity at the whole cross section level was high (index between 1.1 and 3.1, mean = 2), and it did not consistently correspond to a high percentage of SCW. As latewood and SCW may occupy large stem areas of tree treeline seedlings, we strongly encourage consideration of these percentages for studying their ecological performance. BIcounter could potentially be added to CooRecorder, with applications in dendroecology and dendrogeomorphology.

Declining trends in long-term *Pinus pinea* L. growth forecasts in Southwestern Spain

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A warmer and drier climate stands out as one of the primary factors contributing to the observed and anticipated decline in Mediterranean forest ecosystems. *Pinus pinea*, a key conifer in the Mediterranean region, exhibits its largest populations in southwest Spain, offering diverse ecological services. While the sensitivity of this species to drought is acknowledged, there has been no prior assessment of the potential decline in productivity in southern Spain. In our study, we employed a modeling approach to assess *P. pinea* growth, incorporating climate variables and an extensive dataset of tree ring chronologies spanning from the early 20th century to the 2010s. Subsequently, we projected annual increments for the period 2030-2100 using regionalized estimates from a global change model under three greenhouse gas emission scenarios. The climatic conditions between winter and mid-spring emerged as the most influential for our model. Climate predictions indicated an escalation of potential water stress, and our forecasts outlined a downward trajectory in annual growth, particularly pronounced in the most severe climate change scenario. These projections constitute the first long-term forecasts for the growth of *P. pinea* in southern Spain. While our model may not be directly applicable to higher latitudes, where distinct climate-growth relationships have been noted in previous studies, it does serve as a valuable benchmark for researching and managing the potential climate-induced decline in productivity of *P. pinea* populations in the Southern Iberian Peninsula.

The influence of forest management on the radial growth of Norway spruce (*Picea abies* L.) trees in the north of the Eastern Carpathians

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The Norway spruce (*Picea abies* L.) is one of the most important tree species in European forests and is among the most widespread forest species in Eastern Europe. The research material was made in five experimental blocks between 780 and 1000 m.a.s.l. with ages between 50 and 110 years in the north-eastern Carpathians from Roumania. To establish the increases were used 300 increment cores of living tres and the tres ring data was use to evaluate de growth trends. The growth rate of trees shows a decrease in the last decades, regardless of the extraction rates of the surrounding tres. The results show us the response of the trees to the management measures within the stands.

CS-TRD: A Cross Section Tree Ring Detection method

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This work describes an automatic Tree Ring Delineation method for complete Cross-Sections of trees (CS-TRD). The method detects, processes, and connects edges corresponding to the tree's growth rings. The method depends on the parameters for the Canny Devernay edge detector (σ and two thresholds), a resize factor, the number of rays, and the pith location (*the soft portion of the wood slice, concentric to all the tree rings but not allways near the geometric center of the slice)*. The first five parameters are fixed by default. The pith location is estimated using a fully automated method based on the concentric shape of the structure of the wood ring slices (APD): using the ring's local orientations, which are estimated using the 2D structure tensor, the pith candidate is the optimal point of a cost function designed for this problem. We also present a variant (APD-PCL), using the parallel coordinates space, that enhances the method's effectiveness when there are no clear tree ring patterns. Furthermore, refining previous work by Kurdthongmee, a YoloV8 net is trained for pith detection, producing a deep learning-based approach to the same problem (APD-DL). All proposed approaches for pith detection outperform existing state-of-the-art methods and can be used in CPU-based real-time applications. The CS-TRD method is fully automated and achieves an F-Score of 89% in the UruDendro dataset (of Pinus taeda) with a mean execution time of 17 seconds. The UruDentro dataset is composed of 119 images of wood slices with their ring annotations delineated at least by two experts. Algorithms, codes, and datasets are publicly accessible, following the principles of open science.

The response of Quercus robur and Quercus pedunculiflora to climate in the forest-steppe area of southeastern Romania

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Global climate change impacts all regions of the world, including the forest-steppe zones in Romania. In the last decade, the effect of environmental changes in southeastern Romania has been manifested through increasing temperatures and more frequent and intense drought periods with significant impact on tree growth processes. The objective of this study is to comparatively observe the response of trees to climatic factors in relation to their position within the forest stand.

The research was conducted in the Bărăgan forest stand for two oask species: common oak (Quercus robur) and grayish oak (Quercus pedunculiflora), in two locations: inside the forest and at the forest edge. In each research plot, 21 trees were chosen for sampling and one core from each tree was extracted. A cubic smoothing spline function with a 50% frequency cutoff at 30 years was applied on individual tree ring width series. The climatic data (daily temperature and precipitation) were provided by Slobozia weather station for the period 1960-2022. The bootstrap Pearson correlation between cumulative temperature and precipitation on seasons of 21 to 120 days and tree-ring width index chronologies was computed. Water deficit effect on tree growth was modelled using VS-Lite processed based model. Significant differences in radial growth were observed between the oak trees inside the forest and those at the forest edge. The oak tree inside the forest showed a positive and statistically significant correlation between growth indices and precipitation from August of the previous year to May of the current year. On the other hand, the oak tree at the forest edge does show statistically significant correlations with precipitation in this interval, except for spring. As for the common oak in the BE Bărăgan area, the radial growth indices show a positive and significant correlation with temperatures from spring only in the forest interior.

Integrating Dendrochronology and Isotopic analysis to evaluate prolonged drought effect on *Quercus ilex* L. forest

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Drought frequency is increasing in the Mediterranean forests due to warmer climate and longer periods without precipitation. The Holm oak (*Quercus ilex* L.) is a Mediterranean species that is well adapted to dry environment and it is widely spread in Mediterranean area. Unlike some deciduous trees, this evergreen oak does not have well-defined tree-rings, making measuring of its width a challenging. This study aimed to investigate the effect of drought on tree growth over time, using tree-ring widths, and to infer eco-physiological effects of water shortage through stable isotope analyses. Dendrochronological samples were collected from *Q. ilex* L. trees growing at a Mediterranean site in the Vesuvio National park (Southern Italy). Dendrochronological measurements of tree- ring width (TRW) and $d^{13}C$ measurements allowed to develop a site chronology that was analyzed jointly with climatic time series (temperature, precipitation). The correlation between growth and precipitation highlighted that this species is sensitive to water availability. Moreover, reduced growth rate was observed during prolonged drought period. In conclusion, our results highlight how a better understanding of Mediterranean species adaptation to drought stress is crucial for sustainable forest management and protection in the face of climate trends.

Stable carbon isotopes of oak rings reflect a strong drought signal independently of elevation in eastern Slovakia

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In contemporary dendroclimatic studies, the growing importance of stable isotopes in tree rings is evident, given their proven stronger climate signal compared to the analysis of tree ring widths. Despite this recognition, the dependence of the climatic signal of stable isotope ratios in tree rings on elevation has not been fully elucidated. In this study, we collected 136 samples (15–31 per site) of living trees from six different elevations ranging from 130 to 630 m above sea level. From each site, six samples with annual resolution were carefully cut for subsequent analyses of stable carbon and oxygen isotope ratios ($\delta^{13}C$ and $\delta^{18}O$). Mainly April-July precipitation and June–September Standardized Precipitation Evapotranspiration Index (SPEI) control oak annual increments, as determined by tree-ring widths (TRWs), and the length of the influential period decreases with elevation. Similarly, April-July precipitation and July-September SPEI influence the value of $\delta^{13}C$ in tree-rings, but this influence is more stable over the entire elevation range. On the contrary, $\delta^{18}O$ values provide overall lower positive correlations with March–April temperature and negative correlations with growing season drought, especially in middle elevations. Although numerous studies have demonstrated a stronger signal in the $\delta^{13}C$ and $\delta^{18}O$ chronologies, our findings indicate a weaker climatic signal in $\delta^{18}O$ chronologies compared to the $\delta^{13}C$ and TRW ones. Additionally, $\delta^{18}O$ values significantly differ between lower and higher sites. In contrast, no statistically significant difference was found in $\delta^{13}C$ values, and their correlations with climate remain stable across all elevations, except for the highest location representing the limiting elevation for oak growth. Our results confirm the potential widespread utilization of $\delta^{13}C$ chronologies for climate reconstructions. **Acknowledgements:** The paper was prepared with support of the Czech Science Foundation through grant 23-08049S, Central European HYDRoclimate from Oak stable isotopes over the past 8000 years – HYDRO8.

A half-millennium record of disturbance history in the Bohemian Forest

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The Bohemian Forest stands as one of the largest continuous *forested* regions without human intervention in Central *Europe* and has been called the '*Green* Roof of *Europe*'. Encompassing both the Šumava National Park in the Czech Republic and the Bavarian Forest National Park in Germany, this region has sparked extensive discussion on the origin and historical species composition of its forest ecosystems, crucial for definition of conservation management strategies. This study present a unique trans-boundary dendrochronological dataset comprising over 7,000 tree-ring series spanning the latest 500-year period, including the ancient pre-indistrial era when virgin forest dominated the mountain landscape. By analyzing growth release and canopy recruitment events, we aimed to elucidate the narrative of natural disturbances (i.e. windthrows and insect outbreaks) in the history of the Bohemian Forest and describe differences in disturbance regimes between regions and impact of within-stand heterogeneity. Despite a similar tree-species composition, our findings reveal striking differences across the Czech-German border. Trees on the Czech side tend to be significantly older (median = 157 yrs) compared to their Bavarian counterparts (median = 96 yrs). Additionally, severe disturbances, associated with historical records of extraordinary windstorms and bark beetle outbreaks, dominates on primarily northern-exposed slopes on the Czech side contrasting with the southern-exposed Bavarian Forest reflecting more local events. By constructing stand-specific disturbance chronologies, we uncovered significant temporal synchronicity. While spruce mountain forests were heavily affected by the windstorm in 1820s, watterlogged and peat forests were mainly disturbed during the 1870s. Mixed ravine forests, on the other hand, faced the greatest wind disturbance during the 1840s and 1850s. These results can be used as a guideline to analogous Central European strict protected forests to emulate natural disturbances.

Exploring climate growth limitations of European beech and silver fir along the gradient of Carpathian arc.

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Changing temperature and precipitation patterns significantly influence tree climate-growth limitations. The influence of climate change varies among species and can differ across geographical regions. The Carpathians, a vast mountainous area of Europe, host a significant presence of *Abies alba* and *Fagus sylvatica*, both of which exhibit distinct climate-growth responses despite sharing similar ecological niches. Our study aims to discern the effects of climate change across various Carpathian regions and forecast the future trajectories of *A. alba* and *F. sylvatica* within this area. We selected eight sites along the Carpathian arc with similar elevations for our study, sampling 14 to 17 mature canopy trees of both species at each site. Using the Vaganov-Shashkin process-based model, we simulated radial growth and computed growing season parameters, temperature, and moisture limitations. Model calibration covered the period from 1985 to 2015, utilizing EOBS climate data, and projections extended from 1985 to 2050. EOBS data were used for 1985-2022, while bias-corrected EURO-CORDEX of RCP 4.5 scenario was used for the period 2023-2050. Our findings unveiled three distinct regions in the Carpathians with varying climate-growth limitations: northern, southwestern, and southeastern. Northern sites primarily experienced temperature limitations by cold temperatures, while southern sites were predominantly constrained by insufficient moisture, intensifying eastward. Despite these distinctions, a gradual convergence from northern to southwestern sites was observed. *A. alba* in northern sites exhibited significant temperature limitations and showed a better response to climate conditions compared to *F. sylvatica*. Conversely, *F. sylvatica* consistently showed higher moisture-driven growth limitations than *A. alba*.

Old and young *Pinus* pinea and *Pinus nigra* trees show a different response to drought events in a mediterranean environment

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This research delves into the distinctive growth responses of mature and young *Pinus pinea* (stone pine) and *P. nigra* (black pine) trees to drought events in the Mediterranean environment. The investigation specifically explores how these two age groups within each species adapt to water scarcity, a pivotal factor in the Mediterranean climate. Over a three-year period, band dendrometers and electronic point dendrometers were employed in Sierra de Cazorla (southeast Spain) and Hoyo de Pinares (central Spain) to capture variations in growth and daily stem fluctuations. The results illuminate differences in growth patterns between older and younger trees of both species under drought stress conditions. Notably, older *Pinus pinea* and *P. nigra* trees exhibited a lesser contraction and growth reduction compared to their younger counterparts. The study goes beyond age-related variations, offering insights into the intricate dynamics between tree species and their Mediterranean environment. Understanding the diverse responses of different age groups within these pine species to drought contributes valuable information to forest ecology, facilitating the development of sustainable strategies for forest management and conservation.

Quantitative wood anatomy suggests spatially diverse climatic controls on white spruce growth across the North American treeline ecotone

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Tree growth in cold environments is limited by temperature, but how temperature and water availability together influence wood formation, particularly in hydraulically relevant earlywood, is still largely unknown. We studied six white spruce stands in the northern treeline ecotone of North America that are subject to major climatic changes and include sites in Alaska (3), Northwest Territories (NWT, 1) and Quebec (2). Sites closer to the open Pacific or Atlantic coast, particularly in Quebec, were generally warmer, wetter, and had greater winter snowpacks than sites further inland (eastern Alaska, NWT). Using quantitative wood anatomy and partial correlations, we related time series of earlywood lumen area (EWLA) to daily resolved climate data from the NRCAN BioSIM model (temperature, precipitation, vapor pressure deficit, soil temperature, snow depth) over the last decades. Surprisingly, EWLA was positively related with summer temperature only at the wettest, easternmost site in Quebec, while most other sites showed a negative response to temperature around the time of earlywood formation (May, June). At the same time, EWLA was positively associated with spring and summer precipitation at most sites, but was strongest at the two driest and coldest sites in eastern Alaska and NWT, suggesting water-limited growth. The response patterns to vapor pressure deficit and soil temperature were weaker but showed a similar trend (negative response in Alaska/NWT and positive in Quebec in spring and early summer). The snowiest locations in Quebec tended to show a negative association with snow; thick snowpacks can delay the onset of wood formation. Our results suggest a complex and spatially diverse response of white spruce growth to climate in our study areas along the North American treeline ecotone. As warming continues and precipitation patterns are expected to change, understanding these responses is critical to better assess growth dynamics and carbon sequestration in the future.

Non-stationary climate-growth responses in trees: A global dendroecological perspective

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Climate plays a crucial role in shaping tree physiology by influencing fundamental processes such as the onset and length of the growing season, photosynthesis, respiration, transpiration, cambial activity, and stomatal regulation. These factors are critical to tree growth patterns, affect carbon allocation to various sinks, and ultimately determine trees' productivity and lifespan. Traditionally, it was assumed that climate-growth relationships were stationary over time. Yet, recent evidence has challenged this assumption as changes in ambient climate have triggered disproportionate responses in tree growth. Previous dendroecological studies have focussed primarily on identifying the optimal indicators linked to climate-growth relationships, in particular the effects of crucial seasonal temperature and precipitation variables. Our study extends this perspective by quantifying flexible climate response windows based on daily climate data and identifying parameter-specific periods of strongest influence in the concurrent and previous growing season. We use a global comprehensive dataset of tree-ring widths from the International Tree Ring Databank (ITRDB), supplemented by high-resolution ERA5 Land daily climate data. Using the dendroTools R package, we analyze the influence of combined daily climate parameters on detrended ring widths. Our approach involves assessing the climate-growth relationships within a dynamic 30-year window that progresses annually during the 1950-2020 period, allowing us to identify patterns in shifting climate sensitivity across different seasons. Preliminary findings suggest a complex interplay between temperature and precipitation changes, with a decrease in sensitivity in one season often paralleled by increased sensitivity in another. Notably, these patterns exhibit significant variation across different species and biogeographical regions. Our research contributes to a more nuanced understanding of how trees respond to climate change, offering valuable insights for climate reconstructions, ecological research, and the development of strategic forest management approaches.

Old Wood in a New Light – A dendrochronological database

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The *Old Wood in a New Light* project focusses on digitisation and accessibility of the results of dendrochronological samples analysed and archived at the four Swedish university-based tree-ring laboratories located at Lund University, Stockholm University, University of Gothenburg, and the Swedish University of Agricultural Sciences. Collaboration with the Environmental Archaeology Laboratory and Humlab at Umeå University will enable long-term open access to data and metadata. In this project, we will (1) systematically undertake large-scale entry and open access publication of results from scientifically analysed and archived wood samples in Sweden, and their associated metadata, into the SEAD research data infrastructure (Strategic Environmental Archaeology Database; www.sead.se), and (2) actively promote the database as a resource for new and ongoing interdisciplinary research initiatives. Inclusion of dendrochronological data in the SEAD infrastructure will allow for multidisciplinary studies combining major scientific and societal questions. SEAD is already adapted to this purpose, a pilot study has been undertaken and digitisation workflows and time estimates have been confirmed for the more than 50,000 samples archived at the four universities. Broad coverage of research networks, stakeholder interaction and strategic support from the cultural heritage community are guaranteed by the project partners and an established international and multidisciplinary reference group.

Intraspecific differences in wood anatomical traits of northern red oak (*Quercus rubra* L.) provenances provide opportunities for forest management

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The investigation of provenance trials established with ecologically and economically important tree species provides detailed information about environmental influences on intraspecific variation in tree growth, as well as on growth responses in extreme years. Due to climate change, extreme years (e.g., with drought and late frost events) are increasing in frequency and severity. In this study, we investigate the interannual variation in wood anatomical traits of northern red oak (*Quercus rubra* L.), using increment cores from 12 provenances planted at three sites along a precipitation gradient in Germany. We compare the climate sensitivity of introduced provenances with those from the natural distribution to analyse differences in adaptive strategies. We observe variations in vessel characteristics among provenances and sites, depending on the prevailing environmental conditions. Further, the inter-specific climate sensitivity differs between traits. For example, a high sensitivity of vessel density and relative conductive area to maximum temperature in summer is prevalent on the continental site, while a high sensitivity to maximum temperature in winter is observed at sites with a higher water availability. Furthermore, the sensitivity to precipitation differs between sites indicating a previous year's influence on vessel density and relative conductive area under moisture conditions. In drought and frost years, we observe high variation in vessel characteristics between provenances and sites, indicating different adaptive strategies of provenances to cope with these extreme conditions. Given that provenance-specific responses exist, our findings provide important information for the selection of suitable provenances for forest management.

Annual tree rings in the ever-wet tropical forest of the Americas

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Biological rhythms in many ways are related to ecosystem functioning. In tropical tree ecosystems, plant growth rhythms and forest productivity are explained as a consequence of annual seasonal drought or flooding (water stress paradigm). However, this paradigm ignores what determines tree growth rhythms in tropical forests that receive high annual rainfall and lack dry periods (i.e., ever-wet forests). The lack of a typical dry season in these ecosystems has led to the misconception that they lack a seasonal rhythm in wood formation (i.e., annual tree rings). By combining unique in-situ observations on leaf phenology, dendrometers, radiocarbon (^{14}C) analysis, stable isotopes (^{13}C and ^{18}O), and traditional tree-ring analysis, we demonstrate for the first time the occurrence of seasonal rhythmic growth in several trees from an ever-wet tropical forest (precipitation over 7200 mm y^{-1}) in the Chocó region (Northwest of South América). Also, we found that peak growth activity (wood formation) occurs during the least rainy season and stops during the rainiest season. These relationships suggest that both excess or deficit of environmental resources may explain the seasonal pattern of tree growth. Such findings challenge the established paradigm of non-seasonality in tree growth in the wetter-end tropics and have direct implications for ecology, satellite estimates of biomass growth, and current global vegetation models.

Climate-Growth Relationship Analysis of Trees and Shrubs in the Sub-Arctic - Comparative Study from Øvre Pasvik, NE Norway

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Trees and shrubs in northern latitudes serve as vital indicators of environmental changes, yet shrubs remain relatively understudied compared to trees. This study builds upon previous research on dating the age of shrubs and trees by conducting thorough cross-dating with an increased number of samples. We aim to analyse the radial growth patterns of *Pinus sylvestris* and *Juniperus* spp. shrubs from Øvre Pasvik, located in NE Norway. Our main goal was to compare radial growth patterns and to conduct climate-growth relationship analyses to elucidate trees versus shrubs growth responses to climate variability. Samples from both species revealed common growth suppressions, frost rings and some blue rings. We will compare climate sensitivity of trees and shrubs in relation to changing climate. Despite prior findings of low correlations for shrub specimens, integrating analyses with trees will offer valuable insights into how woody plants respond to climate change in the northernmost parts of Europe. This will enhance our understanding of plant sensitivity to environmental changes in sub-arctic habitats.

The effect of ring width on mercury concentration in conifer tree rings

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Tree-ring mercury (Hg) concentrations have the potential to be used to reconstruct historical atmospheric Hg trends. This study aimed to evaluate whether factors other than atmospheric Hg, such as climatic variables and tree-ring width, could affect Hg concentration in tree rings. Tree rings of two conifer species, European larch and Douglas fir, were investigated in Ústí nad Labem in the Czech Republic. Trees were sampled in the city, at 1.5 km from a chlor-alkali plant, presenting an important local Hg emission source. We found that Hg concentration in tree rings could not be fully explained by historic Hg concentration in the air. For the nine years for which sufficient hourly measurements of gaseous Hg^0 in air were available from the Czech Hydrometeorological Institute, we calculated mean Hg in air during days when meteorological conditions were suitable for tree growth. This improved the correlation between tree-ring Hg and air Hg for fir, but not for larch. Furthermore, we detected a significant positive correlation between tree-ring width and tree-ring Hg concentration in the heartwood of larch, in raw as well as in detrended ring-width and Hg data. This seems to be related to the heartwood formation. Possibly, extractives that are deposited in larger concentrations in narrow rings, increase the weight of these rings without increasing the amount of Hg, leading to a decrease in Hg concentration. Hg concentrations are generally considered to be more suitable for atmospheric Hg reconstructions than Hg masses in tree rings, since concentrations are not expected to be influenced by tree growth. However, our analysis shows that, in the investigated larch trees, tree-ring width does affect Hg concentration and may need to be taken into account when reconstructing historical atmospheric Hg trends.

Elucidating the dynamics and drivers of the Scottish mid-Holocene pine-decline using subfossil *Pinus sylvestris* dendrochronology and peat palaeoecology

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Scots pine (*Pinus sylvestris*) was extensive across Scotland in the early Holocene until a widespread, but varied in extent and timing, contraction occurred in the mid-Holocene – the so-called 'pine-decline'. While the dynamics and drivers of this are not well understood, subfossil pine stumps preserved in peat offer an insight into the growth dynamics of these woodlands and the period of decline. Two strategically located subfossil peat sites (Einich and Corrour) were chosen to assess the characteristics of bog pine growth and decline in regions that represent contrasting spatial and temporal patterns of Holocene pine woodland dynamics. A further five modern-day pine woodlands – two on mineral soil and three on peat (one in a pronounced state of decline with >50% tree mortality), were assessed to typify growth dynamics of pine woodland along a transect of increasing hydrological stress. Supressed growth is characteristic of both subfossil sites, which are most analogous with the declining modern-day site, suggesting that the preserved subfossil remains represent a decline phase of these mid-Holocene pinewoods. From Einich, two well-replicated cross-dated floating chronologies indicate a sizable but fluctuating and low productivity pinewood ~7–8,000 years BP. This contrasts with the Corrour site that indicates sparse and sporadic tree germination and death with numerous poorly-replicated floating chronologies. Comparison of these two subfossil sites indicate the similarly low productivity of bog pines, but also the variable woodland structure and extent during the Holocene. Stratigraphic peat cores were collected from both sites for palaeoecological analysis of pollen, spores, and microfossils as evidence of human activity and/or climatic change. Pollen analysis further supports the dendrochronological evidence of contrasting woodland types – where *Pinus* pollen predominates at Einich but contributes only an inconsistent and secondary component of a heterogenous woodland at Corrour.

A quantitative analysis of the effect of sample size on dendroecological signal in earlywood vessels of ring-porous species

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Replication is a key paradigm in dendrochronology to get robust inferences on climate-growth relationships. The higher the correlation between individual series (common signal, Rbar) and the higher the replication (number of cores and trees, EPS), the more we can trust any climate signal. Unlike some other tree-ring parameters, earlywood vessels (EWV) time series usually display relatively low Rbar. To investigate current practices in quantitative wood anatomy (QWA) of EWV we reviewed 60 papers published during the last 20 years. Most studies collected two 5 mm increment cores per tree for 15-20 trees but used only a smaller subset for QWA. Half of the time series investigated show an Rbar <0.20 and only a third of those who provide the EPS obtain a value >0.80, showing a potential lack of robustness. With these common practices and results in mind, we performed new systematic analyses of how both the number of trees and the tangential strip width (TW) affect the data quality and robustness of two ring-porous species. We collected stem disks from 20 trees of ash (*Fraxinus excelsior,* Hünenberg, Switzerland) and oak (*Quercus robur*, Trino, Italy) and measured EWV on 40 mm TW of each tree using ROXAS. We randomly sub-sampled various strip widths 1000 times (from 5 to 40 mm per tree, using 5 to 20 trees), and we analysed the signal strength (Rbar, EPS) while progressively increasing TW and sample size. Preliminary analyses showed that Rbar continuously increased until a TW of 20 mm. Based on the distribution of Rbar typically found in the literature and our new analysis, we recommend measuring EWV for at least two 5 mm cores per tree for 20 trees. Regarding current developments in image analysis, it is worth avoiding using a subset to improve data quality and robustness of scientific conclusions.

A 242-year beech (*Fagus sylvatica* L.) latewood density chronology as a proxy for summer temperature in Western Europe

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Latewood density has emerged as a robust proxy of summer temperature in various coniferous species, yet its applicability in hardwood species, such as beech (Fagus sylvatica L.), remains largely unexplored. Diversifying the pool of species suitable for temperature reconstructions holds significant advantages for regions historically dominated by broadleaved species. In this study we present a latewood density chronology until 1780 for beech which was constructed using 83 living trees from three distinct sites in the Sonian forest near Brussels (Belgium). 166 increment cores were scanned using high-resolution X-ray micro computed tomography to create a 3D density representation of each core. The resulting density profile of each annual ring allowed to compute the average latewood density and to construct a latewood density chronology. when evaluating the three sites individually, the density chronologies exhibit strong similarities, in contrast to ring width chronologies, which vary due to age and management disparities. Furthermore, the overall density chronology shows a strong and stable positive correlation with June – July temperatures from a nearby weather station. This correlation extends across substantial portions of Western-Europe, highlighting the potential of beech latewood density as a proxy for summer temperature in future dendroclimatological studies. Overall, this study highlights the untapped potential for latewood density-based studies on beech and hardwood species in general, particularly in regions where traditional conifer-based studies are less feasible.

Exploring Mining Subsidence: Insights from Dendrogeomorphic Analysis

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Mining operations can have significant environmental impacts, notably surface lowering and deformation due to overburden disturbance, commonly referred to as mining subsidence. Despite extensive investigation in engineering studies, the dendrogeomorphic approach offers additional insights into this phenomenon. This study investigates the response of black alder (*Alnus glutinosa* (L.) Gaertn) to subsidence, focusing exclusively on tree-ring eccentricity. The Knothe method was employed to identify the years influenced by mining activities, determining the theoretical radius of the primary subsidence influence range from mined-out coal seams. It is assumed that the course of the I_t index, calculated from the onsets of eccentricity, should primarily be associated with mining operations in the area, indicating subsidence. Our results demonstrate that the overall tree growth response, as reflected by the I_t index values, is significantly higher in years influenced by mining activities, confirming the reliability of dendrogeomorphic approaches even in such complex settings of the subsidence process. However, relying solely on the I_t index for subsidence event reconstruction proves insufficient due to the continuous nature of the process. The use of dendrogeomorphology and tree-ring eccentricity provides valuable insights into the subsidence activity. Nonetheless, persistent challenges remain, particularly concerning secondary processes such as landslide activity or residual subsidence, as well as the consideration of different methodological approaches.

Exploring the potential of assisted migration for European beech based on its wood anatomy

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Europe's forests are increasingly under pressure from climate change. To improve their resilience, assisted migration of non-local tree species or provenances offers an important option for forest management. Assisted migration refers to the active introduction of genes supposedly pre-adapted to expected future conditions into local tree populations that would otherwise not be able to adapt or migrate quickly enough themselves to keep pace with ongoing climate change. Here, we explore the potential of assisted migration for European beech (*Fagus sylvatica* L.) by comparing wood anatomical traits and growth dynamics of up to 24 provenances, which were planted within the frame of an international beech provenance trial at three sites in Germany in the 1980s. Given that the same provenances were planted at the three sites, which differ in the climatic conditions they are exposed to, our study allows to assess the contribution of phenotypic plasticity and genetic adaptation in trait expression. Results suggest that European beech is a highly plastic tree species: Whereas differences between sites, emerging from contrasting site conditions, are large, differences between provenances within individual sites are generally low and can mostly not be attributed to provenance origin. Hence, the relevance of assisted migration for beech seems to be low(er) as compared to other tree species.

Introducing the Power Borer: an automated sampling solution for efficient dendrochronological sampling

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Dendrochronology provides invaluable insights into past environmental conditions, climate variations, and ecological dynamics. However, traditional methods of dendrochronological sampling often require time-consuming and labor-intensive procedures, limiting the scalability and efficiency of research efforts. To address these challenges, we present the Power Borer, a pioneering tool designed to revolutionize dendrochronological sampling processes. The Power Borer represents a significant advance in sampling technology, offering an automated solution for increment core extraction. Powered by a battery-operated drill, the Power Borer utilizes a unique planetary gear system to convert high-speed, low-torque input into low-speed, high-torque output, ensuring precise and efficient core sampling. Key features of the Power Borer include its fast-release mechanism that allows for swift core removal, optimizing sampling efficiency, and powerful penetration force, tailored to sample both softwood and hardwood species. Additionally, the Power Borer's robust construction and ergonomic design ensure reliable performance in diverse environmental conditions. The introduction of the Power Borer marks a significant milestone in dendrochronological methodology, offering researchers an automated and efficient tool to unlock the secrets hidden within tree rings. We invite fellow scientists and researchers to explore the transformative potential of the Power Borer for advancing the field of dendrochronology.

Assessing temporal stability of temperature signals in NW North American density records

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The "divergence problem" of reduced temperature sensitivity of tree-ring (TR) records since the middle of the 20th century has been frequently observed at northern and upper treeline sites around the globe. In north-western North America, response to recent warming has been shown to vary strongly on a small spatial and elevational scale. While weak and temporally unstable temperature response in total ring width (TRW) has been prevalent in former studies conducted in the region maximum latewood density (MXD) appeared to be rather unaffected. Here, we present new TRW, MXD and latewood blue intensity (BI) data from two *Picea glauca* (White spruce) sites in the central and southern Yukon, two areas that displayed divergence to a different degree in earlier research. First results show significant correlations ($p < 0.05$) with instrumental May-August maximum temperatures (Tmax) for MXD and BI datasets from the same adult trees including only 25 and 19 samples per site (1901–2021, MXD: $r = 0.59$ and 0.56, BI: $r = 0.44$ and 0.47). MXD and BI achieve comparable results for May to July, but MXD shows a distinct peak in August which does not exist in BI. Still, BI represents a less costly and time-consuming surrogate that is potentially better suited for a larger network than a single-site approach. Moving correlations (30-year window) reveal that the association between our TR proxies and Tmax became weaker between the 1940s and 1970s but has recovered in recent decades. However, the positive long-term trend in the instrumental temperature data, which is more pronounced in mean temperature than Tmax, is not well-captured by our TR data. We aim to mitigate this issue by using larger datasets of 100 MXD samples from a combination of 50 adult and juvenile trees from the same stands. Taking advantage of this more balanced age structure, we apply age band decomposition and create a new dataset which may preserve more low-frequency variability and better track the warming trend.

Unprecedented warming captured by the first Carpathian summer temperature reconstruction using quantitative wood anatomy chronologies

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Knowing the past climate variability comes with great value in understanding the present toll of climate change and global warming on forests. Although some climate records extend to medieval times, high resolution instrumental data spans over a few decades only, in some areas. Fortunately, tree rings were proven to be a valuable source of climate proxy data, with yearly time resolution, that can provide solid information where instrumental are missing. Hereby we present a temperature reconstruction for the past 450 years using tree-rings parameters from Retezat Mountains, Romania. For this we extracted 28 cores from healthy and mature Stone pine (*Pinus cembra L.*) trees, we measured various tree ring parameters - tree ring width (TRW), and for a higher time resolution, we selected 9 cores coming from different trees and analyzed them using quantitative wood anatomy (QWA) techniques in order to obtain chronologies of anatomical parameters. Annual tree-ring widths were measured using LINTAB equipment and TSAP software, and the cross-dating accuracy was statistically checked with COFECHA. QWA samples were prepared using the standard (Gärtner & Schweingruber, 2013) protocol, the microsections were scanned using the 3D-Histech Pannoramic MIDI slidescanner, and the resulted images were analyzed using Roxas software. All TRW and anatomical series were standardized to remove unwanted trends. Climate data was compiled using instrumental data from Targu Jiu weather station (~50km away from Retezat Mountains). Due to the low correlations between TRW and climatic parameters (referinta divergence), here we present only the reconstruction with the cell wall thickness series which confirms its high potential as high-resolution climate proxy. Overall, the reconstructed JJA temperatures show the most important *episodes* of our past climate: the end of The Little Ice Age, Dalton Minimum and Modern Maximum, recent warming being clearly visible. This climate reconstruction marks 2012, 1967, 1952, 1890 and 1794 as the warmest summers, and 1976, 1933, 1838, 1815 and 1676 as the coldest summers.

Oxygen and carbon isotope patterns in tree rings from vital and non-vital beech trees in the Valais, Switzerland

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Tree mortality due to increased drought is a globally observed issue and has been studied widely. The underlying physiological processes are, however, not yet fully understood. One approach to assess the drivers of drought-induced mortality is to retrospectively investigate predisposing factors that may have led to tree death by utilizing tree rings. Here we combine annual growth, and carbon and oxygen isotope ratios ($\delta^{13}C$ and $\delta^{18}O$) in tree-ring cellulose of photo-monitored beech trees (*Fagus sylvatica* L.) with high and low crown vitality at the sites Saillon and Chamoson in the Valais, Switzerland. We sampled 10 trees (6 vital, 4 non-vital) and developed tree-individual isotope time series for the period 1980-2022. Initial results indicate increasing growth of non-vital trees during the first half of their life, followed by a decreasing trend during the second half, across both sites. Conversely, vital trees show a consistent growth increase over their whole life at both sites. Non-vital trees at Saillon show consistently higher $\delta^{13}C$ values over the full study period compared to vital trees while $\delta^{13}C$ values of both groups at Chamoson are similar. For $\delta^{18}O$ a distinct decrease in the most recent 5 years is observed for the non-vital trees at Saillon while no distinct differences are found at Chamoson. Climate correlation analysis indicates a clear dependency of $\delta^{13}C$ and $\delta^{18}O$ on summer moisture conditions with slightly weaker relationships of the non-vital trees. Our initial results support another study in the same region (in prep.) where an unexpected decrease of tree-ring $\delta^{18}O$ of dying trees raised questions. While our investigations are still ongoing, we interpret this trend now towards an increased contribution of the source (xylem) water $\delta^{18}O$ signature and decreased contribution of the leaf water $\delta^{18}O$ signature during xylem cell production due to reduced carbohydrate availability.

Growth-climate response at different stem heights of larch trees in Estonia

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In this study, we examined the influence of climate on annual ring-area increment of larch trees across different stem heights within the stands of the Järvselja Training and Experimental Forest Center in southeast Estonia. The study material comprised stem disks collected from various stem heights, encompassing a total of 20 trees from two distinct sites, characterized as fertile *Oxalis* site type. The age of the studied larch trees were 60 and 36 years, respectively. Average annual ring-area increment chronologies were computed for different heights along the stem for both sites and correlation analysis was used to investigate the relationships between each chronology and climate data. Meteorological data from the Tartu-Tõravere weather station, including monthly mean, minimum and maximum air temperatures, as well as total precipitation sums, were utilized for the overlapping period of 1990-2014. The Pearson correlation analysis revealed consistent growth-climate response across different stem heights for both sites. A notable increase in growth along the stem of larch trees in the older site was observed in response to high precipitation levels in June and July of the previous growing season. Additionally, in the upper part of the stem, temperature during the growing season positively influenced radial growth. Conversely, higher growing season temperatures were associated to reduced growth, especially in the upper stem of the younger stand. These findings suggests that larch trees exhibit varying sensitivities to climate along their stems, highlighting the importance of considering within-tree growth patterns when assessing climate-growth relationships. This also highlights the need for further research into complex growth responses of larch trees under a changing climate.

Conservation of beta-diversity helps guard against the loss of multiple environmentally sensitive species in European primary forests

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Addressing the scope of global diversity loss is a critical social imperative. While the drivers are well recognized, consensus regarding conservation actions are lacking. Assessing spatial variation in species assemblages may provide an empirical framework for delineating conservation targets. The components of beta-diversity (nestedness and turnover) have rarely been evaluated simultaneously for multiple taxonomic groups within unmanaged reference environments at large scale. We demonstrate a methodology for quantifying the spatial organisation of communities, as well as the underlying habitat structure, within primary forests in Central Europe. We sampled community composition at 58 locations for selected groups of taxa: birds, lichens, beetles, and fungi. The magnitude of inter-site differences in species assemblages for each group were used to quantify corresponding levels of total beta-diversity, which were then decomposed into nestedness and turnover components. We assessed the degree of congruence among groups for all three beta-diversity metrics. Finally, using regression methods, we investigated relationships between habitat features and observed alpha-diversity and red-listed species incidence. Levels of total beta-diversity were substantial for all taxa, doubling local alpha-diversity in many cases. Total beta-diversity was lowest for the avian group, reflecting their dispersal ability. Turnover exceeded nestedness for dispersal-limited organisms having obligate associations with deadwood (e.g. fungi). Lichen and fungal groups were correlated in terms of total beta-diversity and turnover, due to similar resource preferences for the constituent taxa. Variation in local deadwood pools was significantly related to alpha-diversity for beetle and lichen groups. Presumably, heterogeneity in the distribution of deadwood therefore also influences spatial patterns of community dissimilarity. We demonstrate the utility of employing beta-diversity metrics to understand mechanisms regulating biodiversity maintenance. Our results provide baseline information for diversity assessment in managed systems. We also reaffirm that beta-diversity estimates may be used to inform management plans designed to maximise representation and viability goals.

Effects of drought and disturbance on the soil CO_2 and CH_4 fluxes and tree growth in a mixed forest and spruce monoculture

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Spruce monocultures have been intensively planted across a wide area of Europe to increase timber production and meet the demand from society. However, evidence suggests that species monocultures may not be as resilient to drought spells and heat waves compared to mixtures of two or more species. The advantage of mixed forests over monocultures is particularly evident when the mixed species occupy different niches, reducing inter-specific competition and enabling better growth and increased carbon sequestration. However, it remains unclear how drought events and heat waves affect carbon sequestration in the soil and how this differs between mixed forests and species monocultures. In this study, we conducted two years of intensive monitoring of soil CO_2 and CH_4 fluxes, measured soil microbial diversity, and assessed long-term (tree ring) and seasonal tree growth to quantify carbon sequestration in a mixed forest and a spruce monoculture. Results showed that severe drought in 2022 significantly reduced the growth of Norway spruce stand and its' forest floor and soil CO_2 fluxes but at lesser intensity impacted C fluxes of European beech and silver fir stand. The bark beetle outbreak in 2023 caused rapid tree infestation and die-back only in the spruce stand (followed by salvage clear-cut harvesting) which subsequently increased soil CO_2 emissions via a sudden increase in litter input from dead trees, soil temperature and water content from reduction of shade and evapotranspiration.

The impact of growth and climate on the resin production of *Pinus pinea* and *Pinus pinaster*

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Resin production serves as a natural defence mechanism for pine trees and is a significant component of forest economic activities, with a wide range of applications. In Portugal, resin extraction primarily targets *Pinus pinaster* trees and to a lesser extent *Pinus pinea*, the two main pine species of the country. The resin tapping period starts in spring and ends in autumn, coinciding with the growing season. Thus, two processes competing for carbon occur at the same time, although their response to climatic parameters might be different. There has been a limited number of studies on the response of resin production of both species to growth and climatic conditions. A field study was made during one growing season in a mixed stand of *P. pinea* and *P. pinaster*, measuring the local climatic parameters, wood growth and resin production. The growth of *P. pinea*, during the resin tapping period, showed a negative relation with VPD, while P. pinaster showed a positive relation with precipitation, emphasizing the higher sensibility of Stone pine to drought, compared to Maritime pine. Resin yield showed a positive relation with temperature and VPD in both species, and a negative relation with growth but only for *P. pinea*. It seems that for Stone pine, the resin production is at a cost of growth. Under a scenario of increasing temperature and VPD, and based in our results, resin yield would increase in both pine species, however, the growth of *P. pinea* will be more affected. Although our results are only based in one site and one growing season, it raised interesting questions on the impact of growth, temperature and VPD on resin yield of two important Mediterranean pine species.

Early successional species show higher tolerance to drought across Europe than late successional species

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Climate change exacerbates forest disturbances through more frequent droughts and fires, undermining the resilience of global forest ecosystems and their ability to recover. The response of fast-growing early successional species to drought is poorly understood despite their key role in ecological succession. Here we assess the drought response of early successional species to extreme drought events across their natural European distribution range. We examined the growth response to drought of three early successional species (silver birch, black poplar, and Scots pine) in contrast to a late successional species (European beech). We used tree-ring widths of 6340 trees from 109 forest sites across Europe to establish species-specific tree-ring chronologies. Multiple linear regression was used to understand which climatic or growth performance variables best explain tree growth during and after drought. The early successional species silver birch, Scots pine, and black poplar demonstrated superior drought tolerance compared to the late successional European beech. Droughts caused a slight, but non-significant decrease in growth for early successional species. European beech was the only species significantly affected by drought. Annual temperature and pre-drought growth were the most important predictors of tree growth during drought, whereas precipitation was the best predictor of post-drought growth. Scots pine and silver birch revealed a more distinct latitudinal gradient, with tree growth during and after the drought being higher in northern Europe than in central Europe. European beech had a high tree growth during drought at sites with lower winter precipitation. Silver birch and black poplar had a higher growth post-drought at sites with generally high precipitation. This study provides insights into the drought tolerance of early successional species. These results could support species selection to promote ecological succession in the face of the expected increase in forest disturbance due to extreme climate events.

Tree-Ring Widths and Stable Isotope Records of Juniper Tree Rings as Climate Indicators in Hezar Masjed Mountain, Northeastern Iran

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Climate change plays a vital role in shaping forest ecosystems and influencing tree growth. Understanding the repercussions of these changes on trees is crucial, particularly in arid and semiarid regions, where sensitivity to climate change is high. In this study, we investigated the climate variables influencing stable oxygen isotope enrichment and radial expansion in tree rings of Persian junipers growing in the Hezar Masjed Mountains in northeastern Iran. We developed a 499-year-long chronology of tree ring width (TRW) and a 200-year record of stable oxygen isotopes ($\delta^{18}O$), spanning 1523-2021 and 1822-2020, respectively. The data from the nearest meteorological station were employed for correlation analyses between climate variables and tree-ring parameters. The TRW-climate relationships reveal a significant positive influence of precipitation and relative humidity (RH) on TRW during March-June, reflecting the growing season. The correlation analysis between tree-ring $\delta^{18}O$ and climatic factors demonstrates a negative correlation of RH with $\delta^{18}O$ from May to August, while no significant precipitation signal was recorded by $\delta^{18}O$. Furthermore, the influence of temperature (mean, max, and min) showed positive and strong associations with $\delta^{18}O$ during late winter and spring. However, for TRW, correlations were only evident in January. Both tree-ring parameters, notably $\delta^{18}O$, exhibited the strongest correlations with VPD. These signals covered distinct time spans (TRW: Mar-May and $\delta^{18}O$: May-Aug), thereby enabling an extended climate reconstruction across seasons. This study unveils the significant potential of $\delta^{18}O$ and TRW in Iranian juniper trees for multi-parameter climate reconstructions. Consequently, our findings contribute to achieving a high-resolution understanding of climate dynamics and atmospheric circulation patterns in Iran.

Ecological impacts of abrupt climate changes on oak dieback in the Zagros oak woodlands, Iran

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Semi-arid regions are among the most vulnerable areas to the impacts of climate change. The Zagros Mountain range in western Iran is about 1600 km long surrounded by arid and semi-arid basins. The mountain range is up to 4500 m high and the general orientation of the mountains which are exposed to westerly disturbances, make the region as a valuable water resource to surrounding arid and hyper-arid basins. The Zagros Mountains are the largest host (about 6 million ha) of Persian oak (*Quercus brantii* Lindl.), with a high diversity in flora and fauna in western Asia. Persian oak is a native broad-leaved oak species growing at elevations between 700 and 2300 m a.s.l. across the Zagros Mts. and has important soil conservation and water regulation functions in the fragile ecosystem. The oak forest was negatively affected by rapid climate changes, resulting in a large-scale oak dieback and insect outbreak in the Zagros oak woodlands. In this study, we analyzed earlywood width and latewood width parameters of Persian oak in order to identify its species-specific characteristics under the extreme climate conditions along altitudinal gradients across the Zagros Mts. Our results show that Persian oak is highly dependent on winter precipitation, while high temperatures during the long dry summer negatively affect the drought tolerant oak species. In addition, we found that severe droughts accompanied with high temperatures during the growing season impose strong negative impacts on the native oak species, resulting in hydraulic deterioration, which could trigger oak dieback and mortality. It is expected that an increase in seasonal maximum temperatures accompanied by precipitation decline may play an important role in stimulating outbreaks of invasive insects and fungal pathogen attacks in the Zagros oak woodlands.

Avalanche effect on *Pinus peuce* forests on the Northwestern slope of Todorka peak in Pirin Mountains

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Pirin National park in Bulgaria is refuge of some of the best-preserved endemic *Pinus peuce* forests in the world. Due to the steep slopes periodically the forests are affected by avalanches. Meanwhile after the construction of Bansko ski resort tourism has grown a lot, which additionally increases the importance of the protection functions of forests. However, this role as well as the complex interaction between forests and avalanches are not well studied and understood. In our study we aim at gathering information about the avalanche regime of several parts of the studied slope. To fill in the lack of data on past avalanches we performed dendrochronological analysis. We mapped the avalanche paths with the use of old aerophotos and modern satellite images. To evaluate the protection role of forests we used the ATES mapping approach and in addition simulated avalanches with different characteristics with the RAMMS::EXTENDED software. The gathered data helped us reveal that much of the forest territory above Bunderitsa meadow has been affected by avalanches. Large avalanches were more frequent in the studied couloirs up to the late 1980s and affected neighboring forests every two to three decades. The trees which were hit by avalanches if not completely uprooted suffered stem breakages, leaning, scarring and branch-removal. This was reflected in the tree-rings mostly by sharp growth suppressions, missing rings, production of reaction wood, callus tissue and less-frequently traumatic resin ducts. Our findings demonstrate that avalanches in the valley are of high importance and require more attention by authorities both as risk factor for human life and as natural disturbance shaping the forest structure and dynamics. **Acknowledgement**: This study was carried in the framework of projects KP-06-N31-3/2019 and KP-06-Austria/2023 funded by the National Science Fund of Bulgaria.

Herbaceous encroachment altered the climatic sensitivity of the growth of *Rhododendron chrysanthum* in an alpine tundra

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The distribution and growth of tundra shrubs are highly sensitive to climate change. A deeper understanding of the growth and driving factors is crucial for revealing the impacts and mechanisms of tundra vegetation change under global warming. In response to climate change, shrub *Rhododendron chrysanthum* in China's Changbai Mountain tundra has been affected by herbaceous encroachment. Here, we analyzed radial growth, functional traits, and climate correlations across varying elevations and encroachment levels. Radial growth of *R. chrysanthum* didn't change at 2050 m a.s.l. but increased at higher elevations (2200 and 2350 m a.s.l.) over time. Growth responses also differed by month and elevation, generally showing better growth with increased precipitation and reduced growth with higher temperatures. At 2050 m a.s.l., growth positively responded to current year April and September precipitation and negatively to current year February temperatures. At 2200 m a.s.l., growth negatively responded to previous year September temperatures. Meanwhile, at 2350m a.s.l., growth positively responded to current year March, August, and September precipitation but negatively to April maximum temperatures. Herbaceous encroachment modified these climatic growth responses. At 2050 m a.s.l., herbaceous encroachment enhanced negative response of growth of *R. chrysanthum* to previous year October and November temperatures, weakened negative response to current year January temperatures, but strengthened positive response to current year April and July temperatures, and June precipitation; At 2200 m a.s.l., herbaceous encroachment increased negative response of growth of *R. chrysanthum* to current year January and February temperatures and positive response to current year June minimum temperature. Herbaceous encroachment shifted functional traits of *R. chrysanthum* toward more acquisitive values. Overall, warmer climates favor the growth of *R. chrysanthum* at higher elevations, indicating a potential range expansion upwards but contraction downwards as the result of adaptation shifts, primarily towards reduced frost tolerance and enhanced light acquisition competition.

Are there any discrepancies between root and stem intra annual growth?

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On a diel scale, trees are found to grow mainly at night, as growth ceases at high VPD levels, which occur during the daylight hours of summer months in temperate climates. Trees rehydrate during the night, creating the turgor pressure needed for cell division and expansion. Such VPD imposed diel growth restrictions can be released during the night and early morning. Diel and seasonal growth patterns are therefore strongly dependent on atmospheric and soil moisture conditions. The importance of temperature for root cambium reactivation and xylem production is well established in cold environments such as boreal and montane forests. In fact, a soil temperature below 6°C has been identified as the threshold for inhibiting root activity. However, much information is available on above-ground intra-annual growth, but data on coarse root growth are lacking. The study analysed long term diel and seasonal growth patterns of *Abies balsamea* and *Picea mariana* to assess the extent to which observed growth patterns are consistent across species and organs. Both widespread species are located in the transition zone between temperate and boreal forests. The main questions of the study are therefore; 1. How consistent are the long-term diel and seasonal growth patterns across species and organs (stem and coarse root)? 2. What are the above and belowground growth climatic drivers in a boreal ecosystem? 3. How important is the role of the absorbed radiation during the vegetative period between the organs?

Quantifying drought impact on conifer growth using dendrometer and sap flow data

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Climate-growth correlation based on tree rings provide information on long-term growing conditions. However, they usually just provide two points (early wood and late wood) per year. This might not be enough for a detailed understanding of growth processes at an intra-annual scale, for instance on the effects on differently timed drought periods. Quantifying tree water deficits and subsequent growth reductions from automatic dendrometer measurements with a sub-daily time resolution is a straightforward way to display drought stress and its impact on tree growth. Additionally, the ratio of tree transpiration (T) measured with sap flow sensors to potential evapotranspiration (PET) may provide further insights on water limitations. The LTSER site Matsch|Mazia is located in an inner-alpine dry valley in the Italian Alps. There, we are conducting band dendrometer- and sap flow measurements on European larch and co-occurring evergreen conifers (Pinus nigra, Picea abies, Pinus cembra) along an elevational gradient from the valley floor at 1000 m to the forest line close to 2300 m a.s.l. Four trees were measured per site and species starting in 2012. We observed massive tree water deficits and reduction of the T/PET ratio during dry periods at low- and at mid-elevation sites which reduced yearly growth rates in dry years. At high elevation no longer drought periods indicated by persistent tree water deficits or reduced sap flow rates were observed. However, daily growth rated were limited by high vapor pressure deficits event even at high elevation, especially for Pinus cembra. Overall dendrometer and sap flow measurements provided valuable additional information to explain observed tree growth pattern.

Site conditions drive *Quercus robur* climatic sensitivity in urban forests

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Urban forests, i.e. trees in parks, gardens, alleys, streets, etc. are a critically important part of any city, providing many ecosystem services and contributing to urban ecosystems' resilience in the face of climate change. However, the heterogeneity of the urban environment, caused by forest fragmentation, differences in local temperature and soil-water availability, physical-chemical properties of the soil, and the terrain's steepness, can influence how trees respond to climate variability, either suppressing or amplifying the climate signal. In this study we delve into the climate sensitivity of *Quercus robur* within Kyiv's urban forests, considering their specific topographic and environmental characteristics. Using dendrochronological methods, we developed ring-width site chronologies in nine urban forests where oaks are both dominant in broad-leaved and sub-dominant in mixed forests. Employing the bias-adjusted standardized growth change approach, we identified the most frequent negative (1963, 1964, 2015), and positive (1966, 1980) growth years. Moreover, the frequency of negative pointer years has increased in recent decades, indicating an increased vulnerability of *Q. robur* to climate change, particularly extreme droughts. To examine the response of trees to climatic fluctuations we utilized a double-moving window approach providing a daily correlation analysis. Finally, linear mixed-effects models were used to identify the site-specific topographic characteristics affecting urban forests' sensitivity to precipitation and temperature. Importantly, our results pinpoint that under urban conditions, *Q. robur* growth is tightly connected with precipitation during dormant and early growing seasons, and trees' sensitivity to precipitation is determined by the steepness of the slope. In conclusion, the study's outcomes underscore the significance of considering complex topography in dendroecological studies and provide a basis for developing a tailored approach for urban forest management and preservation in areas characterized by diverse landscapes.

Dendro-ecological traits as predictive indicators of oak decline

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In the current context of climate change, rising temperatures and prolonged drought during the summer period are negatively affecting forest ecosystems. In this picture, an increase in decline and mortality rate of forest trees has been reported worldwide, which is compromising diverse and numerous essential ecosystem services provided by forests, like carbon sequestration. Therefore, an in-depth comprehension of which environmental and ontogenetic variables shape tree decline dynamics is urgently needed, to predict the fate of forest trees in rapidly changing contexts. Although clear predictive indicators of decline and mortality are missing, recent research has shown that early clues to the onset of future decline and mortality phenomena could be searched in growth performances. Pedunculate oak (*Quercus robur* L.) represents one of the most important species afflicted by decline within the floodplain European forests. This study aimed to test the existence of differences in growth rate and carbon sequestration between spatially closed pairs of declining (D) and non-declining (ND) trees. The study was conducted in five experimental areas located in northern Italy, and the radial growth of 125 pairs of D and ND trees was retrospectively characterised. Our results showed a significant decrease in radial growth, and consequently in carbon sequestration, of D individuals in the recent decades. A complex influence of climate on growth dynamics has also been observed, which we can therefore exclude being driven by the effects of a single extreme climatic event. A deeper understanding of how these dynamics operate over the long term will help to improve management and restoration tools to preserve floodplain forest ecosystems, which are extremely vulnerable in the face of current climate change.

Exploring Peatland Dynamics: Dendrochronological and Palaeoecological Insights into Climate Change and Forestry Impacts

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Dendrochronology is crucial in paleoenvironmental research, enabling the reconstruction of climate changes. With its high temporal resolution and localized data coverage, dendrochronological records complement sediment analyses. Understanding climate change's extent, rate, and effects is a paramount contemporary scientific challenge. Escalating average air temperatures and precipitation pattern shifts significantly impact global forest ecosystems, especially vulnerable pine monocultures facing extreme fires, droughts, insect outbreaks, cooling, and intense winds. Peatlands (often covered or surrounded by monocultures) serve as natural data archives for climate change assessments, aiding comprehension of ecosystem dynamics over time. We focus on unravelling the peatland and forest history over the past 300 years. Our research was conducted within the Okoniny peatland and surrounding pine trees in the Tuchola Pinewoods (N Poland). Investigations aimed to evaluate forestry alterations' repercussions on local vegetation and peatland hydrology alongside the ecosystem's reactions to extreme events. Our reconstructions are based on multiple proxies, including pollen, plant macrofossils, charcoal, testate amoebae, and various historical sources. Dendrochronological data (with the *Pinus sylvestris* L. tree-ring record) were compared to the peatland record, revealing the impacts of forestry management shifts and climate warming on the peatland ecosystem. Pollen evidence indicates the transition from a lacustrine to a peatland environment before the 1830s during intensifying agricultural activity nearby. The 20th century saw agricultural decline and *a surge in Pinus sylvestris dominanc*e. Tree ring analysis detected and precisely dated extreme events, demonstrating significant water stress on *Pinus sylvestris* over the past three decades. Research outcomes are vital for peatland and forest ecology, paleoecology, and forestry practices within the context of forestry management and safeguarding valuable ecosystems. A study financed by the National Science Centre, Poland, grant no. 2020/39/D/ST10/00641.

Growth Responses of Temperate Forest Tree Species to Climatic Extremes in the Western Carpathians: A Comparative Analysis of Primary and Managed Forests

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This study investigates the radial growth dynamics of three common temperate forest tree species across selected Western Carpathian primary mountain forests (Dobročský prales and Badínsky prales) and nearby managed forests, which also represent an elevational zonation of beech-fir mountain forests. Through RWI comparative analysis, we evaluated the growth responses of Norway spruce (*Picea abies*), European silver fir (*Abies alba*), and European beech (*Fagus sylvatica*) under both managed and unmanaged regimes. Our findings reveal that, despite the structural differences between primary and managed forests, the radial growth patterns of the tree species in the primary forests were not significantly different when compared to managed forests. Notably, during periods of drought and heat, distinct species-specific responses were observed. Following the dry period of 2011-2013, European silver fir exhibited a radial growth decline at lower elevations (Badínsky prales), while Norway spruce was notably impacted by the intense heatwave in 2015 in both sites. Conversely, European beech demonstrated a relatively stable radial growth compared to other species during most dry periods; however, a marked decrease was observed in 2016, after the extreme heat of the preceding year. Our investigation underscores that even within the structural diversity of mixed mountain primary forests, extreme droughts and heatwaves have a significant impact on tree growth. The different physiological attributes of the studied species led to varied, and at times contrasting, growth responses to the same environmental stressors. Our study highlights the complexity of primary forest ecosystems' reactions to climate extremes and emphasizes the importance of species- and management-specific analyses for understanding resilience and adaptability in the context of climate change.

Tree-ring widths and quantitative wood anatomy in beech trees from common garden experiments in Slovenia and Hungary

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International provenance trials of ecologically and economically important tree species are crucial to deciphering the influence of environmental factors and intraspecific variability on tree growth and performance under climate change to guide assisted gene flow and assisted migration of tree provenances and species. In this context, we compared inter-annual trends in tree-ring widths (carbon sequestration potential) and vessel characteristics (conductivity optimisation) of four beech provenances in two international provenance trials, one in Slovenia (Kamenski hrib, a core beech growing site) and one in Hungary (Bucsuta, a marginal beech site) in 2009–2019. We found different patterns of inter-annual variability in mean vessel area and tree-ring widths among provenances and sites, pointing to diverse genetic background and environmental influence on these two wood-anatomical traits. The average values of the vessel area varied less between provenances at Kamenski hrib than at Bucsuta. Weather conditions differently affected tree-ring width and mean vessel area. Furthermore, the length of the period of response of vessel area to the analysed weather conditions differed in summer and winter periods. The differences in the mean vessel area within the tree ring were more pronounced in the weather-wise extreme years, regardless of the provenance. Consistent with previous studies, we confirmed that site conditions affect the climate sensitivity of trees, which is more pronounced at marginal sites or in extreme years. The findings on how different environmental conditions affect the radial growth of young beech trees of different origin are very important for future forest management.

A Millennium-Long Hydroclimate Reconstruction for a Northern Swedish Site

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While Northern Fennoscandia has proven to be an excellent region for tree-ring-based temperature reconstructions, extracting a hydroclimatic signal from woodlands at this high latitude is often challenging. However, we have identified a moisture-sensitive site located at a relatively northern latitude (63.0°N, 18.5°E), near Skuleskogen National Park along the Swedish east coast. For Scots pine, tree-ring width and blue intensity have here revealed a significant precipitation signal for late spring and early summer. This site's susceptibility to drought is attributed to its location in the High Coast region, which has undergone rapid land uplift since the last glaciation. This fast uplift has given rise to a rather unique landscape with steep cliffs, deep valleys, and shingle beaches high above present sea level. Much of the soils has been washed away leaving behind rocky outcrops forests with very thin soil cover, primarily found on exposed bedrock, where drought-resistant Scots pine stands as the by far most dominant tree species. These slow-growing pines often reach ages of 400-500 years, with dead wood often preserved for many centuries on the ground in relatively good condition.

We are currently developing a chronology that extends back to the 11th century, the anticipation is that we can encompass most of the medieval period, with remaining, yet not dated material. The primary focus of the study is on utilizing Blue Intensity, with relatively high-resolution imagery (6000 dpi) captured using the Skippy system developed at the WSL (Swiss Federal Institute for Forest, Snow and Landscape Research). A millennium-long reconstruction of precipitation and/or a drought index in this area will provide valuable insights of regions environmental history and climatic fluctuations over time.

Enhanced crossdating using multi-tree-ring parameters

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Beyond ring-width data, new tree-ring parameters such as Blue Intensity (BI) and stable isotopes are now often used for dendro-historical dating. However, except for a few rare examples, historical dating methods generally still focus on the use of one tree-ring variable at a time. In this poster, I introduce a method that utilises multiple tree-ring parameters (e.g. ring-width, earlywood BI and latewood BI), each representing different climatic signals, to essentially increase the degrees of freedom for identifying a significant crossdate. Initially, sliding correlations between the phase master and the reference chronology are used to create a running time-series of correlation values. This is performed for each parameter. For the three-parameter situation, these three running correlation time-series are averaged with the assumption that each parameter will independently identify the same temporal location for maximal correlation and even if further multiple spurious peaks of correlation are identified, these presumably random peaks will be minimised when averaged over the three parameters and the correct common peak maximised. When the mean correlation values are then transformed to a T-value or a P-value denoting significance, the independence of the different TR parameters essentially increases the degrees of freedom so providing more confidence of the correct crossdate. This poster will introduce the basic methodology but also present nuances on the method that adjusts the degrees of freedom to consider time-series autocorrelation and also between parameter correlation which reduces parameter independence.

Insights from living trees: dendroecology as a tool to investigate timber exploitation and management throughout medieval and modern Occitania (France)

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The Bosca project, led by Nicolas Poirier (TRACES Laboratory, University of Toulouse – Jean Jaurès, France), aims to comprehensively explore wood production, transportation, and use throughout medieval and modern Occitania (France). It seeks to examine historical forest management and exploitation practices to highlight the crucial role that forest ecosystems played for past civilisations and continue to play nowadays. By focusing on three key study areas – the Aure valley (Pyrenees), the Montagne Noire, and the Grésigne – known for their significance as primary wood sources in Occitania during the late Middle Ages and the modern era, the dendrochronological study developed in the framework of this project will first aim to observe ring-width growth tendencies associated with modern sylvicultural practices in living trees. We will focus specifically on oak (*Quercus* sp.) and silver fir (*Abies alba* Mill.), which are the main species used in historical construction in Occitania. In a second step, the study will concentrate on identifying similar growth tendencies in (i) a non-published dendrochronological dataset already existing in Occitania, developed from the analysis of historic wooden buildings in the region, and (ii) a dendrochronological dataset developed within the framework of the Bosca project. Finally, to gain deeper insights into the organisation of timber trade networks along the primary waterways in Occitania (Garonne, Tarn, Aude, and Hers rivers), a dendroprovenancing analysis will be conducted using the established reference chronologies for oak and silver fir in the region. Here, the project's methodology and initial findings from the three study areas mentioned above will be presented.

Are weather-growth relationships heritable?

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Tree-ring analysis is a powerful tool for the assessment of weather sensitivity of tree growth, which has been commonly advertised as complementary for projections of forest growth. Still, due to phenotypic plasticity and local genetic adaptation, as well as the low frequency effects of climatic conditions, the practical application on the weather-growth sensitivity estimates has been quite seldomly reported. Furthermore, sensitivity of growth has been proposed as an adaptation to environmental fluctuations. Given the large-scale nature of climatic changes, forest adaptation to accelerating climatic changes requires proactive management, for which tree breeding has been considered highly effective. the success of breeding, particularly for sustainability, implies on the presence of genetic over the traits crucial for ability to cope with environments as well as of those of economic importance. Commonly, tree morphometric have been the main source of quantification of such traits, however, they represent conditions in the past, which are being outdated. IN this regard, sensitive of growth is a promising trait for breeding for sustainability. Heritability estimates of weather sensitivity of increment was assessed based on provenance trials in the eastern Baltics combining methods of dendrochronology and quantitative genetics addressing inter annual variability and responses to weather anomalies. Various degree of genetic control over growth sensitivity on annual basis was estimated with that for water availability and winter-spring temperature showing the strongest effects. Though, the genetic control regarding weather anomalies was lower, and was particularly related to recovery of trees. These estimates suggest presence of genetic control over the sensitivity of growth suggesting potential for such traits to contribute to breeding for sustainability.

Exploring the climatic responses of several Australasian conifer species and elucidating evidence for volcanic responses through a novel image capture system

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Recent studies, using ring width (RW), blue intensity (BI) and quantitative wood anatomical parameters, have identified strong climate responses in Australasian tree ring records from Tasmania and New Zealand. In this study, using both scanner based, and high-resolution image captured data from an expanded network, we aim to understand if this climate response can be strengthened and whether it is possible for BI parameters to capture volcanically forced cooling, where RW has broadly failed in this region. Six native species are considered in this study (10 sites), *Halocarpus biformis*, *Dacrydium colensoi*, *Lagarostrobos franklinii*, *Athrotaxis cupressoides*, *Libocedrus bidwillii* and *Athrotaxis selaginoides*. In previous studies, all these species have shown some degree of growing season temperature response in BI chronologies, with the exact window of response varying slightly, depending on species and site. Opposite to the Northern Hemisphere, typically the latewood BI summer temperature response is negative, while the strongest response is exhibited in the earlywood BI. Some of these species are very slow growing, providing a challenge for attaining robust BI data from scanned images. The addition of high-resolution BI data using the ATRICS system should, in theory, allowed narrow rings to be more accurately measured, improving the quality of BI data generated. However, while this system has proved useful, at least for measuring narrow rings, which are common in *Lagarostrobos franklinii* and *Halocarpus biformis*, optimising the BI data from these images has been complex, with optimal system settings varying by species. Additionally, like previous studies, the presence of a strong and coherent volcanic response has been difficult to discern. This may be a function of the site's proximity to the ocean, where reduced sunlight hours (resulting from relative cloud cover) mean the impact of (volcanically induced) solar radiation reduction on tree growth patterns may be minimal.

The response of Norway spruce intra-seasonal chronologies to weather variability depicts the impact of extreme drought on growth reduction in 2022 in the Western Carpathians

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The recent decline of Norway's spruce (*Picea abies*) forests in Central Europe has brought attention to the importance of studying forest health and vitality. Climate change, bringing droughts and increased temperatures, is considered the primary driver of dieback and declining health in these forests, along with associated phenomena such as insect outbreaks. The study was conducted on two provenance trials, with a total of 24 trees selected (8 from each provenance). The trees from both sites, regardless of their provenance, were analyzed together. Both sites mainly differed in altitude, resulting in different climates and seasonal weather patterns. The sub-montane site was located at 710 m a.s.l.., while the montane site was between 1150-1200 m a.s.l., and had a colder and wetter climate more suitable for natural spruce distribution demands. Throughout 2019-2023 we performed measurements of stem circumference changes using non-invasive automatic band dendrometers. From the obtained seasonal chronologies, daily increment proxies were extracted. These were further analyzed to understand the effect of weather on seasonal growth dynamics in 2019-2022. Overall, the diameter growth was higher at the mountain site than at the sub-montane site. At the beginning of the seasons in May, the growth at both locations was influenced by temperature, with its influence lasting longer towards summer at the montane site or during individual years. After this, precipitation began to be the most important factor, more at the sub-montane site. June was the most important month for increment formation, especially at the sub-montane site. In 2022, an extreme drought occurred, which reduced the whole seasonal increment by 31-42% at the sub-montane site and 22-29% at the montane site compared to the 2019-2021 seasons. This extreme year led to the death of several trees in 2023, and by the autumn, the entire sub-montane site had experienced massive dieback.

Is the Effect of Drought on Stem Radial Increment Less Intense in Spruce-Larch-Beech Mixed Stands than in Monocultures?

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We analyzed stem radial increment (SRI) and tree water deficit (TWD) in 10 young larch, spruce, and beech mixed and monoculture stands growing in lower altitudes of fertile Czech forests. We selected short distances between stands to keep the same climatic conditions. SRI and TWD were calculated at the single tree level and averaged curves represented stand responses. The main aim was to evaluate growth responses to environmental conditions in 2022 and 2023 and to determine if the presence of larch could mitigate the effect of drought on other tree species. Although precipitation in the growing season (March–September) of 2023 was 9% less than in 2022, we recorded higher mean SRI by 22% in almost all stands. This effect could be caused by uneven distribution of precipitation in spring 2023 (predominantly in March–April). Beeches were affected by climatic conditions at the beginning of the 2023 growing season (later growth) and at the end (growth extended). Spruces were affected too (earlier growth), and larches showed no significant differences between seasons. Beeches in mixtures with larches and spruces exhibited the highest mean increments (497µm). Spruces had the highest mean SRI (435µm) in monocultures and, surprisingly, one of the lowest mean TWD (24µm). Overall, the lowest TWD (13µm–19µm) was recorded in a mixture of spruce and larch. However, the method applied did not detect a response to water stress (TWD = 0µm) in beech. We speculate that automatic dendrometers are not an accurate tool for the identification of TWD in beech. Generally, the highest water stress was observed in larches during both seasons. The differences between seasons in mean TWD were smaller in larch (by 45%) than in spruce (by 69%). In conclusion, the effect of drought on radial increments shows fewer differences between monocultures and mixtures than expected.

Enhanced Land-Atmosphere coupling has caused strong climate signal in tree-ring oxygen record—a case study from Serbia

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Tree-ring stable oxygen isotope ($\delta^{18}O$) has been widely used to reconstruct atmospheric climate and land environment over the past. Climate sensitivity of tree-ring stable oxygen isotopes ($\delta^{18}O$) has been challenged under the context of global land and atmospheric condition changes. Here we developed intra-annual tree-ring $\delta^{18}O$ series from northern Serbia, and each annual tree-ring comprises four parts (parts 1, 2, 3, 4) during 1950–2015. We found the intra-annual tree-ring $\delta^{18}O$ variabilities in all parts are dominated by soil moisture. However, the vapor pressure deficit (VPD) signal in part 2,3,4 has become significant since 1980s, especially in late growing season. The influence of soil moisture on tree-ring $\delta^{18}O$ has also strengthened simultaneously. The stronger atmospheric and soil moisture signal was accompanied by enhanced land-atmospheric coupling since 1980s, which is characterized by enhanced variance of VPD and soil moisture variations in August and June since 1980s. Our findings are valuable for research that aims to explore the influence of land-atmospheric coupling on tree-ring $\delta^{18}O$ record and the ecological response of trees to anthropogenic climate and environment changes.

Growth-limiting climatic factors of historic *Sorbus torminalis* trees in Kyiv, Ukraine

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Wild service tree (*Sorbus torminalis*) stands as a rare and endangered species, protected by law in many European countries. But for its resistance to urban environment, insects and disease, it would not be frequently used in the urban greening, e.g. in botanical gardens, parks, arboretums, and roadside especially outside its distribution range. As an introduced long-living tree species, it serves as an important source of knowledge about species' acclimation process and its growth limiting factors. In Kyiv, the oldest live *S. torminalis* trees have been mainly planted in the botanical gardens and arboretums after the 1950s. Also, a few trees of this species are preserved in front of the historical Liberman's mansion (1880s), and the year of their planting remaining unknown. The dendroclimatological investigations of this species are scarce and have been provided only in Central European forests, within its natural range. Here, we studied remnants of *S. torminalis* alley in a historic area in Kyiv to determine their age and identify the environmental factors that restrict individual tree growth beyond its natural range in, utilizing dendrochronological approaches. Our results showed that the three preserved *S. torminalis* trees were planted posthumously to the last building owner S. Liberman (1917), and they are the oldest of known alive trees of this species in Kyiv. The stationary partial correlation analysis revealed that *S. torminalis* is sensitive to higher air temperature and moisture excess in the period of wood formation in Kyiv. Our findings highlight the historical, cultural and scientific significance of similar studies and propose that the *S. torminalis* species could find extensive use in urban forestry, particularly in regions facing soil moisture deficits.

Growing Through Dry Spells: Unveiling Tolerance Thresholds in Broadleaved and Coniferous Tree Species During Soil Water Scarcity

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Trees depend on atmospheric and soil moisture for growth, exhibiting varying degrees of sensitivity among different tree functional types. Concerning climate change, understanding trees' tolerance to dry conditions is crucial. This study aims to determine the threshold of Consecutive Dry Days (CDD; precipitation ≤ 0.1 mm) and critical limits for environmental parameters, marking the onset of reduced tree growth in response to water scarcity in central Europe. Dendrometer data recording the growth changes of European beech, Norway spruce, and Scots pine in four Bavarian forest ecosystems, underpin our investigation. We investigated changes in stem circumference variations (ΔSV) and environmental variables— precipitation (ΔP), available soil water for trees (ΔASW), soil water potential (ΔSWP), and soil temperature (ΔST) in the root zone between CDD and Consecutive Wet Days (CWD; P> 0.1 mm). The analysis differentiates broadleaved and coniferous species across trees' early (E), main (M), and late (L) increment growth phases. Generalized Additive Models revealed single and intricate interactions among the environmental variables and their effects on ΔSV. Significant random effects emerged for CDD and CWD lengths, alongside the three growth phases, affecting ΔSV of both tree functional types. We determined CDD thresholds and critical limits of environmrntal factors triggering growth reductions. Despite prolonged CDDs in the M phase, *Fagus* experienced a growth depression only in the L phase (CDD_L = 7 days, ΔP decreased by 0.3 mm compared to the last CWD, ΔSAWCL = 3mm). Conifers showed a growth depression after CDD_E = 2, CDD_M = 5 and CDD_L=3 days. Notably, broadleaved and conifers exhibited the highest resistance against drought conditions during the M phase, coinciding with their maximum growth rates. These results are useful for informed afforestation decisions and formulating adaptive forest management strategies in addressing climate change impacts.

Applied Examples of "MultiXdateR

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