TRACE 2021

Tree Rings in Archaeology, Climatology and Ecology

BOOK OF ABSTRACTS

16-17 June 2021

Stockholm University

Lund University

University of Gothenburg

TRACE 2021

Tree Rings in Archaeology and Ecology

16-17 June 2021, Lund, Sweden

Book of abstracts

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Foreword

Dear tree-ring friends,

It is our pleasure to finally welcome you to the TRACE 2021 – Tree Rings in Archaeology, Climatology and Ecology - conference. It has not been an easy task to prepare for the meeting during this pandemic and constantly changing conditions. But the Swedish team together with the Association for Tree-Ring Research (ATR) decided already in 2020, when the pandemic forced us to cancel the event, that we should give it a second try in 2021 instead. When we realized that the pandemic would retain its grip well into 2021, we went from the idea of a hybrid conference to an event completely online. So, this is the first TRACE meeting to be completely virtual. It is indeed sad not to meet face to face, but at the same time it is very climate-friendly with a small carbon footprint, and likely the way many meetings will be conducted in the future.

We hope that TRACE 2021 will be an opportunity to exchange knowledge and experience in contemporary key aspects of tree-ring science. The conference aims at providing a forum for scientist and students that use tree rings as a proxy of climatological, environmental, and cultural heritage studies. In this book of abstracts, a wide range of contemporary tree-ring research from all around the world is presented. These address methodological issues in cross disciplinary and cross-scale studies, while different aspects of tree-ring research ranging from dendroclimatology and forest ecology to tree physiology and dendroarchaeology will be highlighted in four conference sessions.

TRACE 2021 is organized by the three university-based tree-ring laboratories in Sweden linked to Lund University, University of Gothenburg, and Stockholm University, with support from the ATR. We would also like to take the opportunity to thank the organisers of the pre–conference workshops as well as the sponsors and the financiers who made contributions enabling us to provide this conference free of charge.

We warmly welcome you to TRACE 2021!

The Swedish Organizing Committee

Organizing committee

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Björn Gunnarsson	Stockholm University
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TRACE 2021 Conference

Tree Rings in Archaeology, Climatology and Ecology

June 16-17 2021, Lund, Sweden

Wednesday June 16

09:00–09:30 Welcome

Dendrochronology in Sweden – Old Wood in a New Light Database and introduction to different Swedish laboratories and projects presented at TRACE

Johannes Edvardsson, Hans Linderholm, Björn Gunnarson

Session 1 – Trees in a Changing Climate

09:30–09:35 Introduction by chair **Hans Linderholm**

09:35–09:45 **Angela Luisa Prendin** (talk) Influences of summer warming and nutrient availability on *Salix glauca* L. growth in Greenland along an ice to sea gradient

09:45–09:55 **Emanuele Ziaco** (talk) Multi-decadal patterns of terrestrial and aquatic productivity in a sub-alpine lake in the Siskiyou Mountains (California, US)

09:55–10:00 **Andreas Burger** (video) The wetter the better? A first comprehensive assessment of tree growth and climate sensitivity of Ulmus laevis along a hydrological gradient

10:00–10:10 **Ivan Tychkov** (talk) Effect of climate change on the phenology of conifers in Central Siberia

10:10–10:20 **Jen Baron** (talk) Anthropogenic drivers of *Pinus strobus* growth in a protected area since 1950: Evidence from tree rings and carbon stable isotopes

10:20–10:40 Break

10:40–10:45 **Martin Šenfeldr** (video) Dendroclimatological study of *Quercus robur* and Fraxinus angustifolia in floodplain forest ecosystem

10:45–10:50 **Nadezhda Semenyak** (video) Dendroclimatic signals in the pine and spruce chronologies in the Solovetsky Archipelago

10:50–11:00 **Nela Maredova** (talk) Environmental factors driving tree growth responses to climate across NE Asia

11:00–11:05 **Enrico Tonelli** (video) Late frosts effects on Apennines beech forests: insights from tree rings

11:05–11:15 **Philipp Römer** (talk) Fading temperature sensitivity of long tree-ring density chronologies from Corsica (France)

11:15–11:30 Break

11:30–11:40 **Christopher Leifsson** (talk) Functional legacies after extreme drought events in forest ecosystems: a large-scale analysis

11:40–11:50 **Václav Treml** (talk) Trends in climatically-driven extreme growth reductions of *Picea abies* and *Pinus sylvestris* in Central Europe

11:50–11:55 **Martin Šenfeldr** (video) Dendroclimatological study of *Quercus robur* and *Fraxinus angustifolia* in floodplain forest ecosystem

11:55–12:00 **Nadezhda Semenyak** (video) Dendroclimatic signals in the pine and spruce chronologies in the Solovetsky Archipelago

12:00–12:15 Discussion and summary (**Hans Linderholm**)

12:15–13:15 Lunch break

Session 2 – Old Wood in the Limelight

13:15–13:25 Introduction by chair (**Anton Hansson**)

13:25–13:35 **Oliver Nelle** (talk) Of beech and ash – dendroarchaeology of the neolithic lake shore settlement Olzreuter Ried (SW-Germany)

13:35–13:40 **Alar Läänelaid** (video) Ships were made of oak, pine or larch

13:40–13:50 **Marta Domínguez Delmás** (talk) Non-invasive dendrochronology on half ship models from the Rijksmuseum (Amsterdam, The Netherlands) reveals their production dates and shipyards

13:50–14:00 **Coralie Mills** (talk) SESOD: The South East Scotland Oak Dendrochronology project

14:00–14:15 Break

14:15–14:25 **Martin Bridge** (talk) How old is that post-mill?

14:25–14:35 **Anne Crone** (talk) American oak imports to the British Isles in the 18th and early 19th centuries; the dendrochronological evidence

14:35–14:45 **Diogo Cláudio Pavão** (talk) Dendrochronological potential of the Azorean endemic gymnosperm *Juniperus brevifolia* (Seub.) Antoine

14:45–14:55 **Evrim Sahan** (talk) The first tree-ring based fire history of black pine forests in Turkey

14:55–15:05 **Jorge Martinez-Garcia** (talk) Automated 3D tree-ring detection and ring-width calculation from X-ray computed tomography

15:05–15:20 Discussion (**Anton Hansson**)

15:20–15:35 Break

15:35–17:00 **Video & Poster session – Mingle around virtual stands!**

> 3 min video (pre-recorded)

> Poster + 1 min speed presentation

> Chat with presenters online

17:00–18:00 ATR annual meeting (**Organizers, ATR board**)

Thursday June 17

Session 3 – Inside wood

09:00–09:05 Introduction by chair (**Björn Gunnarson**)

09:05–09:20 "Invited speaker" (**Alan Crivellaro**)

09:20–09:30 **Domen Arnič** (talk) Intra-annual variation in vessel features in European beech (*Fagus sylvatica* L.) in years with extreme climate conditions

09:30–09:40 **Alberto Arzac** (talk) Intra-annual density fluctuations beyond the Mediterranean: IADF respond to temperature in southern Siberian pines

09:40–09:50 **Daria Belousova** (talk) VS-Cambium-Developer (VS-CD): new opportunities to quantify a cambium activity of conifer species

09:50–10:00 **Marek Fajstavr** (talk) The intra-annual density fluctuation as an acclimation response to water use efficiency of tracheids in *Pinus sylvestris* L.

10:00–10:05 **Siti Fatimah Hanum** (video) Seasonal growth dynamics of Beech (*Fagus sylvatica* L.) on sandy soils in the Netherlands during the dry summer 2018

10:05–10:20 Break

10:20–10:30 **Jelena Lange** (talk) Forward modelling reveals a complex pattern of climatic control on wood formation in conifers at cold-limited sites

10:30–10:40 **Negar Rezaie** (talk) What can xylem tell about extreme weather events?

10:40–10:50 **Paulina Puchi** (talk) Wood anatomy and tree-ring isotopes reveal hydraulic deterioration as the main cause of Araucaria araucana dieback in southern America

11:50–11:55 **Alba Anadon-Rosell** (video) Effects of dominant moss species on shrub growth and xylem anatomy along a precipitation gradient in the subarctic tundra

11:55–12:05 **Petter Stridbeck** (talk) Growing season changes in Swedish forests – early wakening, early retreat?

12:05–12:20 Discussion and summary (**Björn Gunnarson**)

12:20–13:20 Lunch break

13:20–13:50 Special guest – "Diversity in dendrochronology" (**Valerie Trouet**)

13:50–14:05 Break

Session 4 – Cutting Edge Dendrochronology

14:05–14:10 Introduction by chair (**Johannes Edvardsson, Tzu Tung Chen**)

14:10–14:20 **Eileen Kuhl** (talk) A density provenance model to improve millennium length temperature reconstructions

14:20–14:30 **Miloš Rydval** (talk) High-resolution reflected light imaging for dendrochronology: towards the development of unbiased reflectance timeseries

14:30–14:40 **Jesper Björklund** (talk) Dendroanatomy – a new contender in Dendro-climatology

14:40–14:50 **Paolo Cherubini** (talk) Tree vitality and forest health: any better indicators than tree-ring widths?

14:50–14:55 **Achim Bräuning** (video) A new interdisciplinary approach to illustrate climate change on forest ecosystems

14:55–15:00 **Giulia Resente** (video) Mask, Train, Repeat! Artificial Intelligence for Quantitative Wood Anatomy

15:00-15:15 Break

15:15–15:25 **Rob Wilson** (talk) Evaluating the dendroclimatological potential of Blue Intensity on conifer species from Australasia

15:25–15:35 **Valentina Vitali** (talk) High-frequency stable isotope signals in uneven-aged forests as proxy for physiological responses to climate in Central Europe

15:35–15:40 **Elisabetta Boaretto** (video) Discovery of annual growth in a modern olive branch based on carbon isotopes and implications for the Bronze Age volcanic eruption of Santorini

15:40–15:50 **Cristina Valeriano** (talk) Recovering shifts in drought imprints from tree growth to understand the vulnerability to dieback

15:50–16:00 **Jeanne Rezsöhazy** (talk) Reconstruction of the Southern Hemisphere climate over the past millennium taking into account explicitly the links between climate and tree growth with process-based dendroclimatic models

16:00–16:15 Break

16:15–16:25 **Matthew Goodwin** (talk) Hydroclimate proxies using stable isotopes in grey mangroves (Avicennia marina)

16:25–16:35 **Paula Ballikaya** (talk) Nanoparticle concentration in trees is higher through leaf delivery

16:35–16:45 **Elisabet Martínez-Sancho** (talk) Is ring porosity a favorable strategy for oaks under different climate types?

16:45–17:00 Discussion and summary (Johannes Edvardsson, Tzu Tung Chen)

17:00–17:15 Break

17:15–17:35 Closing session and award ceremony (**Organizers, ATR board**)

Workshops

Maximize the signal to noise ratio from your next talk

Organizer: Alan Crivellaro, Department of Geography, University of Cambridge

Date: 2-4 PM (CET), 1 June & 8 June

DendroTools R package: dendroclimatological analysis using daily climate data and simple nonlinear machine learning methods

Organizer: Jernej Jevšenak, Slovenian Forestry Institute, Department of Yield and Silviculture, Večna pot 2, Slovenia

Date: 10 AM (CET), 15 June

Blue Intensity for Dendroclimatology

Organiser: Rob Wilson, University of St. Andrews, UK & Ryszard Kaczka, Charles University, Prague, Czech Republic

Date: Session A June 11th from 12pm (CET), Session B June 14th from 12pm (CET)

Events

Pre-conference event

Advances in Tree Ring analysis using optimised LA-IRMS

Organiser: SERCON LIMITED

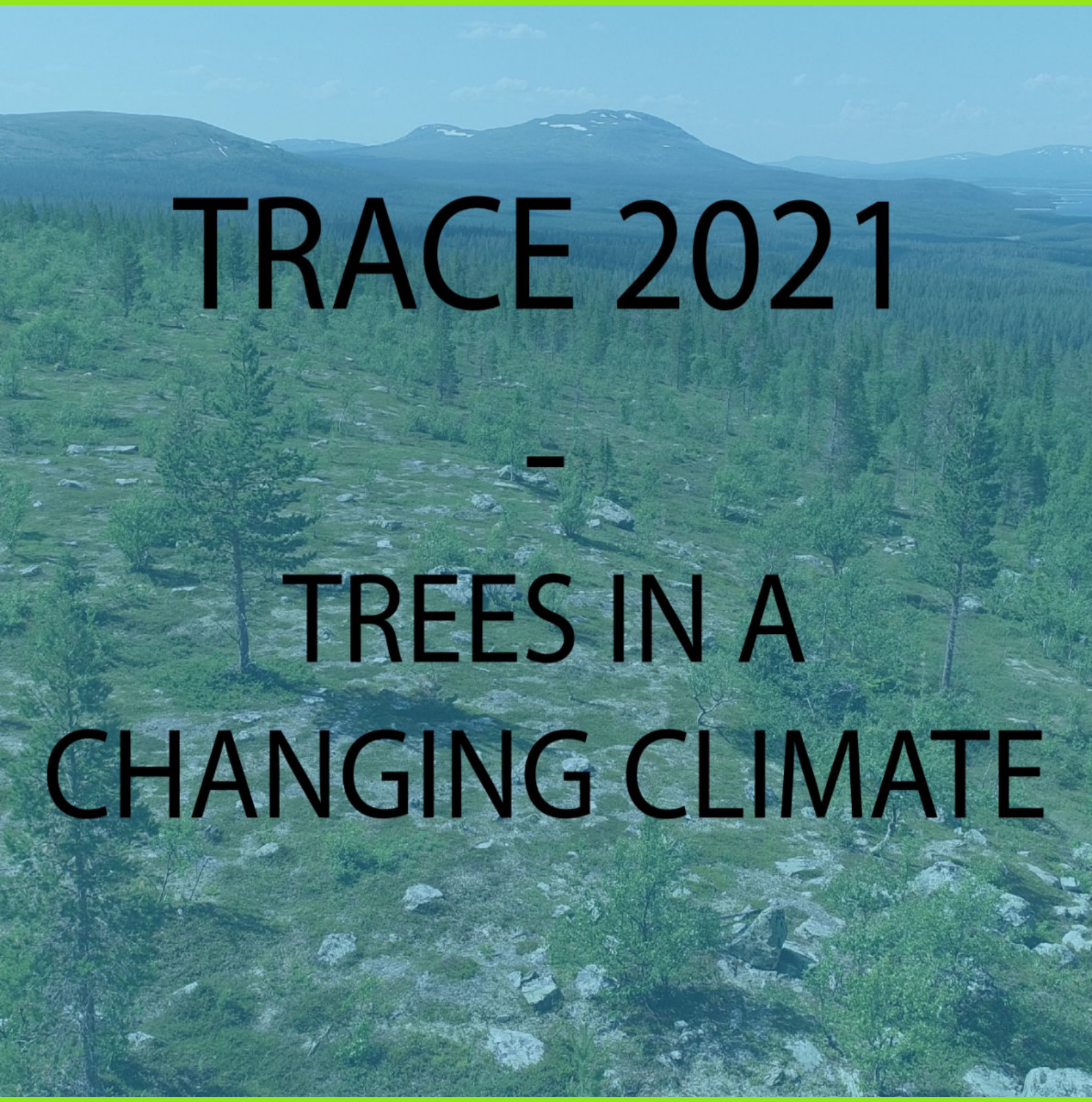
Date: Presentation with Q&A Tuesday 15th June 11am (CET)

Post-conference event

I-BIND - International Blue Intensity Network Development Working Group Kickstart meeting

Organisers: Rob Wilson, University of St. Andrews, UK & Ryszard Kaczka, Charles University, Prague, Czech Republic

Date: 18th of June, 2 pm (CET)



TRACE 2021

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TREES IN A CHANGING CLIMATE

Anthropogenic drivers of *Pinus strobus* growth in a protected area since 1950: Evidence from tree rings and carbon stable isotopes

J. N. Baron[1], L. D. Daniels[1], F. J. Longstaffe[2]

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Anthropogenic climate change poses a significant threat to the composition, structure, and function of protected areas. The Pinery Provincial Park, Ontario, Canada contains some of the most rare, biodiverse, and threatened oak savanna and coastal dune ecosystems in North America; however, it is not well understood how climate change impacts tree growth in this protected area. We quantified the impacts of climate change on *Pinus strobus* (Eastern white pine) growth at the Pinery from 1950–2017 using annual ring-width index (RWI), stable carbon isotope composition of cellulose (carbon), and intrinsic water use efficiency (iWUE). Breakpoint and climate-growth analyses detected significant changes in the growth (RWI, carbon), and iWUE chronologies in the early 1990s and early 2000s associated with shifts in winter and late-spring precipitation, temperature, and standardized precipitation evapotranspiration index (SPEI). Specifically, decreased growth and increased iWUE in the 1990s is associated with dry and warm conditions, while increased growth and constant iWUE through the 2000s is associated with wet and warm conditions. Additional breakpoints in the carbon isotope record distinguish growth phases in the 1950s, 1960s, and 1970–1990s coinciding with management decisions related to infrastructure, pine plantations, and prescribed burns. Based on these results, we suggest that climate change and anthropogenic management have driven growth of *P. strobus* at the Pinery since 1950, with the impact of climate change becoming increasingly important since 1990. We discuss the implications of these findings in the context of future climate change and oak savanna conservation.

Functional legacies after extreme drought events in forest ecosystems: a large-scale analysis

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The threat posed by extreme drought events to the integrity of forest ecosystems is gaining increasing scientific attention. As droughts become more severe and frequent, widespread tree mortality is expected to rise. Temporarily depressed tree-growth after droughts (so-called legacy periods) is regularly reported as a consequence of drought impacts. However, little is known about how droughts change the relationship between tree-growth and climate. Such alterations in the climate sensitivity of tree-growth can help improve our understanding of underlying physiological mechanisms that link drought events and subsequent recovery processes in trees. These insights can ultimately improve both our understanding of tree vulnerability, as well as future projections of tree-growth under climate change.

Here, we identify post-drought deviations in climate sensitivity (CSD) in large-scale tree-ring data networks using the standardized precipitation evapotranspiration index (SPEI). We identify significant CSD during legacy periods compared to non-legacy periods using linear mixed models, and differentiate the responses by anatomical and climatological factors. We explicitly sample for extreme droughts with an ecological response by applying a combined climatological and ecological drought threshold.

Results show that CSD after extreme drought events are widespread but not uniform. The strength and duration of CSD are found to be related to anatomical and climatological factors, revealing a complexity in responses that depend on multiple factors. These results demonstrate a novel layer of drought responses that improve our understanding of tree vulnerability on a mechanistic level.

Environmental factors driving tree growth responses to climate across NE Asia

N. Maredova[1,2], P. Fibich[1,2], J. Dolezal[1,2], O.N. Ukhvatkina[3], A.M. Omelko[3], A.S. Vozmishcheva[4,5], K.A. Korznikov[5], P.V. Krestov[5], Kagawa[6], T. Sakai[6], J.-S. Song[7], N.S. Suzuki[8], P. Janda[9], V. Bazant[9], I. Ulbrichova[9], M. Svoboda[9], M. Macek[1], M. Kopecky[1], T. Hara[10], J. Altman[1]

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[9]*Faculty of Forestry and Wood Processing, Czech University of Life Sciences in Prague, Czech Republic*
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In the context of ongoing climate changes, the variability of tree growth responses to climate has been frequently discussed. However, the environmental factors driving spatially varying growth-climate relationships are still poorly understood. To improve the current understanding, a large tree-ring network consisting of 124 sites was utilized to investigate the effects of various geographical and climatic variables on growth-climate relationships across northeast Asia. The relationships between tree growth and monthly Palmer Drought Severity Index, precipitation, minimum, mean, and maximum temperature were calculated based on Pearson's correlation coefficients. Redundancy analyses were used to investigate how the growth-climate relationships are affected by latitude, longitude, elevation, and climate variables obtained from *TerraClimate and WorldClim dataset. Besides others, the common drivers of all* growth-climate relationships were longitude and precipitation seasonality, having opposite effects over the dormant period. Our findings are essential for projecting future impacts of climate changes on tree growth and developing forest management strategies in northeast Asia.

Influences of summer warming and nutrient availability on *Salix glauca* L. growth in Greenland along an ice to sea gradient

A.L. Prendin[1,2,3], S. Normand[1,2,4], M. Carrer[3], N. Bjerregaard Pedersen[5], B. Elberling[6], U. Treier[1,2,4], J. Hollesen[7]

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Climate warming is not the only abiotic factor currently affecting the Arctic ecosystems. The Arctic vegetation growth responses to environmental gradients and nutrient availability are still poorly understood. Archaeological sites in the Arctic represent unique nutrient hotspots to study the long-term effect of nutrient enrichment. We analysed time-series of ring width of *Salix glauca* L.. collected at nine archaeological sites and in their natural surroundings along an east-west environmental gradient in the Nuuk fjord region, Southwest Greenland.

We assessed the temperature-growth relationship for the last four decades along the ice to sea gradient distinguishing between soils with or without past anthropogenic nutrient enrichment (PANE). The inner fjord sites showed a stronger temperature signal compared to the outermost ones. Individuals growing on the (PANE) soils presented wider ring widths than the individuals growing on the surrounding soils and stronger climate relation especially in the inner fjord sites. Thereby, the individuals growing on the archaeological sites seem to have benefited more from the climate warming in recent decades. Our results suggest that higher nutrient availability due to human activities that took place centuries ago could still play a role and therefore should be considered when assessing growth-drivers of Arctic vegetation.

Fading temperature sensitivity of long tree-ring density chronologies from Corsica (France)

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Maximum latewood density (MXD) from high-elevation conifers can represent a valuable proxy for summer temperatures at annual-resolution. Long-lived black pines (Pinus nigra) from the upper treeline in Corsica are one of the rare opportunities to reconstruct southern European climate variability to medieval times. Here, we present MXD measurements from 20 living and relict black pines, which extend existing chronologies by 386 years towards the past and present. Covering the period 1168–2016 CE, our new MXD chronology contains high- to low-frequency variability and correlates significantly ($p \leq 0.01$) with regional April-July and September-October mean temperatures from 1901–1980 CE (r = 0.52). The observed temperature sensitivity, however, declines towards present ($r_{1980–2016}$ = -0.14). Scaling the MXD chronology against post-1900 CE instrumental temperatures highlights a divergence of 1.76°C between colder reconstructed and warmer measured temperatures in the early-21st century. In suggesting a shift from thermal to hydroclimate constraints, our findings questioned the suitability of MXD chronologies from high-elevation Corsican pines for climate reconstructions.

Trends in climatically-driven extreme growth reductions of *Picea abies* and *Pinus sylvestris* in Central Europe

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Extreme tree growth reductions represent events of abrupt decline of forest productivity and carbon sequestration. The long-term trends in extreme growth reductions are, however, almost unknown. We analysed trends in extreme growth reductions in Central-European conifer species *Pinus sylvestris* (PISY) and *Picea abies* (PCAB) between 1901 and 2018. Twenty-eight sites throughout the Czechia and Slovakia with 1120 ring width series representing high and low-elevation forests were inspected for extreme growth reductions and their link to climatic drivers. Our results show that while PCAB exhibits distinct climatic patterns of extreme growth reductions for high (both temperature and drought-sensitive) and low elevations (drought-sensitive), extreme growth reductions in PISY are a consequence of drought stress both in high and low-elevation forests. Greatest extreme growth reductions were observed at low-elevation PCAB confirming high drought sensitivity of spruce. Long-term trends were characterized by relative stability (PCAB low), stability with abrupt increase in 1970-80s (PCAB high) and slightly increasing (PISY low) or decreasing trend (PISY high). Climatic drivers of extreme growth reductions however changed over time involving decline of low-temperature induced EGRs in 1990s (PISY, PCAB low) or in 2010s (PCAB high) and increase in EGRs caused by growing-season drought (all sites but PISY high). We demonstrated the higher growth volatility at lower than at upper distributional range margin of PISY and PCAB in Central Europe as well as the increase of EGRs triggered by growing season drought not only at low elevation sites but also in upper margin of PCAB distribution.

Effect of climate change on the phenology of conifers in Central Siberia

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Current trends of increasing temperature have a strong effect on the growth of conifer trees, especially in areas where the temperature is a limiting factor. To study these changes and to predict their future effect, we applied the Vaganov-Shashkin model on a latitudinal transect along the Lena River (72–60°N) containing various terrestrial ecosystems (41 sites) for the period 1960–2014. According to the simulations we are confirmed trends to early growth season (0.18–0.19 days/decade) and as a result, an increasing the duration of growing season. The start and end of each growth season were limited by temperature for all sites, but during the middle part of the growing seasons, the limiting factors varied between sites. According to simulation entirety of growth, the season does not limit by one climatic factor. For sites with strong temperature limitations in the middle of the growing season were observed days with soil moisture limitation and vice-versa. For sites with high-temperature limitation (northern sites of the transect), an increase in the duration of the growing season led to an increase in the width of the annual ring, compared to colder years. But for sites with soil moisture limitation, the duration of the season did not have a similar effect and the width was affected more by precipitation and transpiration. The study was supported by the Russian Ministry of Science and Higher Education (projects #FSRZ-2020-0010 and #FSRZ-2020-0014).

Multi-decadal patterns of terrestrial and aquatic productivity in a sub-alpine lake in the Siskiyou Mountains (California, US)

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Understanding the linkages between terrestrial and freshwater ecosystems, including their past and current responses to climatic and environmental changes, is crucial to define effective future ecosystem management strategies. This task is hindered by the lack of long-term datasets of biological and physical parameters for aquatic ecosystems. The Castle Lake Environmental Research and Education Program is a unique example of long-term monitoring programs providing continuous annual series of aquatic productivity since 1959. We compared ~50 years (1961-2010) of forest net primary production (NPP) derived from ring-width chronologies of white fir (*Abies concolor*), lodgepole pine (*Pinus contorta*), and ponderosa pine (*Pinus ponderosa*) from the Castle Lake basin with aquatic productivity to investigate patterns of variability in terrestrial vs. aquatic NPP and their environmental drivers. During the period 1970-2000 terrestrial and aquatic NPPs were clearly decoupled, whereas moderate coupling was observed in the period 1961-1970 and after the year 2000. Drought stress (vapour pressure deficit) in a 57-days period between July 8th and September 2nd, would determine a drop in forest productivity in the following year, while aquatic productivity showed a positive correlation with current spring temperature and a negative effect of January precipitation, with a thicker snowpack delaying the date of ice melt. Our work is opening new opportunities to broaden the understanding of combined responses of terrestrial and freshwater systems to regional and continental climatic patterns (i.e. ENSO; PDO), providing the basis to assess the vulnerability of these systems to future climatic changes and plan effective mitigation strategies.

Endless growth: warmer climate induces double tree-ring growth of Siberian pine on Khamar –Daban

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The Khamar-Daban mountain range stretches 350 km along the southwest of Lake Baikal. Its northern macroslope is covered with dark coniferous mixed forests, with a local Siberian pine dominance (*Pinus sibirica*). Massive dieback of Siberian pine has been observed for the last several years in the region. Increasing temperatures and reducing precipitation negatively affect tree resistance. As a result, the forests get exposed to pathogens to a large extent. However, there have been no cases of Siberian pine dieback at the lakeshore part of the range until now.

A field study of pine stands was conducted in the summer of 2020. The visual assessment showed crown drying, intensive resin flow, and insect damage. A detailed examination revealed the root system destruction and the presence of "wet wood."

For climatic analysis, we used data from the Babushkin weather station and the nature chronicle of the Baikal Nature Reserve. We did dendrochronological research of dying trees in the coastal zone of Lake Baikal and healthy trees in the Baikal Nature Reserve territory. Cores were taken from 30 trees. Changes in ring width correlated with late summer and autumn temperatures and summer precipitation. Investigating wood samples, we found anomalies of tree ring structure in the form of "double growth" and "false ring". Such anomalies are typical both for trees on experimental routes and for the reserve (control). We suppose these anomalies are indicators of increasing growing season length due to the warmer first half of autumn and warmer temperatures in the autumn-winter period in general, and more frequent winter thaws.

Phenological shifts in southern Siberian pone growth compensates warming-induced drought stress

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Temperature is considered the driver factor of tree growth in boreal regions. However, the importance of soil moisture increases with decreasing latitude. Here, we combined dendrochronological measure-ments with evidence from tree growth modelling (VS-model) and remote sensing (MODIS) to quantify changes in the climate sensitivity of *Pinus sylvestris* L. growth and phenology along a latitudinal gradient (56–53°N) of increasing drought in southern Siberia (Russia) between 1960 and 2017. We find tree growth predominantly depends on soil moisture availability, although the timing and intensity of the climate sensitivity were earlier and stronger at the southern site. Moreover, the climatic control intensity decreased in recent decades, suggesting more favorable growth conditions. VS-model phenology simulations were verified by MODIS estimation between 2001 and 2014. Results suggested an advance of the starting of growing season along the whole gradient, at a rate of 5.6 days/decade in the southern site in recent time. Our study reveals that earlier growing season onset triggered by warming springs might compensate much of the expected growth reduction by drought stress later in the season. These results suggest that *P. sylvestris* is adjusting its growth and phenology as a response to changing climate conditions by shifting the timing of the starting of the growing season to a favorable climate window. However, we speculate that predicted climate change will likely exceed the species' physiological tolerance in much of Eurasia's forest-steppe by the end of the century. The study was supported by RNF 18-74-10048 and FSRZ-2020-0014.

Changes in climate – radial growth relationships after the reservoir construction – a case study of Norway spruce and Siemianówka Lake (E Poland)

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The study examined the influence of Siemianówka reservoir (E Poland) construction that finalised in 1990 on the growth of Norway spruce (*Picea abies* L.) with the special interest in its dependence on the climate – radial increment relationships. We sampled 3 sites within the reservoir vicinity, and 1 site located downstream the Narew river, which was assumed to be already beyond the possible range of the reservoir impact. At each site we selected 30-40 dominant trees and took single increment core from the breast height. Obtained samples were measured and residual chronologies were developed. Later on we correlated increment indices with precipitation and temperature data acquired from E-OBS v17.0 database. In general radial growth of analysed Norway spruces was influenced by precipitation in May and June of the year of tree-ring formation, as well as by temperature in winter and spring. The Siemianówka reservoir construction changed sensitivity of the investigated trees to precipitation and temperature. The relevance of the influence of precipitation on their radial growth increased, whereas the impact of temperature decreased. We indicated 3 negative pointer years (all after the reservoir construction) that were common for all the analysed sites. They were caused by the low precipitation, which confirmed high vulnerability of Norway spruce to moisture shortage.

Effect of competition reduction on the radial growth of different species in the south of Alps

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Forests play a significant role in climate change mitigation through the capture of CO_2 from the atmosphere and the fixation of C in biomass. The strong connection between forest structure, microclimatic parameters, and tree ecophysiological behaviour, is well known. In mature stands, characterized by closed canopies, silvicultural interventions modify the forest structure, consequently also the micro-climatic conditions, and competition (e.g. light and nutrient). After the silvicultural treatments, a stem radial growth stimulation can be observed, which could be related to an increase of light, soil water, and nitrogen availability.

In this context, among the activities of the project LIFE CLIMARK, we conducted a study with the aim to evaluate the effect of silvicultural treatments on tree growth. The specific objective was to evaluate the effect of the competition reduction on the growth of different species, growing at similar climatic conditions. Hence, in a pure beech and in a mixed (spruce, fir, and larch) forests, subjected to different treatments options, we collected wood cores inside permanent plots, where all tree positions were measured. The objective of the study was to evaluate the response, in term of growth, to different silvicultural treatments of different species.

Tree-line dynamics of *Abies spectabilis* in the summer monsoon dominant region of western Himalaya

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The Himalayan region is characterized by multifaceted tree-line structures growing under different climatic regimes. Assessment of future response and sustainability of tree-line forming taxa towards unprecedented global warming requires the understanding of their dynamics in past, beyond the observed records. Using tree-rings we investigated the age stand structure and tree-line dynamics of *Abies spectabilis* (silver fir) presently forming the upper conifer limit in the summer monsoon (ISM) dominant valleys, Tungnath and Triyuginarayan in Uttarakhand, and Chanshal in Himachal Pradesh. The recorded fir trees of ~462 years age at ~3280 masl elevation in Tungnath; ~292 years age at ~3318 masl in Triyuginarayan and ~370 years age at ~3460 masl in Chanshal confer that in the ISM dominant valleys of Himalaya this species occupied the elevations of 3300 and 3400 masl between 1550 and 1750 C.E. time frame, which corresponds to the globally known Little Ice Age (LIA) phase. In the ISM dominant Himalayan region the less intense LIA phase as compared to higher latitudes of north Atlantic regions might have provided climatic conditions favorable for tree-line advancement. Subsequent post LIA densification of conifer forests at those altitudes was followed by a slow advancement rate or even stagnant tree-lines reported in few valleys during 20th Century C.E. The moisture stress conditions in dry months at higher altitudes due to conspicuous temperature rise could be the environmental factor governing the tree-line dynamics. Moreover, the topography, unfavorable soil conditions and anthropogenic activities are also altering the climate ridden tree-line dynamics.

Current state and resilience of three main tree species in Southern Germany with regard to drier and hotter weather conditions over the past 50 years

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Bavaria in southeastern Germany represents a diverse topographical region and differs significantly in the growing conditions for forest ecosystems due to varying altitudes and climatic conditions. To investigate the current condition of tree species in this region, one deciduous and one coniferous tree species were studied in each of three middle mountain ranges and three corresponding basins. Climate-growth relationships over the past 50 years between climate proxies and tree ring widths were examined using response analysis. By comparing two 25-year sub-periods, the temporal stability of tree responses in climate growth correlations was assessed. Additionally, tree responses to climatic extreme events were analysed using pointer year analysis. First results indicate that although European beech (*Fagus sylvatica*) and Norway spruce (*Picea abies*) benefited from a prolonged growing season at high altitudes, each species at every study site evinced a high vulnerability to drought events. Especially, Scots pine (*Pinus sylvestris*) at low elevation sites showed strong negative responses to the latest drought years, but also trees in humid areas revealed a noticeable increase in drought stress. As tree responses strongly differed among species and locations, a combination of dendroclimatological results and climate modelling efforts is essential to assess the spatial heterogeneity of climate change effects within a topographically diverse region like Bavaria. By analysing growth responses to specific weather types, and by modelling their changes in frequency under climate change conditions, an improved forecast about future growth conditions is envisaged.

Changes in tree growth synchrony in Siberian *Pinus sylvestris* forests are modulated by fire dynamics and ecohydrological conditions

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Boreal forests account for one-third of the total forested lands on Earth, thus they play an important role in carbon cycling and climate regulation at global scale. Wildfires constitute one of the major disturbances of the boreal ecosystems. Fire regime has intensified during the last decades in some boreal regions such as south-western Siberia, which also holds the largest peatland area in the world. Following a dendroecological approach, our study aimed at exploring spatial synchrony of tree growth in forest stands located in that region inhabiting sites subjected to different fire regimes and substrates: mineral soils with fire disturbances (MB), mineral soils without fire evidence (MU) and peat soils (P). In addition, fire impact on tree growth at MB sites was reconstructed since late 19th century, as well as, post-fire growth legacies. Tree-ring suppressions pointed to 1952, 1967, 1977, 1983, 2003 and 2012 as potential fire years. Spatial synchrony of peatland sites was higher than that of mineral soil sites. Both MB and MU sites showed a positive temporal trend of growth synchrony driven by an increasing growth responsiveness to precipitation. However, trend of MB synchrony turned negative after mid-1980s, which could be related to a loss of climate sensitivity of the trees and increased fire frequency in the region. Legacy effects on growth lasted from one to four years after fire and were positively related to tree age and negatively to tree diameter. The retrospective analysis of tree growth may contribute to a better understanding of changing fire dynamics and its impact on contemporary terrestrial carbon cycling.

Tree-ring-based hydroclimatic reconstruction for the northwest Argentine Patagonia since AD 1055 and its teleconnection to large-scale atmospheric circulation

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Moisture availability has a significant influence on the dynamics, stability and function of terrestrial ecosystems. In this study, we use wood samples from 260 *Austrocedrus chilensis* trees growing in northwestern Patagonia to reconstruct the Standardized Precipitation Evapotranspiration Index (SPEI) for the last millennium (1055 - 2014). Our reconstruction explains 41.6% of the variance contained in the November-December SPEI at a 1-month scale for the period 1930-2013. The SPEI reconstruction provides a long-term record of pluvial and drought events for the periods 1055-1300, 1550-1700, and 1900-2014. Although the SPEI reconstruction indicates that the frequency of extreme events has increased since 1950, our record indicates that current levels have not exceeded previous levels, particularly those recorded around the Medieval Warm Period and toward the end of the Little Ice Age. The spatial and temporal relationships associated with the South Annular Mode and the Pacific Sea Surface Temperature variability as expressed by the Tripole Index indicate that the temporal variability observed in the SPEI reconstruction is modulated by hemispheric-scale atmospheric circulation dynamics. These climate forcings are likely responsible for the intensity and the rate of occurrence of extreme weather events in northwestern Patagonia. Furthermore, the SPEI reconstruction shows a spatial and temporal pattern similar to that observed in previous PDSI-based reconstructions. This study provides robust evidence of hydroclimatic variations for extratropical sectors of South America, improving our knowledge of the climate dynamics during the last millennium and allowing us to review the recently observed increase in wet and dry events in a long-term historical context.

What is the delay in growth reaction and climate response after the disturbance of a light-demanding species- the European larch (*Larix decidua Mill.*)?

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The aim of this study was to analyze the radial growth response of the European larch (*Larix decidua* Mill.) on windthrow after 15 years. We raise the following questions: how quickly can a light demanding tree species benefit from an open stand in a post-disturbance plot? Does the occurrence of the catastrophic disturbance change the growth of surviving trees' response and their sensitivity to the climate? This study is based on cores from 83 larches collected from a post-disturbance area in the Slovakian High Tatras. The time lag between the disturbance event and release was related to DBH, age and tree's previous growth. The time lag between the year of event and of growth reaction was 4.6 years on average and 4 years by median in a multi aged group of trees. The climatic analyses were conducted using a residual chronology. The most noteworthy change in the reaction for temperature is visible during the last ca. 15 years, when the positive influence of temperatures of May and June disappears, and the significant negative influence of July temperatures occur. Light demanding tree species may react to canopy opening with a substantial delay, which can be a result of environmental stress. The growth reaction of larches for climate after windthrow can be compared to a shift towards a lower elevation in a mountain environment, where mid-summer high temperatures and a shortage of water are limiting factors of growth.

The buffering effect of Lake Baikal alleviates climate impact on *Pinus sylvestris* L. radial growth

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Large lakes play a significant role in regulating local and regional climate conditions. Since climate influences tree-ring formation, it is expected that Lake Baikal's thermal mass will potentially impact tree growth in the surrounding areas. In this study, we aimed to determine the influence of Lake Baikal, the world's largest by volume freshwater reservoir, on *Pinus sylvestris* L. secondary growth by modifying climate conditions and alleviating climate limiting factors of tree growth in its surrounding area. We evaluated the variability in the climate response of pine tree-ring, earlywood and latewood widths to temperature, precipitation and relative humidity in four sites (two inland and two coastal sites) in the Baikal region for the 1960–2016 period. An increasing negative effect of summer temperature and a positive effect of relative humidity on tree growth along the assessed period of time were observed especially at sites away from the lake. The results suggest that Lake Baikal's water mass mitigates the climate control on tree growth by acting as a thermal and hydric buffer in the downwind coastal sites. Particularly, Lake Baikal stabilizes the relative humidity throughout the year, protecting coastal trees from low water availability. Our results also confirm the high plasticity of *P. sylvestris* to thrive in different environmental conditions. That will probably allow for a better adaptation of that species to the projected warmer regional climate as compared to non-drought-tolerant species inhabiting the same region. Supported by RNF 18-14-00072, FSRZ-2020-0014 and RFFI 20-44-240002.

Variability in climate-growth reaction of *Robinia pseudo-acacia* in Eastern Europe

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As a consequence of native tree species decline and distribution range contraction in Europe, acclimation of the non-native tree species at the edge of their distribution is gaining importance. The spatiotemporal pattern of secondary growth and climate sensitivity among six black locust stands along continentality gradient in Eastern Europe were investigated to demonstrate site-specific growth reactions of black locust populations that may indicate species plasticity in adapting to future conditions. We have demonstrated that despite comparable bioclimatic conditions, climate sensitivity of black locust populations is highly variable, both temporally and spatially. The winter and spring temperatures appear to be the main climatic drivers of the growth pattern. In turn, previous winter and current summer precipitation appear to be the main discriminatory climate factors. Divergent growth reaction of black locust stands implies high plasticity of secondary growth and thus high probability of acclimatization to future climate. This should be considered when formulating non-native species management strategies in line with sustainable forestry.

Growth trends of silver fir, European beech and Norway spruce in the Carpathian Mountains

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As important primary biomass producers, woody plants form an essential part of the strategy for current climate change mitigation. Quantification of growth trends can infer on different potential of tree species to adapt to climate change and thus contribute to the mitigation strategy. In this study we present growth trends of the three main tree species forming the Carpathian forests: *Fagus sylvatica* L., *Picea abies* L., *Abies alba Mill.*. Using state-of-the-art dendrochronological methods, we examine the growth trends in the past and predict their possible development in the future. For this study, we used over 1800 cores sampled in the Low Tatras, Polana, northern and southern Romania. To find out the differences in the current productivity levels between different parts of the Carpathians, we developed height-diameter (H/D) curves. We subsequently quantified trends in basal area increments (BAI) over the period of 1950 - 2019 along an altitudal gradient, of trees in different vertical (social) position. Moreover, BAI trends were compared between pure and mixed stands.

Tree age and size outperform topographic effects on growth trends and climate responses in Central European coniferous forests

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Trees do not respond to climatic conditions uniformly, but instead show individualistic growth responses. The extent of and causes behind this within-stand variability represent significant uncertainty in predictions of how forests will respond to future climate change. We analyzed patterns of individualistic tree growth within two types of conifer stands of Central Europe – high-elevation *Picea abies* and low-elevation *Pinus sylvestris* forests. We quantified the relative effect of age, size, competition, topographic conditions, and between-tree distance on variability in growth patterns and climate-growth responses using principal component analysis and linear models. Our results show that *Picea abies* stands with dominant temperature limitation exhibit greater growth coherency than *Pinus sylvestris* stands characterized by drought-limited growth. Growth variability and individual climate-growth responses in both forest types were mainly driven by tree size and age, while the effect of topographic conditions was marginal. Drought-limited *Pinus sylvestris* stands exhibited higher sensitivity to climate forcing for juveniles compared to mature trees, while the relationship was inverse at temperature-limited *Picea abies* stands. In both forest types, climate sensitivity changed over time with increasing tree age. Our results indicate that age- and size-specific growth responses to climate can cause the temporal instability of climate-growth correlations and growth trends at stand level as a result of changing age and size structure over time. We suggest that data sets used for large-scale assessments of growth trends and climate-growth responses should be carefully selected considering age and size homogeneity of samples.

Provenances of Scots pine—what to expect regarding the plasticity of weather-growth responses?

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Climatic changes are causing substantial ecological, as well as economic consequence to forests across vast areas, thus portraying the necessity for the adaptive climate-smart management. In this regard, assisted gene transfer and/or migration have been identified as highly effective means to mitigate the effects of global changes. The goal of such management is to propagate forest reproductive material, ecological requirement of which match the projected environmental changes in the future. For this, comprehensive information on growth responses to environmental fluctuation and, particularly, weather across climatic gradients is desirable, thus improving the robustness of long-term extrapolations. Populations and metapopulations of trees have evolutionary adapted to certain conditions resulting genetic specialization, hence the changes in climate might trigger disproportional responses. Accordingly, nonlinear responses to tree-ring width to weather fluctuations have been observed across regional climatic gradient. Several provenance trials assessing performance of diverse metapopulations of trees under variety of climates have been recently revised as the source of information regarding the local specialisation and its potential for adaptive management. Furthermore, the coupling of the provenance trials with tree-ring analysis across climatic gradient can identify the genetic specialization of metapopulations in terms of plasticity of growth responses highlighting differences in adaptability.

Differences in drought sensitivity of tree ring series between generative and coppiced *Quercus petraea* trees

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Coppicing was abandoned in North-Western and Central Europe in last century. Return to this type of management is now discussed due to conservation of biodiversity, biomass production and adaptation to ongoing climate change. But there is only little information about differences in climate sensitivity between generative and coppiced oak trees. Therefore, the aim of this study was to detect the differences between climate sensitivity in tree ring series between generative and coppiced *Quercus petraea* trees. We hypothesised that generative trees will show stronger precipitation signal compared to coppiced trees as generative are more sensitive to drought due to their lower ratio of roots to aboveground biomass. We sampled trees at three different sites across Czech Republic. At each site, we created robust tree ring chronology both for category of generative and coppiced trees (in total six site standard chronologies). Then, we calculated correlations between indexed tree-ring widths and monthly climatic variables (precipitation, SPEI - Standardized Precipitation and Evaporation Index) for the period 1930 - 2018. Trees at all sites showed similar climate signal. Both categories showed strong precipitation and SPEI signal (significant correlation in May – July), but this signal was slightly stronger for generative trees, since they were significantly correlated in more monthly climate parameters.

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Preliminary assesment *of Araucaria araucana* resilience to extreme drought events

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Extreme climatic events represent disturbance factors shaping forest dynamics, inducing decline in growth and die-off episodes, furthermore modifying tree resilience. *Araucaria araucana* (Molina) K. Koch, an iconic northern patagonian conifer, is considered an endangered species according to IUCN classification. We applied dendroecological and statistical methods to reconstruct resilience, in terms of resistance and recovery, of 10 forest stands to three successive extreme dry spells occurred during the 20th century, with particular attention to site conditions (xeric vs. mesic environments). Resistance and recovery showed differences along the considered dry spells, with a decrease in resistance for the more recent drought, whereas recovery values on the opposite showed an increasing trend. Xeric woodlands were less resistant than forest located in mesic areas, while recovery did not show any difference among the selected environments. At the tree-level, we found an inverse relation among resistance and recovery indices in xeric stands, suggesting possible different strategies when facing extreme droughts. Resistance (recovery) in both environments was positively (negatively) associated with tree growth, represented by basal area increment values. Tree age positively influenced growth resistance but only in mesic environment. These findings suggest that the *A. Araucana* is less resilient to extreme droughts in xeric than in mesic environments. The expected increase in frequency and intensity of extreme drought for northern Patagonia suggests that the emerged results should be considered in conservation plans of this natural resource.

Age and altitude influence on Norway spruce response to climate

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In this study, it was analysed the variability of Norway spruce tree growth response to climate in relation to age and altitude, in the Gheorgheni region (Eastern Carpathians). The general climate in the study area is specific to mountain regions with frequent thermal inversions. A number of 1138 tree-ring samples were analysed, distributed in three age categories: under 60, between 60 and 100, and over 100 years; the samples were also divided into three altitudinal categories: below 1200 m, between 1200 m and 1400 m, and above 1400 m. Climatic dates were provided by a local weather station situated in the Gheorgheni region. Our results have shown a positive and significant correlation between average temperature and tree-ring width index in January and March of the current year and September of the previous year for trees under 60 years and no significant correlation for older trees. Precipitations values in September of the previous year are positive and significantly correlated with the tree-ring width index for trees under 60 and over 100 years. For lower altitude (below 1400 m), precipitation in April current year and June of the previous year are a limitation factor for Norway spruce growth.

Has the Norway spruce growth rate in diameter changed in recent decades? Case study on Norway spruce from Gheorgheni region (Eastern Carpathians)

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Accelerated growth processes, in diameter and height, in recent decades have been found in the main forest species at European level. The present study brings scientific arguments regarding the modification of the diameter increment in Norway spruce from the Gheorgheni depression, by applying the retrospective analysis based on the variation of the tree ring width. The research is based on information on radial growth from 1147 spruce trees in 49 research sites covering various ages and growing conditions. The results obtained showed statistically significant differences between the breast height diameter from 1901-1940 and that from 1941-1980, respectively 1981-2019, for all reference ages considered (20, 40, 60 and 80 years). The breast height diameter of spruce in the Gheorgheni depression at the age of 60 is 37 cm in the period 1981-2019, being 22% higher compared to the period 1901-1941 (29 cm). The change in the radial growth rate follows a variation similar to the evolution of the thermal regime during the vegetation season, characterized by a succession of periods with slight heating until the 1940s, cooling in the period 1940-1980, and significant warming in the last four decades.

This study was conducted under the project CRESFORLIFE (SMIS 105506), subsidiary contract no. 5/2018, co-financed by the European Regional Development Fund through 2014-2020 Competitiveness Operational Program.

Early summer temperature and precipitation (but not sea surface temperature) influence *Juniperus* growth at Faroe Islands

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Climate change is observed and predicted to profoundly affect the northern ecosystems. The variations of the North Atlantic Oscillation, the Arctic sea ice loss, the increasing in temperature and summer precipitation are influencing these temperature-limited environments at faster rate than global average. Growth responses of northern shrubs, especially the ones growing in coastal region, could be used as a yearly resolution proxy for Sea Surface Temperature (SST) due to the close link between ocean and costal climate.
In this study, we investigate the climate sensitivity of the common juniper (*Juniperus communis* L.), one of the most widespread conifer in the northern hemisphere. We analysed ring width time series of 92 individuals collected in Svinoy, Faroe Islands and assessed the associations with several atmospheric and oceanic climate parameters over the last century (1900-2019).

We were able to build a chronology of almost two centuries, currently representing the longest ring width record across the whole archipelago. Despite the high inter-individual variability, typical of this species, the analysis shows a consistent and negative role of early summer temperature (June) and precipitation (July) for shrub growth. On a contrary, ring width showed no significant correlation with SST.

Further analysis on northern and southern North Atlantic Currents variation in a larger area could potentially improve the significance of our results. Juniper demonstrated to be an excellent environmental proxy and, within a larger network, could be fruitfully considered for climate reconstruction.

Contrasting climate sensitivity of ring width, maximum density, and xylem anatomical traits of *Pinus cembra* L. growing at treeline in South-Western Carpathian Mountains

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In this study, we explored the dendroclimatic potential of Swiss stone pine in the Romanian Carpathians through the conventional parameters of tree-ring width, maximum density, and anatomical-traits chronologies. For this, 28 mature living trees were sampled in the Retezat Mountains, South-Western Romania close to the treeline, and nine were selected for anatomical analysis that was performed on the same cores as maximum density and tree-ring width measurements. Moreover, to improve the time resolution of the climate growth relationships, each ring was split into 10 intra-ring sectors and resulting chronologies were contrasted with daily climatic data. Except for tree ring width, all chronologies showed a strong positive or negative response to the climatic factors of the previous or current year. Cell wall thickness featured similar correlations with climate as the maximum density and was mainly influenced by temperatures at the start of the growing season and during summertime, whereas the lumen area seemed mostly affected by precipitations. The higher time resolution given by the 10 sectors allowed us to discover that different tracheid rows, according to their position in the ring, can be influenced by distinct climatic windows, moreover, the same anatomical traits can be sensitive to different climatic parameters along the seasons. This study showed that analysis of xylem anatomical traits at the intra-ring level and the use of daily temperature records along with customary dendrochronological parameters can provide insightful information into the long- and short-term climate influence on the xylem structure of Swiss stone pine.

Drought resistance for conifer species decreased when droughts are early, prolonged and intense

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It is becoming increasingly apparent that severe droughts have reduced forest productivity and trigger tree mortality. Conifer species contribute to nearly one-third of the global forest carbon stock. Drought triggers tree mortality across the globe due to embolized cavitation, and it is important to know how conifers are resilient to drought. This study evaluates drought effects on resilience for 20 conifer species in a common garden experiment by quantifying their three growth resilience indices, i.e., resistance, recovery and resilience. We found that drought leads to reduced growth (82% of species), but conifers are highly resilient (80%) drought, which means that there are no legacy impacts (e.g., embolism, reduced leaf or crown loss). Drought resistance decreased when droughts occurred earlier in the year (for 65% of the specieD), or when water deficit was strong (55% of species). Drought severity had especially negative effects on drought resistance of *Picea* and *Larix* species. Surprisingly, hydraulic traits cannot explain the resilience of conifer species. Our study provides a portfolio of species to better manage towards resilient and climate-smart forests under changing climate conditions.

Different Nothofagus species from southernmost Fuego-Patagonia/Chile record AAO signals

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For the region of southernmost South America (Fuego-Patagonia), information about current changes in climate is still comparably scatchy. In addition, reliable instrumental climatic records are scarce, short and incomplete precluding a comprehensive description and quantification of climate variability in a longer temporal perspective. This holds especially true for the areas of southernmost Chile, namely Fuego-Patagonia. Trees as natural recorders of climate variability can help to overcome these limitations. Tree-ring width series from Patagonia were successfully used to reconstruct temperature and atmospheric circulation patterns. The present work seeks to study climate variability and the influence of the Antarctic Oscillation Index (AAO) on the radial tree growth of *Nothofagus betuloides* and *Nothofagus pumilio* forests situated in southernmost Chile.

For our investigation area in southern Chile, we successfully developed seven tree-ring width chronologies based on two southern beech tree species (*Nothofagus)*. The investigation regions are i) the surroundings of Punta Arenas (*N. pumilio;* 53°9'36"S, 71°1'54"), ii) the Yendegaia National Park (*N. pumilio*; 54°50'17"S, 68°45'17"W), and the Isla Navarino (*N. pumilio* and *N. betuluides;* 54°58'50"S, 67°36'23"W). Investigation of climate-proxy relationships reveal significant correlations with air temperature, relative humidity and large-scale effective climate phenomena like the Antarctic Oscillation. In contrast, the impact of precipitation on tree-growth in Fuego Patagonia is comparatively weak. All our chronologies were investigated for common growth patterns, and correlated with global and regional climatic variables. To test supra-regional representativity, we compared our findings with other regional TRW chronologies. Our results underline that the local tree species *N. betuloides* and *N. pumilio* can serve as reliable proxies recording climate variability during the last few centuries in southernmost Fuego-Patagonia.

Spatiotemporal changes in climate response of declining Norway spruce

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The aim of the study was to investigate the spatiotemporal changes in growth – climate relationship of spruce stands in Northern Moravia - the primary focus of recent spruce decline in the Czech Republic. We expected increasing sensitivity of trees to summer temperatures and precipitation. We hypothesized that (1) the pattern of climate response depends on altitude and soil moisture conditions, and (2) changes in climate response can serve as 'early warning' signal on the susceptibility of trees to bark beetle attack.

In 2018 increment cores were taken in Nízký Jeseník highland and at the foothills of Hrubý Jeseník and Beskydy Mountains. In total 14 spruce stands located along an altitudinal gradient were sampled. Where possible, pair sampling sites (wet and normal) were selected.

Key role in growth dynamics was clearly visible within the summer months with significant response to seasonal J-J-A precipitation for all plots in Nízký and Hrubý Jeseník regardless of altitude and soil moisture conditions. The response to climate was unstable over time at both site and regional level. A significant positive response to summer precipitation has been observed since 2001 for sites up to 700 m a.s.l., for sites located in higher altitude it was only after 2015. The spatiotemporal pattern of the increasing sensitivity to summer drought corresponds to the spreading of bark beetle in both areas. In contrast, spruce in Beskydy was not limited by summer precipitation throughout the analysed period, nevertheless, since 2015, bark beetle gradation have been observed even here.

Drought is not death warrant: growth stability of Siberian larch in South Siberian forest-steppes

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In moisture-limited regions where droughts leave a significant "footprint", monitoring of quantitative climatic parameters and of forest adaptation and acclimation to these parameters is of utmost importance due to the ambiguity of spatial patterns in reaction of tree growth to drought and the variety of drought resistance strategies exhibited by trees. This is a case study of Siberian larch (*Larix sibirica* Ledeb.) radial growth in forest-steppe along the foothills of the Bateni Ridge (Kuznetsk Alatau, South Siberia), its climatic response and stability under the influence of droughts. In this region, moisture deficit is increasing due to warming of the vegetative season by 0.14–0.19°C per decade; droughts were observed in 1951, 1963-65, 1974-76, and 1999. At five sampling sites, dependence of larch tree-ring width (TRW) on precipitation and standardized precipitation-evapotranspiration index (*SPEI*) during April–July of the current year and June–September of the previous year and on maximum temperature during current May–July and previous July–September was revealed. We propose the use of a linear regression model TRW(*SPEI*) as an individualized indicator of climate aridity, biologically significant for larch in the study area. Larch in the study area tolerates moisture deficit, rebounding after the end of stress exposure. The spatio-temporal patterns of the stability indices revealed that despite the decrease in growth resistance and resilience indices with drought severity, these characteristics are higher at more arid sites.

The wetter the better? A first comprehensive assessment of tree growth and climate sensitivity of *Ulmus laevis* along a hydrological gradient

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Global change in general, and the recent drought years in particular, have negatively affected forest vitality in Central Europe. In this context, structurally and compositionally diverse forests are gaining importance as well as less common tree species that might contribute to resistance and resilience of forest ecosystems.

Therefore, we assessed the possibly misjudged and hardly studied tree species European white elm (*Ulmus laevis* Pall.) in northeastern Germany. Contrary to its reputation, *Ulmus laevis* is described in the literature as unaffected or minimally affected by Dutch elm disease, as a trigger for species diversity, and as a tree with notable growth rates being a source of valuable timber.

We collected tree cores and obtained measurements of nine tree/stand parameters from 160 trees of different ages, along a hydrological gradient on both mineral and organic soils. Using tree ring-widths, we aim to identify climate signals and correlations focusing on different hydrological regimes.

First results point towards higher radial growth rates on mineral than on organic soils; higher soil moisture favors growth, especially in drought years. We also found significant growth increases for trees that benefit from severe ash dieback and increasing light conditions.

This first comprehensive study contributes new insights into the autecology of *Ulmus laevis* and dismantles old prejudices.

Tree- rings in *Goupia glabra* from a non-seasonal and hyper humid forest

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Tropical dendrochronology states periodic droughts and flooding as the main triggers for tree rings. But in environments lacking such conditions rhythmic growth is unexpected. However, recent research shows several trees with well-defined tree rings in Chocó Region, a hyper humid neotropical forest. We hypothesize a negative relationship between tree-rings of *Goupia glabra* and precipitation (during rainiest months) in Chocó region, Colombia (annual precipitation over 7219 mm). We observe annual tree-rings, verified by radiocarbon dating and by the successfully crossdating of 28 trees. The chronology span for 153 years (1867-2019). The serial intercorrelation was 0.34 (p-value < 0.05), expressed population signal (EPS), signal-to-noise ratio (SNR) and mean sensitivity of the chronology were 0.95, 20.26 and 0.32 respectively. The chronology yielded positive and significant correlation with precipitation ($r = 0.48$, p-value < 0.05), with Southern Oscillation Index (SOI) ($r = 0.34$, p-value < 0.05) and negatively with Oceanic Niño Index (ONI) ($r = -0.36$, p-value < 0.05). Our results suggest water excess is not a limitation for *Goupia glabra*. This is the first chronology successful cross dated in the neotropical rainiest forest.

Dendroclimatic signals in the pine and spruce chronologies in the Solovetsky Archipelago

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The climatic signal in tree-ring chronologies is an important factor for integrating into regional chronology. We analyzed the climate signal in blue intensity (BI) of pine (*Pinus sylvestris*) and spruce (*Picea abies*) chronologies at the Solovetsky archipelago (64.5-65.1 N – 35.3-36.1 E).

For this purpose, we used two pine and two spruce chronologies, spanning the periods of 1901-2016.

Correlation coefficients between proxy data and climate variables are calculated using the R dplR (Bunn, 2008) and treeclim (Zang and Biondi, 2012) packages for monthly data. The climate signal in the parameters of tree rings was estimated using the response functions of the BI between mean monthly temperature and precipitation for the period from June to September of the current year (15 months). We used monthly CRU TS 4.03 data with a 0.5 ° × 0.5 ° grid from the closest point to the sampling sites (64.75 ° N, 35.75 ° E).

We found that in this region, pine and spruce react similarly to meteorological parameters: the blue intensity of both pine and spruce shows the strong correlation of mean monthly temperature from June to August (r = 0.2 - 0.5). Thus, the blue intensity is a suitable parameter for combining chronologies and creating a long tree-ring chronology by including historical wood.

The study was funded by the Russian Scientific Foundation №17-77-20123.

Dendroclimatological study of *Quercus robur* and *Fraxinus angustifolia* in floodplain forest ecosystem

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The *Quercus robur* (QURO) and *Fraxinus angustifolia* (FRAN) represent key tree edificators in floodplain forest ecosystems of Central Europe. These ecosystems have been affected in the past by declining groundwater levels due to rivers regulations and currently they are facing to changing climate. We aimed to investigate sensitivity of QURO and FRAN to precipitation and ground water level fluctuation in the largest area of floodplain forests in the Czech Republic. We constructed several robust tree ring chronologies both for QURO and FRAN and then we analysed growth trends as well as climate growth relationships. The growth trends were studied by trend break-points analysis (Rsoft, package strucchange) and climate sensitivity was detected by computing correlations between tree ring indices and monthly precipitations and minimal ground water level position values (Rsoft, package treeclim). We found higher sensitivity of FRAN to precipitation and ground water level fluctuation compare to QURO. The FRAN showed stronger precipitation and water level fluctuation signals in its chronologies compare to QURO. In addition, the FRAN reduced growth more rapidly due to the artificial water level decline in the past than the QURO. In the context of ongoing climate change, FRAN will be more endanger to drought and groundwater level fluctuations compared to QURO.

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Late frosts effects on Apennines beech forests: insights from tree rings

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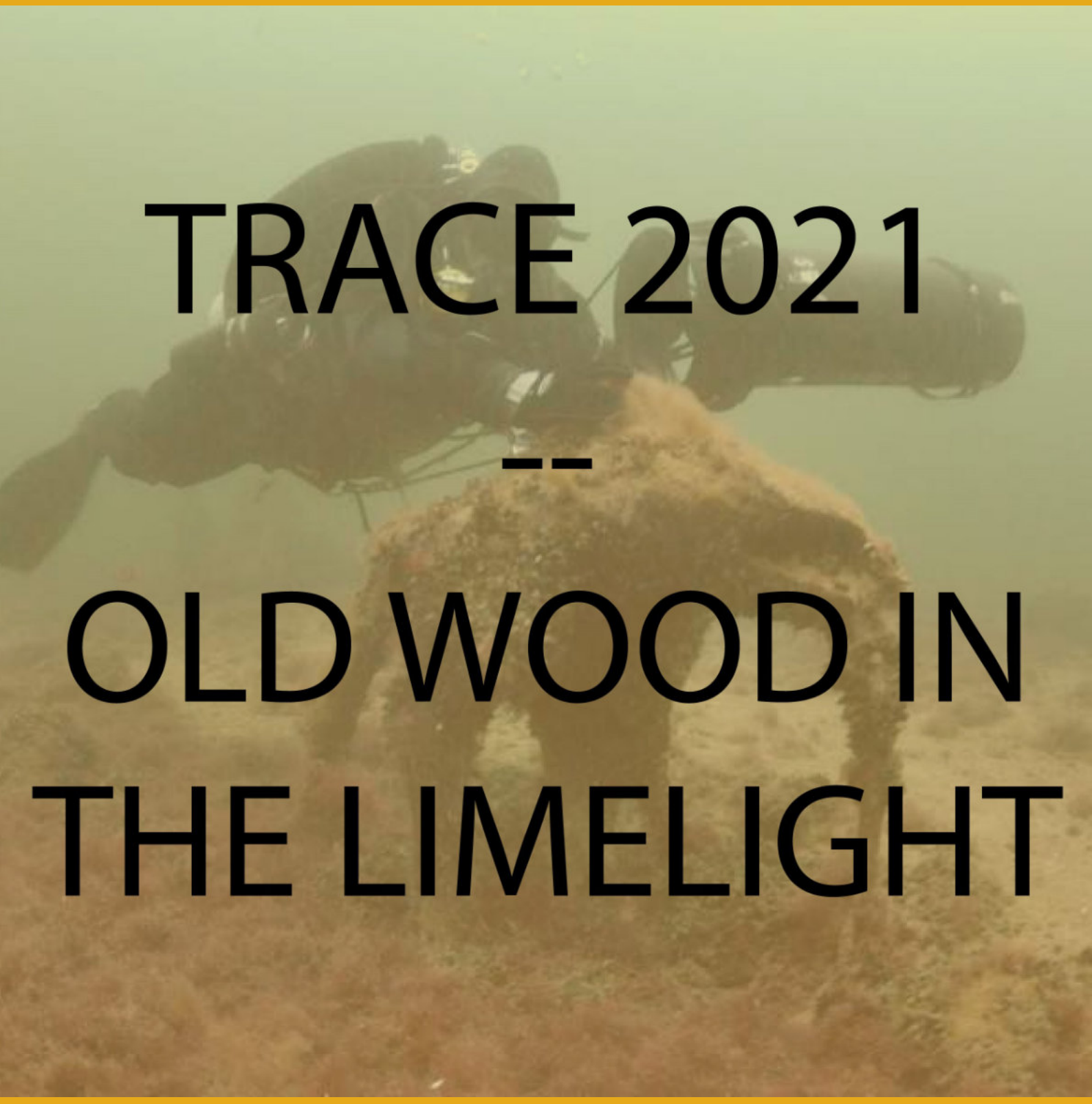
In recent years, climate extreme events are affecting forest productivity through impacts on phenology and radial growth. European beech in particular manifested an increasing sensitivity to late spring frost events, especially in Mediterranean mountain areas. Upon reviewing literature and satellite images we selected four sites with recent severe frost events in the Central and Southern Apennines, Italy. In each site we cored a total of 60 dominant trees distributed in three altitudinal zones along a 300 m gradient. Our objectives were: (i) to assess the frequency and severity of late-frost events from tree-ring data; (ii) to quantify frost effects on beech radial growth, and (iii) to compare the beech response at different elevations. The climate-growth relationship of beech trees and post-frost recovery were also assessed. We used satellite images (Sentinel-2) to detect the incidence of late frost and the recovery time of beech in each plot using Normalized Vegetation Index (NDVI) and Enhanced Vegetation Index (EVI). Our results confirm that water deficit during the previous/current growing season and late spring frost are the main factors limiting beech growth. Trees affected by spring frost show low NDVI and EVI values until late June. The radial growth reduction in impacted trees ranges from 36% to 82%. However, these trees show high levels of recovery and resilience within two years after the events. Superposed epoch analysis (SEA) detected as statistically significant only the impact on the years of frost occurrence. An increasing frequency of these events could alter the resilience capacity of beech in mountain areas.



TRACE 2021

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OLD WOOD IN THE LIMELIGHT

How old is that post-mill?

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The investigation of a number of post-mills over the last 25 years has shown that many have main posts that represent trees of exceptional dimensions which are re-used several times, and may even be transported to new sites. Many sites that appear superficially to be of C18th origin have much older content in their complex structures. At least 13 structures have been dated and many of these have revealed previously unknown dates amongst their timbers, with arguments over which is the oldest becoming slightly meaningless.

American oak imports to the British Isles in the 18th and early 19th centuries; the dendrochronological evidence

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Like all dendrochronologists those in the British Isles retain datasets of tree-ring data which stubbornly refuse to date. Many of these datasets contain relatively long oak ring-sequences which, on the basis of documentary evidence or architectural style, are likely to be from 18th or 19th century contexts. The failure to date some of these datasets has been surprising given the ease with which both native and imported timber can now be dated in the British Isles.

The diminishing supply of native-grown timber in Britain was a major concern by the late 16th century and one of the reasons for the establishment of the New England colonies along the eastern seaboard of America was the hope that they could supply Britain with its timber requirements. A few buildings and shipwrecks had already been successfully dendroprovenanced to the eastern seaboard but there had not been any co-ordinated and methodical approach to identify North American oak in the British Isles dataset.

This paper presents the results of a Historic England-funded project, the aim of which was to establish a reliably dated dataset of American import assemblages in the British Isles.

In all 43 assemblages were analysed, of which 21 have now been successfully dated. These include churches, cathedrals, stately homes, warehouses, shipwrecks and furniture. The results imply that only small amounts of white oak for domestic use were being transported across the Atlantic from the early 18th century, coming primarily from the states of Pennsylvania, New York and Massachusetts.

Non-invasive dendrochronology on half ship models from the Rijksmuseum (Amsterdam, The Netherlands) reveals their production dates and shipyards

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Historically, ship models have been used as representatives of their larger counterpart to convey aspects and events of naval and maritime history. Half models however, are thought to have had a more technical purpose, representing the design of half of the hull of ships to be built. They were constructed at shipyards using a wooden backboard as support. Although for some half models the ship is identified and dated, historical documentation is fragmented and spread out through different archives. As a result, almost two thirds of the half models in the Rijksmuseum collection (Amsterdam, The Netherlands) cannot be attributed to a specific shipyard, are not associated with actual ships, and have therefore been assigned broad production date ranges. Here we present the results of non-invasive dendrochronological research carried out on the oak (*Quercus* sp.) backboards of 63 half models from the Rijksmuseum with the aim to understand the wood supply and timber processing techniques in 18th century Dutch shipyards. Surprisingly, several clusters have emerged for which the backboard derives from the same tree. The known date and production shipyard of some of the half models in those clusters allows ascribing the rest to the same shipyard, and to date their production time within a range of two to four years from each other. These results have helped conservators discover subtle common features in half models from the same cluster, and have pointed historians towards specific archives and ranges of years to search for associated documentation.

Automated 3D tree-ring detection and ring-width calculation from X-ray computed tomography

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Tree ring analysis is essential in the understanding, modelling and assessment of the evolution of wood samples over time. It provides quantitative data about the whole ring structure which can be used, for example, to measure the impact of the fluctuating environment on the tree growth, to support global vegetation models and for the dendrochronological analysis of archaeological wooden artefacts. There currently exist several methods for tree-ring detection and tree-ring parameters estimation from imaging data. However, despite advances in computer vision and edge recognition algorithms, detection of tree-rings is mostly limited to 2D datasets and performed in some cases manually. This contribution presents a new approach to extract the whole 3D tree-ring structure directly from X-ray computed tomography data and illustrates how average tree-ring widths can be estimated from it. The approach relays on a modified Canny edge detection algorithm, which detect fully connected tree-ring edges throughout the measured image stack. The obtained results show that the approach performs well on six tree species having conifer, ring-porous and diffuse-porous ring boundary structure. In our study image denoising proofed to be a critical step to achieve accurate results.

SESOD: The South East Scotland Oak Dendrochronology project

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Scotland has a diverse, international timber supply history, yet our native dendrochronological record has many gaps, making it more difficult to identify, date and provenance our own domestic historic timber. The HES-funded SESOD project aims to develop a long regional native oak tree-ring chronology for a key gap in SE Scotland, a challenging area given many early buildings were destroyed historically during wars with England. However, SESOD, now in its final year, has made good progress, working back from the long record developed from the Old Oaks at Dalkeith Park near Edinburgh, it has dendro-dated and provenanced some surprisingly early surviving timber structures, some in very well-known iconic buildings 'hidden in plain sight'. It has revealed a complex timber supply history here, with some unexpected results pointing to potential for more such significant 'hidden' early survivals, adding to the case being made in our 'Timberwatch Scotland' campaign for better support for dendrochronology in Scotland. SE Scotland is a region with a different climatic regime than the wetter, warmer SW where most of Scotland's oak reference data derives, and the SESOD samples will become important to the future development of the oak isotope climate record, with the potential to help form a basis for oak isotope dating developments too, crucial in a country where young native timber was frequently used. Allow me to take you on a brief SESOD dendrochronological journey through some of most iconic old woods, buildings and archaeological sites in Edinburgh, the Lothians and the Scottish Borders.

Of beech and ash - dendroarchaeology of the neolithic lake shore settlement Olzreuter Ried (SW-Germany)

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At the shore of a lake in Neolithic times in upper Swabia, houses of at least two settlements were built around 2900 BCE and 2820 BCE, according to dendrochronological dating of *Fagus* and *Fraxinus* timbers, ^{14}C-AMS-measurements and ceramic typology. Being conserved in a nowadays peatland, the site "Olzreute-Enzisholz" was partly excavated and around 4000 waterlogged wood samples and more than 3000 charcoal fragments were taxonomically identified, and around 800 suitable timbers were analysed dendrochronologically, to understand the chronology of the village and the resource management of the Neolithic settlers. Houses were built mainly from beech and ash timbers, which were cleaved and axed from sometimes more than 200-year-old trees. Wooden floors were constructed from ash, beech, hazel and alder branches. Tree ring patterns show openings of the woodland well before the construction of the settlement, maybe connected with a so far unknown precursor village. Oak was rare in a *Fagus*-dominated landscape at the beginning of the third millennium BCE in Upper Swabia, a hilly region in the wider northern Alpine foreland. The archaeologically targeted excavation of fire places of houses made it possible to gain charcoals as the remains of fuelwood use, to be compared to the record of waterlogged construction timber. Thus the site of Olzreuter Ried represents an example of both interdisciplinary research involving archaeological and natural science methods, and the integration of dendrochronology and anthracology to better understand chronological patterns of woodland usage by relatively mobile Neolithic people.

Dendrochronological potential of the Azorean endemic gymnosperm *Juniperus brevifolia* (Seub.) Antoine

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Trees exposed to sub-tropical or tropical climates without a marked seasonality, may show a low degree of interannual variation, impeding a straightforward dendroclimatological approach. Subtropical regions, and areas in transitional climates such as the Azores archipelago, are widely unexplored in terms of dendroclimatology, providing opportunities to work with endemic trees, including *Juniperus brevifolia* (Seub.) Antoine. To evaluate the dendrochronological potential of *J. brevifolia*, we analysed wood anatomy and tree-ring patterns, cross-dating capabilities, and correlation with climate parameters. We sampled 48 individual trees from two natural populations (São Miguel and Terceira islands) using an increment borer. In addition, a Trephor tool was used to obtain wood microcores for exploratory micro-anatomical analysis. Although the transition from latewood to earlywood was marked by thick-walled fibers unclear ring transitions or partially indistinct ring boundaries and wedging rings were present, complicating the cross-dating process. After a thorough analysis, a reliable ring-width chronology was built and detrended. Master chronologies were built and correlated with aggregated daily temperature and precipitation data using the dendroTools R package. The climate-growth relationships indicated positive correlations with middle Summer precipitation in São Miguel, with Autumn precipitation and late Spring temperature in Terceira, and a negative correlation with August temperature in São Miguel. Considering our results and the importance of *J. brevifolia* as a dominant tree in the Azores natural forests, we conclude that it shows an acceptable potential for dendrochronological research and this study provides baseline information to help fill the knowledge gap regarding the climate–growth relationship of Azorean trees.

The first tree-ring based fire history of black pine forests in Turkey

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Wildfires are natural events that have prevailed in ecosystems for about 400 million years. The formation of vegetation structures is still carried out by wildfires today. However, in the Mediterranean Basin, the frequency of forest fires will increase with the effect of changing climate, and the fire regime of black pine forests will change. The species adaptation and forest dynamics of such ecosystems affected by fire in many parts of the world should be understood clearly. In this study, we aimed to reconstruct the fire history of black pine forests for the first time in Turkey using dendrochronological methods, to reveal fire seasonality, to understand the relationship between fires and climate, and to determine the causes and changes of fire frequency. A total of 62 samples collected from three sites, we created a 367-year long (1652-2019) composite fire chronology. Superposed Epoch Analysis showed that past fire years coincided with regionally dry years in two study sites. Fire frequency decreased sharply after the beginning of the 20th century in all study sites. Two major fire years (1853, 1879) were common to all sites, while two additional fire years (1822, 1894) were common between two sites. Recent fire records of forest service and our dendrochronological records indicated a similar fire seasonality between today and the past. Our results suggest that fire suppression efforts and forest management activities had increased in the 20th century, and the spread of fires has been actively suppressed since the first forest protection law in Turkey in 1937.

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High precision dendroprovenancing by means of wood anatomy

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So far, tree-ring width series have been extensively used to locate the geographic origin of archaeological wooden artefacts on national and continental scales, allowing the reconstruction of past European timber trade networks. By contrast, due to the similarity of tree-ring width signals produced by closely spaced forests, provenancing studies carried out on a more local scale are likely to provide insignificant results and they are therefore rarely undertaken. In this study, based on the approach developed by Akhmetzyanov et al. (2019), we suggest that wood anatomy can be used alongside tree-ring widths to increase the precision of dendroprovenancing. In order to test this hypothesis, we sampled 80 oak trees in four forest stands located within a radius of 30 km from the city of Limoges (France). Time series of anatomical parameters (earlywood width, latewood width and earlywood vessel size) were derived from core images processed using CooRecorder and ROXAS software. The PCGA (principal component gradient analysis) performed on these series revealed that earlywood vessel size is the most useful feature to discriminate between the four forest stands. We believe that these results will be of primary importance to pinpoint the origin of the timber employed in Limoges' timber-framed houses, considering that historical documents attest the regional nature of the wood supply area. This study is part on an ongoing PhD thesis, and it represents a valuable starting point for the construction of a more extended tree-ring network.

The Gribshunden Shipwreck

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The Royal carvel ship *Gribshunden* was carrying the Danish King Hans when it sank in the Blekinge archipelago in 1495 after a fire broke out on board. When the ship sank, King Hans was on his way to the Swedish town of Kalmar in order to try to reinstate the union between Denmark, Norway and Sweden. The shipwreck was rediscovered in the early 1970s and has been investigated several times since the early 2000s. Dendrochronological analysis of nine oak samples from the ship structure revealed that the trees were felled in the winter of 1482/1483 and that the samples originated from the Meuse River valley in northern France. Apart from the ship structure, the wreck also contains a large amount of well preserved artefacts that will not only give an insight to the life on board the ship, but regional trade patterns will also be revealed. In the ongoing excavation project, the dendroarchaeological aim is to retrieve barrel staves in order to date and determine the provenance of the wood. This will help us answer questions regarding the production and lifespan of the barrels, as well as trade patterns that emerge from the barrels. The Gribshunden shipwreck, the same type of ship that brought Columbus to the Americas, is the only preserved carvel ship known to date, and research on this wreck will give us a unique insight into the Late Medieval way of life.

Studies of subfossil and recent oaks (*Quercus* spp.) with Blue Intensity

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The dating of timbers from archaeological or subfossil contexts is always a challenge. The common opinion is that physical and chemical structures of the xylem restrict possible dating methods to tree-ring width measurements only. However, there are examples of successful use of other parameters in terms of archaeological (Wilson et al. 2017; Loader et al. 2019) and even subfossil wood. Here we present the very first attempt to apply Blue Intensity (BI) on subfossil oak wood dated to the Neolithic (here ca. 4600 to 4400 BCE). We tested if BI can be applied to date hardwood modified significantly in its colour by fossilisation processes. The focus was on crossdating samples and building a floating chronology, as the dating itself would require a BI master chronology. We examined 15 samples from two sites in Germany, a gravel pit in Fischbeck, Lower Saxony and the opencast mining near Kaster, North Rhine-Westphalia. The samples were already dated using tree-ring width. Moreover, they were analysed for $\delta^{13}C$ and $\delta^{18}O$, which helped to verify the BI results. We tested different procedures at each step of sample preparation and measurement, e.g. different solvents, sanding, scanning and employing all three channels of RGB standard. For the purpose of comparison we examined samples from living oaks to learn about the differences of subfossil and living wood. The very first results are promising, as we successfully measured BI and crossdated derived time series of subfossil oaks.

Overview of dendro-archaeological studies in the French Alps: assessing the silvicultural practices in the mountains.

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In the French Alps, dendrochronologists are studying timbers used in mountain (rural buildings, mining structures) for about twenty years. 1730 Larch, Spruce Fir, Scots pine and oaks timbers (cores and sections) were tree ring dated at more than a hundred buildings located between 790 and 2356 m a.s.l. Several felling dates clusters were identified, from the 11th c. to the 20th c. Except during the second half of the 14th century, trees were felled during all times, which testifies to an almost continuous activity of buildings' maintenance, repairs and transformation.

The evolution of felled timbers age and diameter over the last ten centuries reveals the forest resources management by rural societies. We show an increase in the age of the trees felled from the 11th to the beginning of the 14th century, up to ca. 250 years old. From the end of the 14th to the beginning of the 20th century, the trees were felled at a median age of 100 years. Moreover, diameters of the used trees used are more or less constant over time (around 20-25 centimeters), because these dimensions are perfectly suited for the (mostly studied) structural elements of mountain constructions.

As diameter has remained constant whereas the age of the felled trees has changed, growth conditions have therefore improved over the ten centuries studied. A climatic explanation is difficult to retain for this medieval-modern period discrepancy. Rather, anthropic explanation, impacting silvicultural practices and favoring growth would be a more relevant hypothesis.

Tree ring analysis of *Araucaria angustifolia* in response to hydropower plant operation in Southern Brazil

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The Paraná Electric Energy Company, "COPEL GeT" (research and development), is running the "ANEEL (National Agency of Electric Energy)" project (PD-06491-0405/2015) with Federal University of Paraná and "SIMEPAR (Paraná Meteorological System)". The aim of this study was to use meteorological series and *Araucaria angustifolia* tree ring chronology to investigate possible changes in local climate due to the construction of a hydropower plant in Paraná State, southern Brazil, in 1980. Hydropower plants are important sources of energy supply, but the climate impacts of dams are still poorly understood. In order to identify those climate changes, tree ring analysis emerges as a valuable tool. Dendrochronological analyses were developed from wood cores of 30 trees, extracted by an increment borer. Historical climate data were obtained from local and nearby weather stations. Data were evaluated by principal component analysis, analysis of variance and means test. Tree ring responses to climate variables were analyzed by fitting generalized linear mixed models and Spearman correlation. Time spam ranged from 1800 to 2016, but EPS was satisfactory from 1920 (>0.7). Oldest and youngest trees were 143 and 38 years-old and the average length of series was 62.1 years. Our results detected evidence that hydropower plant may have changed local climate, mainly influencing hydrological cycle. We identified a statistically significant increase in monthly precipitation over other weather stations. Tree ring responses were found to be related to minimum temperature, dam construction and water level (which is probably influencing other derived variables).

First composite tree-ring chronology for the Novosibirsk region in West Siberia (Russia)

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Novosibirsk region is located south of West Siberia. It is famous for several historical sites from the period of the Russian conquest of Siberia. They are Suzun plant, Umrevinsky burg, Krivoshekovo necropolis, Spassky church and others. Historical sources do not determine exactly the build dates of all sites. We collected wood samples from each site and decided to build a tree-ring chronology to date them.

Unfortunately, trees in the region are young - 100-250 years. To continue chronology, we collected wood samples from typical buildings in Novosibirsk villages. At all, it is 24 houses.

Next, we built the chronology. Mean length of series 154. The cross-dating period between living trees chronology and old building chronology was 162 years. The correlate coefficient was 0,46. Now ,the length of the chronology is about 500 years.

As the result, we created the new chronology and dated archaeological sites and old houses in the Novosibirsk region (south of West Siberia).

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Fingerprints of biotic agents in tree-ring and NDVI time series of forest stands

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Phyllophagous insects capable of mass propagations may cause severe damages to trees and forest stands up to increased individual and population-wide mortality. Trees that survive these attacks experience, at least temporarily, significant reductions of their biomass productivity due to the losses of foliage.

This study covers an exemplary case of large-scale defoliation caused by *Lymantria monacha* in pure stands of *Pinus sylvestris* in Brandenburg, Northeast Germany, in the year 2003. Severe needle-loss occurred on roughly 4,000 hectares concentrated on medium-aged stands. The resulting decrease in foliage activity can be detected in time series of remote-sensing images continuous estimates of the NDVI for the area. Based on the magnitude of this reduction and spatial resolution of the images, zones of different degrees of foliage loss were delimited. According to four different defoliation categories we established four temporary research plots in the respective zones to measure current stand characteristics and to extract of borer core samples from representative plots.

Comparative analyses of the four plots focused on (1) sample characteristics such as SNR and EPS, (2) the development of the tree-ring width (TRW) time series in the damage years and beyond, (3) mean ring-width index (RWI) time series and their resilience components, and (4) RWI-climate relationships as calibrated by response and correlation function analyses. We could show that the effects of varying feeding intensity are visible in the TRW and RWI time series. These variations also influenced the resilience components associated with the different plots. We confirmed the assumed plot-specific correspondence between NDVI time series and RWI chronologies, thus proving the reliability of the remote-sensing information to efficiently quantify the extent of defoliation on the stand scale.

Ships were made of oak, pine or larch

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Tree species at genus level were analysed from nine wrecks found at the coasts of Estonia. Knowing tree species is important first for matching tree-ring series of a wreck with ring-width references of the same species. Second, high similarity with certain references indicates region of origin of the wreck timbers. Use of several species in one ship may indicate either shipbuilding traditions, availability of timbers, or later repairs. Ships wrecked at the coasts of Estonia have come from different countries around the Baltic Sea. Some of the ships were made of oak, some were made of pine (sometimes with oak keelson). The oldest dated ship here is an oaken cog (AD 1296 *terminus post quem*), now exposed at the Estonian Maritime Museum. MS "ALAR" was much suffered and repaired, containing oak (1948 *tpq*), pine (1929 *tpq*) and spruce timbers. A recently found wreck (undated) at Kadriorg, Tallinn, contains pine and larch timbers. Local ships like the one found near Kuru village in Lake Peipsi, were made of local pine (1908).

Alongside with determination of the ship type, knowing of tree species of the wreck greatly helps to explain the date and origin of the vessels. This, in turn, adds information about former sea trading and fishing practices through time in the Baltic Sea region.

First dendrochronological studies of *Quercus protoroburoides*

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Quercus protoroburoides Donchev & Bouzov ex Tashev & Tsavkov (Rila oak) is a species with extremely limited and localized distribution. It is found only on several locations on slopes above Rila Monastery (Bulgaria) at elevations between 1500 m and 1750 m a.s.l. The trees are in small groups or scattered, usually situated on ridges slightly higher than the local population of *Quercus petraea* and above mixed fir-beech forests. Since its discovery in 1968 the species was not studied by dendrochronological methods, which was the aim of our study.

We analysed 9 tree-ring cores from the location Boucher collected in 2013 and 33 cores from 20 trees from the location Drushliavitsa collected in 2019. The trees varied in age from 30 to 170 years. Nearly half of them were about 50 years old. The composed tree-ring chronology spans from 1856 to 2019. The mean tree-ring width is 2.349 mm (minimum 1.097 mm, maximum 5.110 mm). The mean sensitivity is 0.219, while the mean 1-st order autocorrelation is 0.680. The mean RBar statistic is 0.283 and the EPS is above the 0.85 threshold for the whole period. Common narrow years are 2015, 2011-2012, 2000, 1993, 1988, 1976, 1971, 1962, 1952, 1933, 1904-1916, 1899, 1888-1891, 1880, 1876 and 1868. Most of these years are characterized by extreme climate conditions, such as droughts, unusually cold summers or delayed start of the vegetation period due to late frost events. Our initial climate-growth analysis based on gridded climate datasets and climate data from Mussala peak indicates that the species is adaptive to common climate variation and only extreme conditions have potentially serious impact on growth.

TRACE 2021

INSIDE WOOD

Intra-annual variation in vessel features in European beech (*Fagus sylvatica* L.) in years with extreme climate conditions

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Due to climate change, the frequency of extreme climatic events (e.g., summer drought) is expected to increase in the future. The aim of this study was to investigate the influence of dry and wet summer conditions on tree ring width and vessel features in beech. Three optimal beech forest sites in Slovenia were selected, representing the main Slovenian beech provenances (Idrija, Javorniki, and Mašun) with different leaf phenology and thus different growth strategies. Collected cores were prepared for observation under light microscope and wood anatomical features were analysed using Image Pro-Plus and Roxas. Growth rings formed in years with dry summers (with less precipitation and minimum and maximum temperatures above the long-term average) were analysed. Results showed that summer drought affects both tree ring widths and vessel features. Comparing years with wet and dry summers, tree ring increments were 33 % narrower in years with dry summers, while relative conductive area and vessel density were 26 % and 18 % higher, respectively. Drought also affects intra-annual trend in vessel size and distribution. In the first half of the tree ring width, vessel size was similar between wet and dry years. However, in case of dry summers vessel size began to decrease already in the beginning of second half of the xylem increment. In a case of wet summer years, the vessel size began to decrease after 70 % of tree ring width. The results are crucial for understanding the plastic response of European beech to changing climatic conditions.

Intra-annual density fluctuations beyond the Mediterranean: IADF respond to temperature in southern Siberian pines

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Intra-annual density fluctuations (IADFs) result from sudden changes in the cambial activity due to the intra-annual variability of environmental factors. Thus, IADFs have great potential as a climate proxy providing information on short-term variation in the pace of xylem formation, which may occur in any environment with abrupt fluctuations in climate conditions. However, most of IADF research has focused on the Mediterranean climate, with less attention devoted to the temperate climate. We evaluated the occurrence of IADF in dominant and suppressed *Pinus sylvestris* L. trees from two sites with contrasting water availability conditions in the forest-steppe ecotone in southern Siberia (Russia). We found the occurrence of types of IADF E (latewood-like cells band within the earlywood) and IADF L (earlywood-like cells band within the latewood), being the IADF L the most frequent (90% of the total). Tree growth responded mainly to water availability from late spring to early summer conditions. In contrast, IADF occurrence was triggered by a shift from low to warm temperatures during the growing season, with a very high frequency at the dry site, but just a marginal effect of tree status. Our results contribute to building knowledge on IADFs in the Siberian forest-steppe. RNF-18-74-10048 and FSRZ-2020-0014 supported the study.

VS-Cambium-Developer (VS-CD): new opportunities to quantify a cambium activity of conifer species

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We developed a new cambium model which reproduces a seasonal cambial activity of conifer species and can be applied to different habitats. The model is based on a hypothesis of existing a cytoplasmatic inhibitor which is responsible for the cell differentiation. The inhibitor functioning is connected with seasonal temperature, precipitation and solar irradiance variability. The new algorithm is a deep modification of the cambial block included in the Vaganov-Shashkin process-based tree-ring model.

The model is calibrated and verified by the direct and proxy observations of xylogenesis for conifer trees in cold semi-arid environment of Southern Siberia (the Republic of Khakassia) over 1964-2012. Accuracy of seasonal cell production simulation for the average tree of studied site was ± 1 cell .

Software implementation of the new cambium model is based on the R Shiny technology and will be integrated in VS-GENN platform (http://www.vs-genn.ru/). Developed widgets (process visualization tools) allow potential users to control a cambial zone growth dynamics in high resolution time scale (up to one hour).

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The intra-annual density fluctuation as an acclimation response to water use efficiency of tracheids in *Pinus sylvestris* L

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Nowadays, we are facing a global climate change affecting the terrestrial temperate forests resembling the weather conditions of the Mediterranean area. The main stresses; long-lasting drought periods and heatwaves which have a negative impact on the tree water availability. Up to date, we still have very little information about the acclimation processes of drought-suffering Scots pine trees. To tackle this, studying the acclimation processes of water use efficiency on the cellular level is on high scientific demand. We micro-cored six dominant Scots pine trees by using the Trephor tool (weekly intervals) during three successive growing seasons (2014–2016) to investigate the cambial activity and morphogenesis of new xylem cells formed under summer drought stress. The micro-core samples were used for making permanent micro-slides (transverse section) to analyze the duration and rate of tracheid differentiation and their morphometric parameters. We also analyzed the daily tree water status by sap flow and soil water potential measurements. The summer drought periods (daily values of soil water potential and sap flow dropped under -1 MPa and 10 kg day^{-1} respectively) resulted in cambial latency (reduced number of cambial cells). After improved tree water status, the cambial activity was reactivated and thus, the tracheids began to form again. This resulted in earlywood-like tracheids formation inside the latewood zone (intra-annual density fluctuation) responding to fluctuated water availability. Hence, under drought stress, the trees tend to reduce the number of tracheids with smaller radial dimensions (narrower tree rings) and thinner cell-walls to increase their hydraulic efficiency.

Forward modelling reveals a complex pattern of climatic control on wood formation in conifers at cold-limited sites

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Evidence is increasing that temperature control on tree growth can vary across space and over time at high latitudes and high elevations, and that moisture availability can be an important co-limiting factor at otherwise cold-limited sites. Studies at the cellular level can help unravel these complex patterns, but long time series of wood formation data are often unavailable.

Here, we aim to identify growth-limiting factors and patterns of wood formation in conifers at cold-limited sites across space and over time at an intra-annual level. We compiled a dataset of tree-ring width series and xylogenesis observation data for so far five cold-limited sites at high latitude (Quebec, Finland, Siberia) and high elevation (Swiss Alps, Giant Mountains). We applied a process-based (Vaganov-Shashkin full) model to estimate proportions of temperature- and moisture-limited growth and wood formation patterns for 1950 - today.

Even though temperature seems to be the main climatic driver of tree growth at all sites, we found temporally and spatially varying proportions of moisture-limited growth. Furthermore, first results indicate that growth resumption in spring has advanced and thus growing season length has increased over time at all sites.

We will now use xylogenesis monitoring data to improve the models further, and more sites will be added to increase the robustness of the study. So far, modelling of intra-annual tree growth seems to be highly suited to unravel potentially hidden moisture-limited growth, which seems to be more widespread at cold-limited sites than previously thought.

Wood anatomy and tree-ring isotopes reveal hydraulic deterioration as the main cause of *Araucaria araucana* dieback in southern America

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Extreme climatic events such as dry spells accompanied by warmer temperatures have caused forest dieback and increased tree decline worldwide. Nonetheless, the roles played by the two major mechanisms driving forest dieback (hydraulic failure and carbon starvation) are understudied. Here, we apply a retrospective analysis of wood anatomical traits and water use efficiency (WUEi) during the 1800-2017 period to clarify the causes of dieback in three *Araucaria araucana* sites. We selected stands showing recent dieback but featuring different climate conditions, one at the warm-dry Chilean Coastal Range (CHI1), and the other two at the cool-wet Chilean (CHI2) and Argentinian (ARG1) Andes. At all sites declining trees showed higher defoliation and lower growth rates, smaller tracheid lumen area, lower theoretical hydraulic conductivity and thinner cell-wall area compared to non-declining trees, indicating lower water transport capacity and less carbon storage. This likely induced the reduction of tree growth and increased the susceptibility to drought stress and pathogens. Wood anatomical traits evidenced a common divergence between declining and non-declining trees started seven or more decades before any evident dieback sign at canopy level such needle shedding. The WUEi, was higher in declining trees from the Chilean sites, indicating early stomatal closure during drought and a potential carbon starvation due to reduced photosynthesis rates, whereas in Argentina we observed a reverse pattern in the last decades.

Multi-proxy, retrospective quantifications of xylem anatomical traits and tree-rings isotopes provide a robust tool to differentiate dieback causes, and to forecast which stands or trees will show growth decline or, on the contrary, which will be able to survive to forecasted hotter droughts in the future.

What can xylem tell about extreme weather events?

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Since the 1950s, global climate change is causing an increase in the frequency and magnitude of extreme weather events (e.g. droughts, heat waves, and frost). Extreme weather events affect physiology of trees, whose responses are the results of both their tolerance and resilience. Tree stems play an important role in the carbon balance of forest. Part of the carbon (C) fixed by photosynthesis is allocated to the stem, some is respired by stems and emitted into the atmosphere as CO_2. Moreover, stemwood contains most of the total non-structural carbohydrates (NSCs), playing a key role in the productivity and resilience of forest trees.

On the hypothesis that extreme weather events would alter the stem C dynamics, leaf phenology, wood formation, stem CO2 efflux, and NSC dynamic were monitored in a Mediterranean beech forest during a late frost (2016) and a summer drought (2017). The main aim of the study was to unravel the dynamic of C in stemwood, in supporting tree resilience to climate stresses.

The late frost reduced radial growth by 80%. Stem carbon dioxide efflux in 2016 was reduced by 25%, which can be attributed to the reduction of effluxes due to growth respiration. Moreover, we showed that NSCs helped to counteract the negative effects of both events, supporting plant survival and buffering source-sink imbalances under stressful conditions.

Our findings indicate a strong trade-off between growth and NSC storage in trees. Overall, our results highlight the resilience of beech trees to highly stressful events.

Growing season changes in Swedish forests - early wakening, early retreat?

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In Sweden it is now estimated to be close to 2 °C warmer than in the 19th century. This has prolonged the growing season when tree growth restricted by temperature can occur. This is particularly relevant near the tree line, where mean temperature during just a few weeks around summer solstice frequently explains up to half of the variability in ring width.

Phenological observations of bud burst and autumn leaves, conducted throughout Sweden, indicate a shift in plant activity, most evident in Birch. Here we raise the question to what degree the temperature signal in tree ring chronologies has remained stable during this rapid warming, or if it reveals a similar pattern as the phenological observations.

A multi-species network (including chronologies of Scots pine, Norway spruce and Downy birch), sampled along the Scandinavian mountains, have been used to assess whether there are any shifts in the time window when tree ring width correlates with temperature.

Our main finding reveals that the period of peak correlation appears to start earlier but also, somewhat surprisingly, ends earlier. This is also corroborated by the phenological observations. Our results thus suggest a shift in the timing of plant activity rather than a prolongation of the growing season.

We hypothesize that this may be associated with restriction in water availability towards the end of the thermal growing season, and perhaps this can explain why the northern forests at times have been unable to respond favourably to the increase in temperature the last half century.

Dynamics of Xylem and Phloem Formation in *Quercus ilex* L. at a Mediterranean Site

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Holm oak (*Quercus ilex*) dieback has been reported at numerous locations in its natural sites likely due to ongoing climate change. In this context, we followed the cambial activity in *Q. ilex* trees growing at a site in southern Italy in a very dry year, to assess how xylem and phloem production are affected by harsh seasonal climatic variation. As phloem did not show clear growth rings and boundaries between them, we followed the development of phloem fibres and their morphological traits using them as reference to evaluate the phloem production during the year. On the xylem side, we detected a multimodal pattern in cambial production linked with the amount and distribution of precipitation leading to the formation of intra-annual density fluctuations (IADFs). The lowest production of xylem cells was observed in the dry late spring and summer, while the highest occurred in autumn. We detected cambial production of phloem cells throughout the year, even in the periods when no xylem was produced. Our results suggest that phloem production is either favoured or less affected than the xylem production under stressful conditions. We also report how to overcome technical problems with tissue preparation due to extreme hardness and peculiar structure of *Q. ilex* wood and bark.

Earlywood and latewood structure: a magnifying glass for investigation of external and intrinsic inputs in conifer growth. Case study near forest line in Western Sayan Mountains

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Quantitative wood anatomy can provide detailed insight into adaptation of trees to changing environment, especially on the borders of species distribution ranges. This study investigated wood anatomy of *Pinus sylvestris* L., *Pinus sibirica* Du Tour, and *Picea obovata* Ledeb. growing near the upper forest line in the Borus Ridge of the Western Sayan Mountains, where local climate changes rapidly. Anatomical traits reflecting three developmental stages of conifer tracheids (cell division in cambial zone = cell number, cell enlargement = radial diameter, and secondary wall deposition = cell wall thickness) were calculated for earlywood, latewood and total tree ring over 50 years. Similar traits (hydraulic architecture) and low-to-medium between-trait correlations (r = 0.21…0.67) were observed in earlywood of all species, i.e. shared habitat, average climate, and similar habitus provide common trade-off between hydraulic efficiency and safety. In latewood, anatomical traits are strongly interconnected (r = 0.63…0.93) for each species despite having more species-specific values and proportion in the ring. At the same time, latewood traits have more pronounced dependence of heat supply as was shown for vegetative seasons with the highest/lowest duration of temperatures above thresholds 5°C and 8°C and sum of temperatures above these thresholds. Higher proportion of latewood cells with much thicker walls was observed during warm/long vegetative seasons than during short/cool ones.

Could different tapping regimes improve resin yield in *Pinus pinaster*?

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Conifers are an ancient group of woody plants with worldwide distribution and a long evolutionary history dating back to the Carboniferous. Their success relies on their complex defense mechanisms to prevent herbivores and pathogens, which involves the constitutive and/or inducible production of resin that acts as a chemical and physical barrier. Natural resins have a high economical value for different industries, including pharmaceutical, cosmetic, food industries, and are an alternative to synthetic resins from fossil origin. Resin tapping is a traditional forestry activity in Portugal, where *Pinus pinaster* Aiton is the principal species used. Understanding how resin production varies over the growing season, how can be affected by different tapping intensities, and the effects this may have on xylem formation might be useful not only to understand the intra-annual pattern of resin production but also to improve and develop more efficient and sustainable tapping methods. To do so, we followed the radial growth, xylogenesis and resin yield of 18 maritime pine trees tapped during the 2020 growing season under different tapping regimes: none, traditional (March-November), and shortened (June-November). The traditional method produced ~50% more resin and showed higher resin yield during the whole season than the shortened regime suggesting a main role of resin induction. The maximum resin production in both regimes was before summer drought and resin production started to decrease in early October. The number of cells produced was not affected by the tapping regime. However, shifts in carbon allocation might have influenced tracheid features.

Is ring porosity a stable trait in Mediterranean oaks?

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Tree species are characterized by different physiological and morphological traits, reflecting different strategies to exploit resources efficiently and cope with environmental stress. In the Mediterranean basin, evergreen oaks have diffuse-porous wood, i.e. they form vessels of similar size over the growing season. Instead, most deciduous oaks are ring-porous, forming wider vessels at the growing season start, and narrower vessels later. Ring porosity is generally considered a taxon-specific trait, but some authors suggest that it might be affected by environmental conditions. However, specific researches are lacking.

We investigated xylem traits along tree-ring series in semi-ring-porous *Quercus ithaburensis* (deciduous) and diffuse porous *Q. calliprinos* (evergreen) in xeric Lower Galilee (Israel), and on ring-porous *Q. boissieri* (deciduous) and diffuse-porous *Q. calliprinos* in the mesic Golan Heights. We compared xylem anatomical parameters and ring porosity (assessed through the Gini and Porosity Ratio indices) for the rings corresponding to the five driest, five wettest, and normal (i.e. not dry or wet) years of the period 1974–2013. Ring width, vessel size and number were affected by both site conditions and climate variability, evidencing the important role of water availability for xylem formation. Ring porosity indices showed that diffuse-porous xylem structure of the evergreen species was maintained under dry and wet conditions at both sites. However, in the deciduous species, ring-porous structure in wet and normal years shifted to semi-ring-porous in dry years. This suggests that ring-porous strategy might not be realized under future drier climate in the Mediterranean basin.

Drought elicits contrasting responses on the autumn dynamics of wood formation in late successional deciduous tree species

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Wood formation cessation is a key phenological event of temperate deciduous trees. Elucidating the influence of environmental conditions on the timing of wood formation cessation is fundamental for better understanding of tree functioning and potential climate change impacts. Here, we compare wood formation dynamics in autumn in European beech and pedunculate oak stands in Belgium for two years (2017 and 2018), with the second experiencing a severe summer drought. Wood formation dynamics were histologically observed. Wood formation in oak was affected by the drought, with oak trees ceasing cambial activity and wood maturation about three weeks earlier in 2018 compared to 2017. Beech ceased wood formation before oak, but its wood phenology did not differ between years. Compared to 2017, fibre cell wall thickness was smaller in beech but thicker in oak in 2018. We did not find a significant difference in porosity, mean conductive area or the amount of tension wood in either species between years. Presumably oak ended wood formation earlier in 2018 due to an earlier cessation of cambial activity as less cells had to go through the wall thickening phase in autumn. This pattern might indicate contrasting life strategies: favoring fewer but thicker xylem cells for ring-porous species, while more but thinner cells for diffuse-porous species.

Isometric scaling to model water transport in conifer tree rings across time and environments

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Xylem hydraulic properties determine the ability of plants to efficiently and safely provide water to their leaves. These properties are key to understanding plant responses to environmental conditions and to evaluating their fate under a rapidly changing climate. However, their assessment is hindered by the challenges of quantifying basic hydraulic components such as bordered pits and tracheids.

Here we use isometric scaling between tracheids and pits morphology to merge partial hydraulic models of tracheid's component to upscale properties at the tree-ring level in conifers trees. Our new model output is first cross-validated with literature and then applied to cell anatomical measurements from *Larix sibirica* tree-rings formed under harsh conditions in southern Siberia to quantify the intra- and inter-annual variability in hydraulic properties.
The model provides a means of assessing how different-sized tracheid's components contribute to the hydraulic properties of the ring. Up-scaled results indicate that natural inter- and intra-ring anatomical variations have a substantial impact on the tree's hydraulic properties.

Our model facilitates the assessment of important xylem functional attributes because it only requires the more accessible measures of cross-sectional tracheid size. This approach, if applied to dated tree-rings, provides a novel way to investigate xylem structure-function relations across time and environmental conditions.

Growth-defence trade-offs in tapped pines on anatomical traits and resin production

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In the Iberian Peninsula, Pinus pinaster Aiton forests had been traditionally managed for the co-production of resin and timber. Growth-defence trade-offs are not fully understood, however. Resin ducts have been used as a proxy for resin yield as they represent the tree's investment on resin defences throughout its lifespan, but it is not yet clear if these structures can be linked to growth or how well the resin duct network correlates with resin yield. To answer these questions, we compare annual tree-ring width, resin duct traits (absolute and standardized, before and while tapping), and resin yield of two P. pinaster stands tapped for resin extraction in Portugal (VPA and PCO). During tapping, growth rates decreased by ca. 24% in PCO, the population living under greater water availability and longer growing seasons, while those were almost unaffected in VPA. Resin duct production increased exponentially with tree-ring width similarly in both sites and periods, but wider rings and ducts in PCO resulted in greater areas occupied by resin ducts. Anatomical resin-based defences before tapping did not trade-off with radial growth, although, lower growth rates were related to higher resin duct investments in response to tapping. Resin yield was positively associated with tree's size, growth, and duct production but not with duct density or relative area. Tree vigour seems to be the most valuable variable to identify the best resin producers in a stand. Growth sensitivity differences to resin tapping are site-dependent and may not be as negative as previously thought.

Wood rays in xylem of Scots pine of different canopy stratus

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Non-structural carbohydrates (NSC) are crucial for survival and resilience of trees, particularly under intensifying weather extremes. The amount of NSC can be affected by the social status of trees within stand, implying uneven tolerance to natural disturbances. In stemwood of Scots pine (*Pinus sylvestris*), NSC are mainly stored in parenchyma in wood rays (WRs), amount of which express intra- and inter-annual variation. The differences in WR in stemwood of dominant and intermediate (canopy trees with reduced and narrow crowns) maturing Scots pine were assessed by quantitative wood anatomy based on the tangential cuts from earlywood and latewood of the outermost 30 tree-rings. The relative ray area was intermediate, (ca. 5%), yet varied greatly among the studied trees. The size and amount of WR mainly differed between the earlywood and latewood; WRs in latewood were higher although narrower in comparison to earlywood, yet their total amount was higher in earlywood. Canopy status had only a marginal effect, though quantity and height of WR tended to be higher in earlywood of the intermediate trees. The studied WR proxies expressed inter-annual variation, which was correlated to the meteorological conditions prior to the formation of the tree-ring (previous summer and autumn), thus contributing to the carry-over effects of climatic factors. Though, the climatic signals captured by the proxies of WR were weaker than observed before. Nevertheless, the observed differences in mean values and inter-annual variation of WR imply within-stand diversity of carbon allocation patterns.

Flood signals in tree-ring $\delta^{18}O$ and xylem anatomical parameters of *Lagerstroemia speciosa* in Bangladesh: Implications for flood management strategies

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We performed a multiproxy tree-ring analysis to investigate the impact of extreme flood events on tree growth, xylem anatomical parameters and oxygen isotope composition of tree-ring cellulose ($\delta^{18}O$) in a Bangladeshi moist tropical forest and to establish relationships between water level of the regional rivers and tree-ring parameters. By using pointer year analysis, we identified 1974, 1988, and 1998 as extreme flood years in Bangladesh. Superposed epoch analysis revealed significant changes in ring width (RW), total vessel area (TVA), vessel density (VD), and tree-ring $\delta^{18}O$ during flood years. Flood associated hypoxic soil conditions reduced RW up to 53% and TVA up to 28%, varying with flood events. In contrast, vessel density increased by 23% as a safety mechanism against flood induced hydraulic failure caused by inefficient anaerobic respiration and consequent inadequate metabolic energy required for water transport. Tree-ring $\delta^{18}O$ significantly decreased during the flood years due to the amount effect in local precipitation. Bootstrapped Pearson correlation analysis showed that wood anatomical variables encoded stronger river level signals than RW and tree-ring $\delta^{18}O$. Among the wood anatomical parameters, VD showed a strong relationship ($r = -0.58$, $p < 0.01$) with the water level of the Manu river, a regional river of the north-eastern part of Bangladesh, indicating that VD can be used as a reliable proxy for river level reconstruction. Our analyses suggest that multiproxy tree-ring analysis is a potential tool to study tropical moist forest responses to extreme flood events and to identify suitable proxies for reconstructing hydrological characteristics of South Asian rivers.

Fire effects on xylogenesis and productivity of *Pinus pinaster* Aiton

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The effects of wildfires on trees do not always appear in the short term, in some cases they become evident after several years: the flames can trigger complex mechanisms that influence the eco-physiology of the trees causing, in the long term, a reduction of tree vigor or even the death.

Our research aims to identify the fire effect on the growth and ecophysiology of Pinus pinaster Aiton in the short and long term, as well as to understand how climate and in particular heat waves, can affect the recovery time of this species. The study, carried out in a forest stand affected by a severe fire at the Vesuvius National Park in Southern Italy in July 2017, combines dendrochronological and xylogenesis analyses with continuous monitoring of the eco-physiological parameters of the individual plants through the use of the innovative TreeTalker device.

The dendrochronological results suggest, at the end of 2018, a very limited mortality rate: only 2-10% of individuals have reduced their vigor. However, the preliminary data on xylogenesis, collected since spring 2019 every 15 days, suggest a direct link between the damage of the tree's canopy and the cambium activity. Plants with a strong reduction of foliage show a delayed development of cells with secondary and lignified walls, and also a lower cambium production. By August 2019 the extremely damaged plant recorded a xylem cell production 59% lower than that shows by trees with a limited damage of the canopy.

Contribution of cell anatomical parameters to the tree-ring width variability of two larch species in permafrost and non-permafrost zones of Siberia

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In this study, the impact of climatic conditions on radial growth was compared between *Larix gmelinii* Rupr (Rupr) and *Larix sibirica* L. growing in permafrost and non-permafrost zones, respectively, in Central Siberia. We quantified the contribution of xylem cell anatomy to variability in tree ring width (TRW) over the period 1963–2011. Generalised linear modelling identified a general correlation between TRW and cell structure characteristics in contrasting environments. Despite the obvious differences in the growing conditions and related tree-ring formation, relationships between TRW and the number of cells and cell diameter in EW and LW have been proven as non-specific to environmental conditions. The relationship between the tree-ring width and the cell production in early- and latewood were assessed as linear, whereas the dependence between the radial cell size in early- and latewood and the tree-ring width became significantly non-linear for both habitats. The contribution of early (EW) and late (LW) wood cells to TRW variation (average 56.8% and 24.4%, respectively) was significantly higher than the effect of cell diameters (3.3% (EW) and 17.4% (LW)) for habitats. The results showed that different larch species from sites with divergent climatic conditions converge to similar xylem cell structures and relationships between xylem cell production and their traits.

Effects of dominant moss species on shrub growth and xylem anatomy along a precipitation gradient in the subarctic tundra

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In the tundra, bryophytes may be the dominant growth form covering the soil surface of shrub communities. They can modulate soil conditions through their capacity to retain moisture and nutrients and their chemical characteristics. The study of the interaction between shrubs and bryophytes is essential to understand the functioning of shrub communities, which are expanding due to global change. In this study, we collected *Betula nana* and *Empetrum hermaphroditum* ramets growing in moss carpets dominated by *Hylocomium splendens*, *Pleurozium schreberi* or *Sphagnum* spp., which differ in growth habit, density of their carpets and water holding capacity, amongst others. We sampled three ramets per site and moss species in eight locations distributed along a precipitation gradient (571-1155 mm/year) in the subarctic alpine tundra near Abisko, Sweden. To investigate structural and functional responses to the dominant moss species and precipitation regime, we prepared microscopic sections of the shrubs stem base and measured growth rings and xylem anatomical parameters. We also measured shrub leaf C and N concentration and isotope composition ($\delta^{13}C$, $\delta^{15}N$). To understand moss effects on soil characteristics along the precipitation gradient, we measured soil pH and water and nutrient content. Preliminary results on shrub leaf physiology and soil characteristics show a significant interaction between moss species and the precipitation gradient, indicating that mosses modulate the effects of climate conditions on shrubs. We discuss the importance of moss identity combined with the precipitation regime for the performance of tundra shrubs in the context of a changing climate.

Seasonal growth dynamics of Beech (*Fagus sylvatica* L.) on sandy soils in the Netherlands during the dry summer 2018

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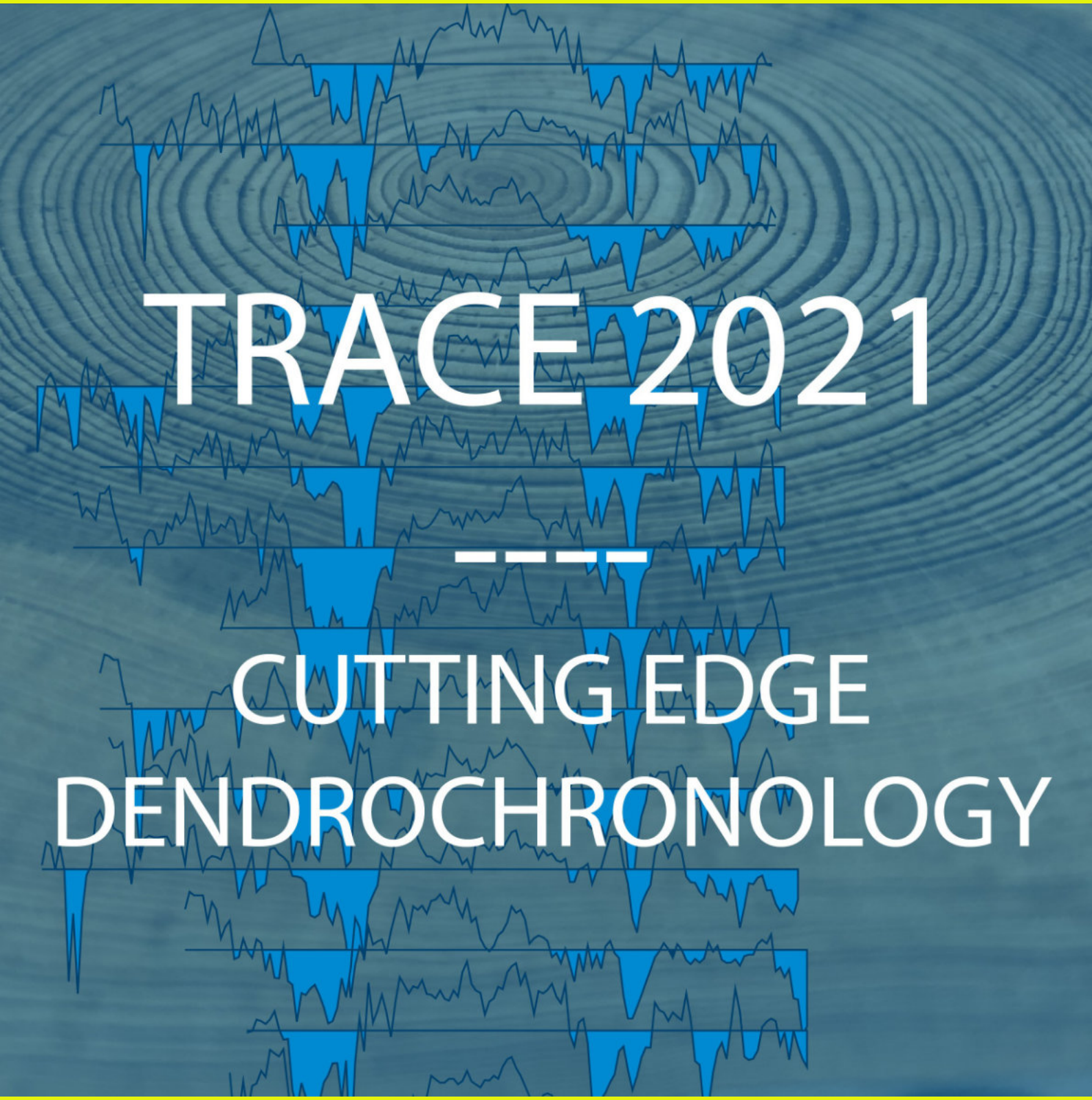
This study focused on studying the dynamics of stem growth of six beech trees (*Fagus sylvatica* L.) growing on sandy soils in the Netherlands in reaction to the extreme dry year 2018. By comparing high-resolution point dendrometer measurements with weekly taken cambial samples we studied the intra-annual growth reaction to prevailing early summer drought 2018. Point dendrometers record stem movements in response to external conditions with high temporal resolution but lack the possibility to distinguish between water-related stem movements and growth-related extension of the stem radius. Cambial analyses based on weekly taken microcores allows to actually study the dynamics of wood formation (cell division) and wood differentiation (enlargement and lignification). Key questions addressed were: How was beech cambial activity affected by the early summer drought in 2018? and in what way cambial analyses complements dendrometer measurements to distinguish between water-related and growth related stem-growth variations? We found that early summer drought caused a cease in cell-production rate. Cambial re-activation, i.e. observation of post-cambial cells occurred c. eight days after rainfall ended the dry period in August. The point dendrometers registered an instant stem enlargement at the day when rainfall occurred. This illustrates the relevance of combining both techniques to understand how drought affects water-related processes and stem growth.


TRACE 2021
CUTTING EDGE
DENDROCHRONOLOGY

Nanoparticle concentration in trees is higher through leaf delivery

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A greenhouse experiment was conducted to a) assess to what extent gold nanoparticles (Au NPs) are taken up by European beech (*Fagus sylvatica* L.) and Scots pine (*Pinus sylvestris* L.) seedlings through the roots and the leaves and b) investigate the influence of the surface charge on the transport of nanoparticles in these two tree species.

In this experiment, 40 *n*m Au NPs with different surface charges (positive, negative, and neutral, hereafter referred to as treatments) were supplied, individually to the leaves and to the roots. Twenty days after the treatments, gold was measured by inductively coupled plasma mass spectrometer (ICP-MS) in total digests of leaves, stems and roots. In the leaf supply, gold concentrations were higher in leaves and stems than in roots. In the root supply, we found higher gold concentrations in the roots than in the stems, but no Au NPs in the leaves. Overall, the measured gold was higher in beech than in pine, probably due to higher stomatal activity in beech that contributed to the nanoparticle uptake. Concentrations of variously charged gold particles were significantly different between root and leaf supply and among different tissues ($P < 0.05$), but differences in distribution patterns in pine were not discernible.

In conclusion, gold nanoparticles are taken up by both roots and leaves and transported to different compartments of trees. However, it seems that Au NPs are delivered faster from the leaves through the phloem to the xylem and are further distributed throughout the plant system, including to the roots.

Dendroanatomy – a new contender in Dendroclimatology

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The most frequently and successfully used tree-ring parameters for the study of temperature variations are ring width and maximum latewood density (MXD). X-ray MXD is currently the state-of-the-art due to the strong association with temperature. We challenge this paradigm when discovering the dendroclimatic potential of dendroanatomy in the first truly well replicated dataset. Twenty-nine mature living *Pinus sylvestris* trees were sampled close to the latitudinal tree line in North-eastern Finland. Ring width, X-ray MXD as well as the blue intensity counterpart, MXBI, were compared with dendroanatomical parameters with regard to their signal properties. Maximum radial cell wall thickness as well as anatomical MXD and latewood density appeared to be the most promising parameters for temperature reconstruction. In fact, these parameters compare favorably to X-ray MXD and MXBI, in terms of shared variation (rbar) and temperature correlations across frequencies and over time. We consider the reason for this interesting result to be the unprecedentedly high measurement resolution of the anatomical technique.

Tree vitality and forest health: any better indicators than tree-ring widths?

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Society is concerned about the condition of the forests. Although a definition of forest health is still missing, to evaluate forest health, monitoring efforts in the past forty years have concentrated on the assessment of tree vitality, trying to estimate tree photosynthesis rates and productivity. Used in monitoring forest decline in Central Europe since the 1980s, crown foliage transparency has been commonly believed to be the best indicator of tree condition in relation to air pollution, although annual variations appear more related to water stress. Although crown transparency is not a good indicator of tree photosynthesis rates, defoliation is still one of the most used indicators of tree vitality. Tree rings have been often used as indicators of past productivity. However, long-term tree-growth trends are difficult to interpret because of sampling bias, and ring-width patterns do not provide any information about tree physiological processes. In the past two decades, tree-ring stable isotopes have been used not only to reconstruct the impact of past climatic events, such as drought, but also in the study of forest decline induced by air pollution episodes, and other natural disturbances and environmental stress, such as pest outbreaks and wildfires. They have proven to be useful tools for understanding physiological processes and tree response to such stress factors. Tree-ring stable isotopes integrate crown transpiration rates and photosynthesis rates and may enhance our understanding of tree vitality. They are promising indicators of tree vitality. We call for the use of tree-ring stable isotopes in future monitoring programmes.

A density provenance model to improve millennium length temperature reconstructions

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Maximum latewood density (MXD) reveals improved temperature reconstruction skills compared to tree-ring width (TRW) and is thus highly valuable for paleoclimate research. Alpine sites, such as the Simplon valley in the Swiss Alps, offer great opportunities to develop long and highly temperature-sensitive chronologies as the period covered by living trees can be extended with material from historical buildings. However, the exact origin of the historical wood is unknown, hence the temperature sensitivity cannot be guaranteed. To solve this issue, we implement a provenance model for x-ray density measurements. We performed a multiple-site sampling of living *Larix decidua* trees (6 sites, 24 series each) along an elevational transect from 1400 to 2150 m asl in the Simplon valley covering the period from 1641 to 2011 CE. This dataset is extended to 985 CE (replication ≥ 5) by including 104 historical series to produce a 1026-year chronology. First results reveal MXD-MJJA temperature correlations ranging from $r \approx 0.3$ at lower to $r \approx 0.7$ at higher elevations. This gradient in temperature sensitivity highlights the importance of the elevational origin of historical material when it is incorporated in a chronology. The new provenance model, trained with density data from different elevations, will be used to estimate the origin of the historical wood and help to improve millennium length temperature reconstructions.

Is ring porosity a favorable strategy for oaks under different climate types?

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Ring porosity is the culmination of a long evolutionary process in which the conductive function is distributed along the growing season. Earlywood vessels, built early in the growing season, are primarily responsible for ensuring sufficient water supply for canopy performance throughout the growing season. In contrast, latewood vessels transport less water, but they are more resistant to embolism and functional for many years. Our study aimed to investigate the effectiveness of the ring-porous strategy displayed by deciduous oak species by determining the relationship between earlywood vessel size and canopy primary production. To do so, we have collected wood anatomical chronologies from more than 20 sites across a large environmental gradient and correlated these to normalized difference vegetation index (NDVI) time series from remote sensing, which were accumulated at different temporal scales across the whole growing season. Using a principal component analysis (PCA), we extracted three major patterns: 1) a constant negative, 2) a constant positive, and 3) a variable (positive in spring and negative in summer) relationship between vessel size and NDVI along the growing season. Relating these patterns to monthly climate conditions indicated that water availability during the growing season explains the variability associated with the correlation patterns among sites. Our study suggests that climate with strong intraannual precipitation variability might induce a mismatch between the hydraulic capacity of trees and canopy primary production during summer whereas this relation is well-tuned under mesic and xeric climates with low intra-annual rain variability.

Reconstruction of the Southern Hemisphere climate over the past millennium taking into account explicitly the links between climate and tree growth with process-based dendroclimatic models

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Trees are one of the main archives to reconstruct past climate variability at the interannual scale. The links between tree-ring proxies and climate have usually been estimated on the basis of statistical approaches, assuming linear and stationary relationships. Yet, both assumptions can be inadequate. This issue can be overcome by the use of process-based dendroclimatic models, such as MAIDEN. MAIDEN (Modeling and Analysis In DENdroecology) is a mechanistic tree-growth model that simulates tree-ring growth starting from surface air temperature, precipitation and CO_2 daily inputs. In this study, we provide a climate reconstruction of continental temperature, precipitation and winds in the mid to high latitudes of the Southern Hemisphere over the last millennium that takes into account explicitly the links between climate and tree growth. To this end, a data assimilation procedure is used to combine the information from the physics of the climate system, as included in climate models, and paleoclimate records, in particular tree-ring width and ice cores records (snow accumulation and $\delta^{18}O$). MAIDEN is used here as a proxy system model, also referred to as an observation operator in the data assimilation framework, to make the link between climate model outputs and indirect climate observations from tree-rings. The ice cores records are directly compared to the outputs of the climate model. More specifically, we evaluate the benefits of using tree-growth models such as MAIDEN for reconstructing past climate with data assimilation compared to the commonly used linear regression.

High-resolution reflected light imaging for dendrochronology: towards the development of unbiased reflectance timeseries

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Climate change is a global-scale issue of societal, economic, and political importance and so understanding the climate of the present within the context of past climate variability is of vital importance. Dendroclimatic reconstructions play an important role in improving our understanding of past climate and the climatically sensitive blue intensity (BI) parameter is gradually gaining prominence as a more affordable and accessible alternative to classical X-ray densitometric measurements. Yet the accurate representation of low-frequency trends and high-frequency extremes using scanner-based BI measurements remains a challenge due to color-related biases and resolution limitations. As part of the REPLICATE project, which aims to develop robust high-quality multi-parameter reconstructions of East-Central European temperatures from Norway spruce tree rings, recent methodological advances in sample surface preparation, imaging and measurement techniques have produced measurements analogous to BI from very high-resolution (~8600 true dpi) images. These quasi-BI series from microscope-based reflected light images of tree-ring sample surfaces approximate anatomical density as they are based on the binary representation of wood anatomical structure. By eliminating color and measuring anatomical density, the most substantial drawbacks of traditional scanner-based BI, including sample surface discoloration biases, are bypassed and hence climate signal optimization is achieved by more accurately representing low-frequency climatic trends and high-frequency extremes. Continued development of these high-resolution imaging and image processing techniques, which show promise in overcoming both color biases and resolution issues, will aid the attainment of unbiased long chronologies. These improvements may ultimately contribute to developing higher-quality tree-ring-based paleoclimatic records and more accurate climate reconstructions.

Recovering shifts in drought imprints from tree growth to understand the vulnerability to dieback

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Forest dieback caused by drought is a global phenomenon affecting biomes worldwide. Affected tree stands show a pronounced loss of leaves, growth decline and high mortality in response to extreme climate events such as heat waves and droughts. However, dieback events do not uniformly affect stands with some trees showing higher vulnerability than other neighboring conspecifics. We investigated if trees showing different vulnerability to dieback showed lower growth rates and higher sensitivity to climate by using dendroecology and the Vaganov-Shashkin (VS) process-based model. We studied two *Pinus pinaster* stands showing recent dieback in the Iberian System, north-eastern Spain. We compared coexisting declining (D) and non-declining (ND) trees with crown defoliation values above and below the 50% threshold, respectively. The mean growth rate was lower in D than in ND trees and the two vigor classes showed a growth divergence prior to the dieback onset and different responsiveness to climate. Non-declining trees were more responsive to changes in spring water balance and soil moisture than D trees in one site. Such interaction between water availability and tree vigor was reflected by the VS-model simulations which showed that D trees tend to grow more and that growth os mainly limited by low soil moisture. However, in the second site ND and D trees showed similar growth rates and responses to climate indicating all trees were chronically stressed regardless their recent vigor status. The presented comparisons indicate intrinsic differences in growth responses to soil moisture between co-occurring trees and different stand vulnerability to drought contingent on site conditions and individual features.

High-frequency stable isotope signals in uneven-aged forests as proxy for physiological responses to climate in Central Europe

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Picea abies and *Fagus sylvatica* are important tree species in Europe, but their physiological performance under climate change at temperate sites is not yet fully understood. We, investigated tree-ring width and stable isotope chronologies ($\delta^{13}C/\delta^{18}O$) at 10 sites in Central Europe. In these uneven-aged stands, we compared the year-to-year variability of dominant and suppressed trees for the last 80 years in relation to the sites' spatial distribution and climate.

The high-frequency signal of $\delta^{18}O$ and $\delta^{13}C$ were generally consistent across sites and species, showing high sensitivity to summer VPD, whereas radial growth correlations varied depending on mean climate. We found no significant differences between dominant and suppressed trees in the response of stable isotope ratios to climate variability. Additionally, we observed a strikingly high coherence of the high-frequency $\delta^{18}O$ variations across long distances with significant correlations above 1500 km, while the spatial agreement of $\delta^{13}C$ variations was weaker (~700 km). We observed a significant enrichment of either or both isotope ratios over the last decades, indicating a general climate-driven decrease in stomatal conductance. This improved understanding of the physiological mechanisms controlling the short-term variation of the isotopic signature will help to define the performance of these tree species under future climate.

Evaluating the dendroclimatological potential of Blue Intensity on conifer species from Australasia

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We evaluate a range of Blue Intensity (BI) tree-ring parameters on eight conifer species (12 sites) from Tasmania and New Zealand for their dendroclimatic potential and also as surrogate wood anatomical (WA) proxies. Using a limited dataset of ca. 10-15 trees per site, we measured earlywood maximum blue reflectance intensity (EWB), latewood minimum blue reflectance intensity (LWB) and the associated Delta Blue Intensity (DB) parameter for dendrochronological analysis. No resin extraction was performed, potentially impacting low frequency trends. Therefore, we focused only on the high frequency signal by detrending all tree-ring and climate data using a 20-year cubic smoothing spline. All BI parameters express low relative variance and weak signal strength compared to ring-width. Correlation analysis and principal component regression experiments identified a mixed climate response for most ring-width chronologies. Despite the weak signal strength, strong calibrations with summer temperatures were noted for the EWB data for most sites. Significant correlations for LWB were also noted, but the sign of the relationship for many species (i.e. five out of the eight species) is opposite to that reported for all conifer species in the Northern Hemisphere. DB performed well for the Tasmanian sites but explained minimal temperature variance in New Zealand. Using the full multi-species/ parameter network, excellent summer temperature calibration was identified for both Tasmania and New Zealand ranging from 52% to 78% explained variance, with equally robust independent validation (Coefficient of Efficiency = 0.41 to 0.77). Comparison of the Tasmanian BI reconstruction with a WA reconstruction shows that these parameters record essentially the same strong high frequency summer temperature signal. Despite these excellent results, a substantial challenge exists with the capture of potential secular scale climate trends. Although DB, band-pass and other signal processing methods may help with this issue, more experimentation, in conjunction with comparative analysis with maximum latewood density and WA measurements, is needed.

Tree-ring stable isotopes variations after major volcanic eruptions

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The precise tree-ring widths (TRW) with annual resolution have already been widely used to investigate climate variations following major volcanic eruptions of the last centuries. The stable isotopes of tree-rings are known to be climatic proxies complementary to TRW, yet there are only limited studies available using stable tree-ring isotopes to trace climate variability after volcanic eruptions. To study which of the stable isotopes carries information of the climate changes driven by eruptions we analysed the isotope values of cellulose from trees living in the periods around the eruption of the tropical Tambora volcano eruption of 1815 CE and of the Icelandic Katla volcano eruptions of 720-780 CE. The $\delta^{18}O$ data with annual resolutions overlapped those of 5y resolution available in the Eastern Alps Conifer Chronology. The $\delta^{18}O$ values detected a climatic variation after Tambora, but not after Katla eruption. A significant correlation was found between the cellulose $\delta^{18}O$ and the summer temperature records of HISTALP database (period 1800-2010). The analysis was extended to the eruptions of one tropical and one Icelandic volcano using the 5-year resolutions data of the alpine database. This confirmed that $\delta^{18}O$ values, but not δD and $\delta^{13}C$ values, were partially sensitive to the eruptions. In conclusion our data indicate that cellulose $\delta^{18}O$ values can provide significant information on the climatic variations following strong volcanic eruptions.

Changes in the growth rates of trees in Eastern North America accounting for the fitness – suitability hypothesis

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Some studies show increasing tree growth rates through time while others show decreasing tree growth rates. According to the fitness-suitability hypothesis, trees growing in areas where conditions are becoming more favourable through time should increase in growth whereas trees growing in areas where conditions are becoming less favourable through time should decrease in growth despite increasing CO2. We calculated tree growth rates for thousands of trees of 39 species at 595 locations throughout Eastern North America based on tree-ring data available in the International Tree Ring Data Bank (ITRDB). For each species, we created species distribution models (SDMs) based on available occurrence locations in the Botanical Information and Ecology Network (BIEN) and the Global Biodiversity Information Facility (GBIF). We then used these SDMs to estimate changes in climatic suitability for each tree population from 1915 to 1995 using the CRU TS3.10 historic climatic databases. Lastly, we assessed the relationships between tree growth (correcting for tree size and ontogeny) and climatic suitability using linear mixed models accounting for species and site-level effects. We found that climate suitability has a positive effect on tree growth rates but that tree growth rates are tending to decrease through time regardless of changes in suitability. These results indicate that changes in climate suitability are important for driving patterns of tree growth, but that changes in other climatic and environmental factors that are not included in our study may be having negative impacts on tree growth, outweighing any potential benefit of increasing CO2.

The role of adventitious roots in the analysis of the modern aeolian processes activity in the temperate climate zone; A case study of "Kozłowska desert", SW Poland

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A spatiotemporal reconstruction of inland dune movements at the anthropogenic „Kozlowska desert", SW Poland, is presented. This unique sandy area with the assemblages of aeolian forms typical for "true" desert is an inactive military training ground (liquidated in 1992) where military actions led to the initiation of geomorphic processes. The reconstruction were carried out by means of growth reaction characteristics of Scots pine (*Pinus sylvestris* L.) and downy birch (*Betula pubescens* L.) trees. 14 increment cores from 12 trees were collected and analyzed following standard dendrochronological techniques. Samples of adventitious roots from all examined trees were collected and prepared to extend the analyses and check their usefulness in dating modern geomorphic processes. Results show differences in reaction of adventitious roots of pine and birch to burial, both in reaction time and shape of the root system. We found evidence in growth-ring widths and wood anatomy of sudden or multi-stage sand movement which confirms usefulness of adventitious roots as an additional source of information about aeolian processes activity. Based on these data, we recommend to use a combination of methods and compare data from the roots to the data from the stems. This will more accurately and more reliably assess the dynamic and activity of landforming processes. We also indicate the need for further research on the use of adventitious root in the dating of geomorphic processes especially from the changes of wood anatomy and root morphology point of view.

Masting creates sex-specific growth patterns in Araucaria araucana tree-rings

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Araucaria araucana is a dioecious evergreen conifer endemic to temperate forests of South America. It is a long-lived species (maximum age > 1000 years), with high potential for tree-ring based climate reconstructions. However, the species' dioecious habit (individuals are either male or female) is associated with distinct sex-specific growth patterns. This introduces novel challenges in the interpretation of their tree-ring chronologies.

We used a network of 10 chronologies from northwest Patagonia (Argentina) to analyse sex-specific growth patterns in *A. Araucana*. For the first time, we show that differences in the growth patterns of male and female trees resulted from their contrasting responses to mast events (years with high seed production). During mast events, the growth of females was strongly and significantly reduced relative to male trees. A growth response of similar magnitude was found in male trees in the previous year, corresponding to the year of pollination. The sex-specific growth responses associated with mast events resulted in a strong and distinct signal in a RWI_{male}–RWI_{female} chronology.

Despite masting-related differences, male and female tree-ring chronologies shared a strong common climate signal. Our results indicate that sex-specific tree-ring signals can be leveraged to isolate mast events in *A. araucana* chronologies, providing an opportunity to develop multi-century reconstructions of large mast events, and improve dendroclimatic calibration for this species.

The comparison of Gompertz function, general additive models and artificial neural networks for modeling xylem and phloem formation

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One of the crucial steps in seasonal radial growth analyses is to model the dynamics of xylem and phloem formation based on intra-annual observations of growth ring formation. The most common approach is the use of Gompertz equation, while other approaches, such as general additive models (GAMs) and generalized linear models (GLMs), have also been tested in recent years. In our study, we explored artificial neural networks with Bayesian regularization algorithm (BRNNs) to evaluate the seasonal patterns of radial tree growth. In addition, we also tested a modified GAM approach that allows more flexible fits. The main result of our work is a function implemented in the R environment that can be used to quickly evaluate and compare three modelling approaches: BRNN, GAM and Gompertz function. Importantly, the Gompertz function has a predefined parameter search grid, therefore initial parameter values are not required. We tested the newly developed function on intra-seasonal xylem and phloem formation data from three different tree species with different data (number of cells or increment widths), site characteristics and climatic conditions: European beech (*Fagus sylvatica*), Norway spruce (*Picea abies*) and pubescent oak (*Quercus pubescens*). Different approaches were evaluated in terms of explained variance and accuracy of estimated onset and cessation of wood formation. In addition, the fitted curves were visually evaluated to derive their main characteristics. Our results suggest that there is no single fitting method that always gives the best results, therefore we recommend always testing different fitting methods and only then selecting the optimal one.

Effects of disturbance on chronology structure of tree ring width and blue intensity in central-eastern European Norway spruce

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Tree radial growth is influenced by various climatic and non-climatic factors. We investigated the influence of disturbance on the structure of tree ring width (RW) and blue intensity (BI) chronologies of Norway spruce from the Carpathian mountains to explore the extent to which disturbance affects the expression of the climate signal in tree rings. Overall, 15122 high-elevation Norway spruce tree cores from 35 stands grouped into 4 sub-regions (Slovakia, Ukraine, North and South Romania) were collected and assessed. Chronology structure comparisons were performed at regional and stand level among chronologies of both parameters developed from 3 subgroups: undisturbed, disturbance-uncorrected (pre-CID), disturbance-corrected (post-CID). Growth-climate relationships of stands with obvious chronology structure variations between subgroups were compared. Results show that effects of disturbance can be observed among RW chronologies of different sample sets and RW chronologies composed of a relatively small number of samples are most susceptible to the effects of disturbance. The Curve Intervention Detection (CID) method can help to identify and remove disturbance trends and improve the expression of the climate signal in RW chronologies. However, this treatment can also lead to over-correction in some cases. BI chronologies appeared to be mostly unaffected by disturbance with minimal structure differences been observed. These results indicate that the influence of non-climatic (disturbance) factors on tree ring time series should be considered when undertaking dendroclimatic research, especially involving the reconstruction of past climatic conditions. Blue intensity is a promising alternative tree ring parameter for dendroclimatological studies with a structure seemingly unaffected by disturbance.

Exploring Blue Intensity as a climate proxy of *Betula utilis* in the Central Himalayas, Nepal

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Himalayan birch (*Betula utilis* D. Don; BEUT) is one of the most frequent tree species of treeline ecotones across the Himalayan mountain range, occurring together with e.g., Himalayan Silver Fir (*Abies spectabilis* (D. Don) Spach) or as predominant . Therefore, studies of growth and dendroclimatology of Himalayan birch are crucial for better understanding how Himalayan and other treeline ecotones, react to recent climate change. Bhattacharyya et al. (2006), Dawadi et al. (2013), and Liang et al. (2014) demonstrated possibilities of building multi-century chronologies with the potential for climate reconstruction. However, both traditional tree-ring width based (Bhattacharyya et al., 2006; Liang et al., 2014; Dawadi et al. 2013, Tiwari et al. 2017, Gaire et al. 2017) and methodologically more sophisticated studies analysing wood anatomy (Pandey et al. 2018) and stable isotopes (Pandey et al. 2020) resulted in highly complex and variable growth-climate responses. These previous results show that growth of BEUT is often affected by drought while temperature also plays an important role. Additionally, the xylem anatomical responses emphasised the importance of carry-over effects for both, precipitation and temperature. The use of broadleaved tree species' Blue Intensity (BI), a tree-ring parameter strongly related to wood density is still in experimental stage. Recent results prove the possibility of deriving coherent and independent of tree-ring width climate signals. Therefore we explored the dendroclimatic potential of *Betula utilis* BI. Here we present results of this first attempt to measure and analyse BI of birch samples from trees growing at ca. 3700 - 4000 m a.s.l. in the Rolwaling Valley, Gaurishankar Conservation Area, Dolakha District, East Central Nepal.

Radial growth response of *Pinus sylvestris* L. and *Fagus sylvatica* L. to technological solutions appplied in rope climbing parks

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Industrial research and development work were carried out to develop a new arboreal platform with a non-invasive tree fastening system. The main disadvantages of the standard platform fastening system are trees injuries, lack of universality, "mobility" and multifunctionality. The health and vitality of 20% to 50% of the trees on which platforms are installed are significantly reduced and lead trees to be cut. The research was carried out on European beech and Scots pine trees at four research plots in two climatic zones within the period 2017 to 2020. Wood samples were taken from the examined trees at the dbh level with the Pressler drill. Samples were collected from three groups of trees at each plot: a) trees with a new designed platform, b) trees with a standard platform, c) reference trees. The analysis of tree-ring widths concerned the years 2010-2016 (before the assembly of the platforms) and 2017-2020 (after assembling of the platform). A decrease in the radial growth after platform installation was demonstrated. Significant differences between these periods for all tree groups on plot B and trees with standard platforms on plot C were demonstrated. Pine trees with the designed platforms on both research plots (A and C) showed the highest value of the growth index in the period 2017-2020, while beech trees with this platforms expressed the lower growth index in this period. It is important to conduct further research over a longer period of time in order to finally assess the impact of the designed platforms on the vitality of trees.

Evaluation of the Vaganov-Shashkin model in a temperate, mesic forest with high precission input data

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The Vaganov-Shashkin model (VSM) has proven its skill to simulate real-world tree-ring width chronologies at many different sites in various tree line ecotones. We test VSM to model tree-growth in a temperate, mesic forest where growth is often controlled by multiple climatic and several non-climatic factors such as management or competition. In contrast to many tree line sites, this challenging setting in central Germany provides plenty of additional environmental data. An on-site weather station and several hydrological parameters monitored for up to 8 years allow us to supply VSM with high precision input data that represent the tree site very well. After transferring the model into the Python environment, we exchanged the "leaky bucket model" which is the model's hydrological subroutine and replaced it with (i) observational data or (ii) with output from a more complex hydrological model. Our results reveal that VSM is able to reproduce local tree growth considerably well ($r_{1947-2018} = 0.55$) and that it benefits significantly from on-site meteorological data ($\Delta r = 0.05$). Particularly, years in which growth is limited by drought stress are less well captured if the closest accredited meteorological station (15 km distance) is used instead. However, the estimates for the trees' water supply cannot be improved with local observational data, indicating uncertainties in the soil moisture measurements or in the thresholds implemented in VSM. To better understand this mismatch we intend to compare simulated tree growth with dendrometer data that are currently collected in this forest.

Non-destructive dendrochronological analysis of Norway spruce at the wood auction 2020 in Slovenia

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On auction of valuable wood assortments 2020 in Slovenia we developed non-destructive protocol for dendrochronological sampling of Norway spruce logs. The assortments at the auction correspond to the first log of the tree. Common approach is to extract the samples at the breast height, being this point the most representative for three characterization. The assortments at the auction offered for timber, veneer, musical instruments, reach very high prices, and it is not desirable to damage them. Therefore, the most suitable place is on the transversal section at the end of the log. Since the log's lengths varied, we focused on 4 to 4,5 m long to obtain homogeneous and comparable dendrochronological dataset. With hand-held cordless trimmer we cut 25 mm wide and 5m deep groove on transversal section along the diameter, to get the tree rings visible. We fixed scale bars at the beginning of two radius, and captured digital photographs, the first form A scale bar from bark to pith and the second from B scale bar from bark to pith. The photos were saved with the corresponding number of logs indicating A and B sample, and later used for analysis with CDendro & CooRecorder 9.6 program for crossdating, tree-ring widths measuring and chronology construction. From 80 logs sampled, 59 were successfully analysed and included into dataset, containing from 79 till 166 tree rings. We measured also acoustic signals, collected volumetric and economic data, which together with the dendroecological dataset can be useful to characterize wood quality parameters.

Detrending methods applied to *Ocotea porosa (Nees & Mart) Barroso* trees

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The tree-ring study allows us to infer environmental conditions and geophysical phenomena in the past, such as, records of temperature and precipitation, fire history, cyclones etc. Tree growth occurs due to several psychological and biochemical factors. To this end, it is necessary to consider the biological factors (internal factors), such as the natural growth trend of the species, when we are interpreting data from tree rings. To analyse external influence signals in the time series it required to remove the natural growth trend in order to maximize the external signals (low-frequency variation). Statistical methods can be applied in the tree-ring time series, this application is known as detrending or standardization. The choice of the detrending method will depend on the purpose of the study, because it will influence in the interpretation of the tree-ring data. Some species have been worked on by dendrochronologists historically, however, the introduction of new species to these studies can significantly contribute to obtaining results on the climatic dynamics of different regions. The Ocotea porosa (Nees & Mart) Barroso tree belongs to the Lauraceae family, and it is known as Imbuia. This specie can reach heights of 10 to 20 meters, and an average of diameter at breast height (DBH) between 50 to 150 centimetres. In adulthood, the height values can reach up to 30 meters, and the DBH of 320 centimetres or more. However, Imbuia is not very used in dendrochronology studies, but some works already address its dendrochronological potential. Imbuia is natural-born in the following Brazilian states: Paraná, Rio de Janeiro, Rio Grande do Sul, Santa Catarina and São Paulo, between latitudes 22°30'S (RJ) and 29°50'S (RS), and it is associated with Araucaria angustifolia (Pinheiro-do-Paraná). In the pine sub-forests, it constitutes the most abundant tree, being commonly found from 6 to 20 adult Imbuias per hectare. Imbuia is possibly the longest-lived tree species in the “araucaria forest”, and it can exceed 500 years of lifetime. Its area of occurrence coincides with the humid climate without dry season and with average annual temperatures ~18°C. Anatomically in cross section of the wood, the presence of distinct growth layers is observed. It is characterized by the flattening of the fibres in the late wood, with cell walls that gradually thicken in the radial direction. At the boundaries between the tree ring growths, there is a sudden transition from cells with thick walls to those with thin walls which characterize the initial wood of the next ring. Aiming at the importance of choosing the best method of detrending for the series of tree rings, this work applied two methods to remove the tendency of natural growth of trees (detrending). The Polynomial and Linear Model (PLM) and the Regional Curve Standardization method (RCS) were the chosen methods. Does the PLM calculate an exponential or linear curve that obtains the smallest possible error, and perform a subtraction and a division (to compare) from the original series, to remove the natural growth trend of tree samples, in order to obtain the tree-ring indices. In the RCS the arithmetic mean of the measurements is used to produce an average curve per year, and then it uses a 67\% spline to obtain a less noisy curve. The results showed that the RCS method obtained better results, compared to the STD if the main goal is the preservation and interpretation of long-timescale variance in tree-ring chronologies, other methods, end up removing part of those long-timescale variance, and consequently, are not highly recommended for dendroclimatic studies.

Relating growth, wood anatomy and microdensity to carbon and water cycling along an 8-year rotation of *Eucalyptus grandis*

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Wood productivity of fast-growing eucalypt plantations is expected to be strongly affected by climate change. A better understanding of the trees physiological mechanisms underlying biogeochemical cycling and productivity is thus needed to anticipate and mitigate the aftermaths of climate change on plantation functioning. The retrospective analysis of eucalypt trees growth, wood anatomy and microdensity can bring important knowledge on tree physiology. In addition, the extent to which these data relate to water and carbon cycling at the ecosystem level remains unclear. In particular, other processes such as soil respiration and evaporation, direct climate effects on cambial activity or changes in within-tree carbon allocation could complicate the interpretation of wood-based data. Here, we aimed to relate growth, wood anatomy and microdensity to eddy covariance carbon and water fluxes along an 8-years full rotation of *Eucalyptus grandis* plantation. A destructive 30 trees-wood biomass sampling was conducted within the footprint of the EUCFLUX flux tower (Itatinga-SP , Brazil). Eucalyptus trees trunk diameter inventories conducted along the whole rotation were used to determined annual and intra-annual growth rings thickness. Wood microscopic structure was evaluated using long histological sections (Core-microtome) and microdensity profiles (X-ray, Faxitron). Eddy covariance carbon and water fluxes, soil water content, soil water table dynamic and meteorological variables were obtained along the whole rotation from the EUCFLUX project. The climate variables and carbon and water fluxes presented a strong correlation with the eucalyptus growth rings. The dendroecological study of eucalyptus is possible and critical for the proper management of these forests.

Inter growth-rings variability and relationship of wood density and chemical traces in Amazonian tropical species

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In tropical tree species, the structure of growth rings has been scarcely explored by complementary physical and chemical parameters. Here, we analyse the relationships among wood density features and tree-ring chemical elements (S, K, Ca, Mn) involved in the annual ring formation of 12 tropical tree species of Brazilian Amazon forest. Transversal wood sections were used for each species to determine tree ring distinction and X-ray densitometry (physical) and X-ray fluorescence (chemical). The profiles of wood density, Ca and Mn, showed intra- and inter-annual patterns that allowed to delimit and characterize the boundaries of annual growth rings. Our results showed significant correlations between tree-ring formation process and intra- and inter- annual changes in density, Ca, K and Mn as markers of seasonality and showing species-specific patterns. The anatomical characterization and the developed of density and chemical profiles in tropical Amazonian species represent a valuable proxy to improve the definition of ring-boundaries and the understanding of seasonal growth patterns in other moist tropical forests.

Climatic context of a millennium-long 'Blue Ring' chronology from Bristlecone Pine and its potential as a record of volcanic forcing on climate

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'Blue Rings' (BRs) are distinct wood anatomical anomalies recently discovered in several tree species. Previous studies connect their occurrence to lower than normal temperatures during the cell wall lignification phase of xylogenesis. Cell wall lignification usually continues after radial growth is completed, after the growth season. Therefore, systematic analysis of blue rings can add another level of time resolution to dendroclimatic studies. BRs are also more sensitive temperature recorders than frost rings which require freezing temperatures to form. We present a continuous chronology of blue rings in North American bristlecone pine from the White Mountains (California) covering the last millennium and their connections to volcanic eruptions known both from historic and ice core records. Additionally we present climatic context of BR occurrence for the period since 1895 when modelled surface temperatures are available for the grid cell pertaining to the study area location (4km spatial resolution, from PRISM Climate Group, Oregon State University). Most recorded BR years coincide with cooling following large volcanic eruptions. The three most prominent events during the last 1000 years, with the highest share of blue rings in bristlecone pine are at: 1453, 1601 and 1884CE (83%, 91%, 69% of blue rings respectively), attributed to known eruptions of Kuawe (attribution still debated) 1452CE -Vanuatu, Huaynaputina 1600CE – Peru, and Krakatoa 1883CE - Indonesia. Fourth most prominent event with 58% of blue rings is noted in 1200CE. Acidity peak in 1200CE is so far recorded only in Greenland ice-cores suggesting northern hemisphere high latitude eruption, but strong BR signal would suggest a broader climatic significance of this event. It is interesting to note that BRs were indicated in 69% of samples in 1884, relating to the known eruption and associated climate impact of Krakatoa (1883), yet no BRs were observed in 1816, the so-called year without a summer which followed the largest historically noted and well described eruption of Tambora, Indonesia (1815). We did find a strong BR signal in 1809 (with BRs continuing in 1810 and 1811) following an unidentified but prominent eruption seen in ice core records. The 1809 and 1815 eruptions are thought to be responsible for the cold decade from 1810 to 1819 thought by some to be the coldest decade of the last 500ys. The source of 1809 eruption remains unknown and scientific debate over the scale of the eruption continues, but bipolar acidity peaks in ice cores point to a tropical eruption with widespread sulfate distribution to both hemispheres and tephra in ice cores points to two coinciding high latitude eruptions of only regional prominence. The BR record supports 1809 CE as an event of global climatic significance illustrating the capacity for BRs to capture cooling events with even higher time resolution and of smaller magnitude than frost ring records, TRW or MXD studies, to help better investigate and understand the impacts of volcanism on climate and society.

Exploring the spatial extent of the climate signal in a *Pinus heldreichii* Blue Intensity chronology from Southeastern Europe

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Tree rings from long-living tree species are one of the most valuable paleo-climate archives. Often the best correlations with the climate parameters of interest, especially summer temperature, are found for Maximum latewood density (MXD). A potential easier and more affordable surrogate for MXD is Blue intensity (BI).

We explore the spatial correlations with climate parameters of a novel BI chronology from Bosnian pine (*Pinus heldreichii* Christ) in the Pirin Mountains, Bulgaria. The tree species is among the longest-living in Europe, currently holding the record of 1230 years and has been demonstrated to be a good archive of past climate variation.

We found strong positive correlations ($r>0.6$) between our BI chronology and July-August temperatures (mean and maximum) over SE Europe expanding from approximately 10°E to 40°E and 35°N to 50°N. The correlations were negative with summer temperatures in the NW Europe. For summer precipitation and drought indices (PDSI and SPEI), we found significant negative correlations for the Balkan region. The correlations with the 300mb geopotential height pressure were positive for the summer for SE Europe and negative for NW Europe. The results were similar for both the Latewood BI chronologies and Delta BI chronologies. These chronologies also had strong correlations ($r>0.70$, reaching 0.88) with previously composed MXD series from the same locations, which were stable over the common period of the last several hundred years (1600-2009). Our results demonstrate good potential to contribute to the understanding of past climate variation in Europe by constructing long and robust BI chronologies from *Pinus heldreichii*.

dendRoAnalyst: A package to process and analyse time-series dendrometer data

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Dendrometers are vital for studying the response of trees to intra-annual environmental changes in different temporal resolutions, ranging from several hours, to days or weeks. Recently, the use of dendrometer has been increasing in forest management and tree physiological studies. Besides the data analysis, data processing is also challenging due to the huge number of measurements generated by self-registering electronic dendrometers. There are two major approaches to analyze dendrometer data: 1) the Stem-cycle approach (SC), and 2) the Zero-growth approach (ZG). We present a package '**dendRoAnalyst**' based on R statistical software to process and analyze dendrometer data using both approaches. This package offers algorithms for managing and cleaning data before the application of different approaches. This includes identifying and erasing sudden jumps in dendrometer data not related to environmental change, identifying the time gaps of recordings and changes in the resolution of data due to different temporal resolutions. Furthermore, the package calculates daily statistics of dendrometer data, including the daily amplitude of tree growth. Both SC and ZG approaches are used to separate radial growth from daily cyclic shrinkage and expansion due to uptake and loss of stem water. In SC approach, the package categorizes the dendrometer data in three phases namely shrinkage, expansion and radial increment while in the ZG approach it classifies the data into two categories, namely tree-water deficiency (TWD) and radial growth (GRO). Additionally, it generates a data frame with records of the beginning, ending, duration, magnitude and various other statistics of each phase. This package is intended to facilitate researchers with collection of functions for the complete study (from processing to analysis) of dendrometer data.

A new interdisciplinary approach to illustrate climate change on forest ecosystems

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By combining climate modelling, dendroecology, and educational research and their exchange of research data and expertise, the composite project BayTreeNet studies the local climate dynamics in a unique interdisciplinary approach. By defining specific weather types and forecasting the probable frequency of these specific weather types using a climate modelling approach, tree responses to current weather conditions can be calibrated, and forest responses to future occurrences of weather patterns can be simulated. Moreover, for a better understanding of climate change and its impacts, the educational research will utilise climate modelling results as well as dendroecological findings to receive an empirically founded teaching concept. To explain interconnections between macro weather situations and forest ecosystems in Bavaria, one approach will be to implement internet-connected "talking trees". Ten of those trees accessible to the public are equipped with a sap flow sensor, a dendrometer, and an internet-based transmission unit. School classes interpret the real-time tree reactions and on-site weather data, and translate the current tree responses into simple text messages via "Twitter". All weather data, tree data, and explanatory text messages are displayed on the project Homepage https://baytreenet.de. By comparing the different activities of trees within the network, the local tree responses to current weather conditions can be related to specific weather types. E.g., during north-westerly winds, trees in basins in the rain shadow of mountain ranges suffer from dry conditions, whereas trees growing at high-elevation sites exposed to the west receive ample amounts of rainfall. These patterns will change if the wind direction is reversed under the prevalence of other weather types. Such an approach allows a deeper understanding that climate change is more than just a regional increase in temperatures, and ecosystem responses are controlled by more complex conditions. Therefore, not only students but also the public will be informed about the effects of concrete climate events on forest ecosystems.

Detrending Tree-ring Widths in Closed-Canopy Forests for Dendroecology and Dendroclimatology

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Canopy disturbance events typically increase light availability within closed-canopy forests resulting in the subsequent rapid growth of surviving, released trees. Using chronologies of tree-ring widths, intervals of rapid growth may be detected and reconstructed as indicators of these past forcing events. Ecologically, these intervals enable reconstructions of canopy disturbance history and its impact on forest age, composition, and structure. Climatologically, these intervals represent noise that impede ring-width reconstructions of past climate. Forest ecologists have developed radial-growth averaging methods to identify the frequency and magnitude of past canopy disturbance events, but these methods do not fully isolate the growth response as a discrete signal. Conversely, dendroclimatic methods remove non-climatic signals from chronologies but not in a manner that generally identifies the frequency and severity of canopy disturbance events. Time-series methods have demonstrated the ability to both identify and isolate these disturbance signals, but they may not be more accurate than radial-growth averaging and have not been widely adopted because of their complexity. We present a new, hybrid approach to identifying and isolating canopy disturbance signals in tree-ring widths using a combination of radial-growth averaging and common dendroclimatic detrending methods. Using examples from deciduous forests in eastern North America, we show how this method uses radial-growth averaging to detect release events and then power transformation and age-dependent smoothing splines to separate a tree's growth response to canopy disturbance from climate. This approach should be useful for both dendroecologists and dendroclimatologists studying closed-canopy deciduous forests.

Discovery of annual growth in a modern olive branch based on carbon isotopes and implications for the Bronze Age volcanic eruption of Santorini

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The volcanic eruption of Santorini in the Bronze Age left detectable debris across the Mediterranean, serving as an anchor in time for the region, synchronizing chronologies of different sites. However, dating the eruption has been elusive for decades, as radiocarbon indicates a date about a century earlier than archaeological chronologies. The identification of annual rings by CT in a charred olive branch, buried alive beneath the tephra on Santorini, was key in radiocarbon dating the eruption, and a subject of long-standing debate, as no one ever proved the possibility of correctly identify annual tree rings in olives. Here, we detect a verified annual growth in a modern olive branch for the first time, using stable isotope analysis and high-resolution radiocarbon dating, identifying down to the growing season in some years. The verified growth is largely visible by CT, both in the branch's fresh and charred forms. Although these results support the validity of the Santorini branch date, we observed some chronological anomalies in modern olive and simulated possible date range scenarios of the volcanic eruption of Santorini, given these observed phenomena. The results offer a way to reconcile this long-standing debate towards a mid-sixteenth century BCE date. In addition, we report the radiocarbon results of a c. 500 years old living olive tree.

Integrating multiple-proxies from tree rings and speleothems to allow paleoclimate studies in Central Brazil using a unique set of subfossil wood

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The last two thousand years were marked by periods of abrupt changes that caused several impacts for societies such as the Late Antique Little Ice Age (LALIA), the Little Ice Age (LIA) and the Current Warm Period (CWP). However, the exact effects in tropical regions remain unclear due to the limitation of the available paleoclimate records. Tree rings provide the most accurate pre-instrumental information of environmental variability at annual resolution, but the tropics lag behind because the tree-rings might not always be annual and clear. The construction of long records using tree rings is another difficult task in the tropics where climate conditions are not good for wood preservation. But ideal conditions were found in the karstic regions from Central Brazil where trunks got trapped inside caves during flooding events. We selected trunks of *Amburana cearensis* whose living trees have proven strong common-growth and rainfall signals. High frequency climate signal will then be synchronized with records from local speleothems to reconstruct conditions during key climatological periods. Based on an extensive ^{14}C dating, a subfossil sample covers the LALIA, two overlap during the LIA and one covers the first half of the 20th century. Gaps between series will be partially filled by old-growth individuals and samples from historical sites. Our attempt is to combine two proxies in order to produce a robust reconstruction of climate conditions, that may reveal the impacts of LALIA, LIA and the CWP in Central Brazil.

Hydroclimate proxies using stable isotopes in grey mangroves *(Avicennia marina)*

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The search for high-resolution terrestrial palaeoclimate records in Australia is hindered by the scarcity of tree species suitable for conventional dendrochronology. However, novel analytical techniques have made it possible to obtain climate information from tree species that do not reliably form cross datable annual growth rings. This study aimed to determine whether stable isotopes in the xylem wood of grey mangroves (*Avicennia marina*) can be used as a proxy for local hydroclimate using correlation analysis. Bomb pulse radiocarbon dating and simple age models were used to estimate the age of each non-annual growth layer in radial sequence, in stems from four mangrove trees in two adjacent riverine estuaries in New South Wales, Australia. Stable isotope analyses of the four stems yielded values which were rounded to the nearest calendar year and averaged to produce mean $\delta^{18}O$ and $\delta^{13}C$ series for the 1962-2016 period. Significant spearman correlations were found between $\delta^{18}O$ and rainfall, sea level, the Palmer Drought Severity Index (PDSI) and the El Niño Southern Oscillation (ENSO), whilst $\delta^{13}C$ was related to temperature, vapour pressure and evapotranspiration. These insights provide new evidence that stable isotope analysis of grey mangrove xylem wood has the potential to yield valuable information about past hydroclimates. Grey mangroves can live for up to 800 years, are extremely common on the Australian coast and throughout the tropics and can provide important information regarding pre-instrumental hydroclimate in regions currently lacking high-resolution climate proxy records.

Experiments in Portable Scanning as a Tool for Minimally Destructive Dendrochronological Sampling of Cypriot Wooden Cultural Heritage

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Traditional dendrochronological sampling methods for studying wooden cultural heritage generally favor collecting physical samples by cutting cross-sections or drilling cores. While useful and necessary for analyses using radiocarbon dating and stable isotope analysis, taking physical samples may be prohibitively destructive on delicate, rare, or sacred wood materials. Previous dendrochronological studies have used X-ray microtomography, CT scanning, and flatbed scanners to generate high-resolution images of wood samples suitable for dendrochronological analysis as an alternative to physical sampling. However, these techniques may be cost prohibitive for some projects, or logistically impossible to implement for objects and structures in remote locations that cannot be disassembled or transported.

We report here on our experiments in, and protocol derived from, using Doxie Flip, a widely available portable document scanner, as a relatively inexpensive tool for scanning wooden cultural heritage *in situ* for dendrochronology. We highlight our work on an ongoing dendrochronological project analyzing painted wooden icons, religious objects, and architectural timbers from Byzantine-medieval churches and monuments in Cyprus (many of which are inscribed on the UNESCO World Heritage List), in which we have measured, crossdated, and built long tree-ring chronologies from samples collected using portable scanning methods alongside physical sampling. Our results indicate that portable scanners are useful for minimally destructive sampling but may not be suitable for wood with particularly narrow ring-growth and micro-rings, or when a near-flat surface cannot be prepared on the sample. We also address the utility of image-based dendrochronology in continuing collaborative international research projects during pandemic-era travel restrictions.

Blue rings and compression wood occurrence in trampled and non-trampled Scots pine roots

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Tree-ring chronologies from roots, in contrast to those from stems and branches, have rarely been analysed. Moreover, our understanding of anatomical characteristics and radial growth of tree roots remains incomplete, especially in relation to ecological factors affecting root growth. For that purpose, we aimed on performing a quantitative analysis of radial growth and wood anatomical changes in tree roots. We focused on compression wood (CW) and blue rings (BRs) in trampled and non-trampled *Pinus sylvestris* roots from a hiking trail located in Brodnica Lakeland, NE Poland. In total, 2,253 growth rings of 38 root discs were analyzed.

Significant wood anatomical changes were revealed only in exposed roots subjected to trampling. In total 41 (91%) rings showing CW were noted for the common period 1971-2015. 28 (62%) of the rings containing BRs were found in trampled roots. Differences in mean monthly climate data were not significant between the years when CW was formed or not. Whereas, mean monthly temperatures for the rings showing BRs were significantly lower in July ($p = 0.004$), September ($p = 0.021$) and November ($p = 0.027$). Additionally, mean monthly precipitation was significantly lower in April ($p = 0.025$) and higher in July ($p < 0.001$) for BRs years. Our study highlights altered growth of trampled roots with a high share of BRs which opens new perspectives for future dendroecological studies on tree roots.

Protocol for optimizing microcore processing for X-ray CT scanning workflow

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Forest ecosystems represent one of the largest carbon sinks on Earth, key in mitigating climate change. In order to better comprehend carbon sequestration, in the last decades, scientists have used, among others, increment cores and microcores to determine the impact of environmental drivers on wood growth and to study wood formation. For the latter cores, so far, destructive methods, which are time-consuming and labour-intensive, have been used to acquire such information. This study, elaborating on the work of Lehnebach et al. (submitted) proposes an alternative, by developing a semi-automated protocol for X-ray computed tomography scanning to optimize the sample preparation process and reduce the time spent on sample processing, scanning and reconstruction, without damaging the microcores. Before scanning, samples have to be dried by critical point drying (CPD). A specialized metal sample holder has been designed for this purpose. It can accommodate and transport multiple microcores safely through different ethanol solutions containers, and at the end it fits into the CPD device. Completely dried, the samples are fixed into a modular sample holder for batch X-ray CT scanning. The modular nature of the sample holder makes it easy to handle and protect the samples from mechanical shocks and mount them on the scanner stage. The samples are later reconstructed using an in-house batch reconstruction program. In conclusion, we present an efficient microcore processing protocol which is highly needed for future studies, where large amounts of samples are analysed. It can be a great opportunity for extensive spatio-temporal wood formation studies.

Mask, Train, Repeat! Artificial Intelligence for Quantitative Wood Anatomy

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The recent developments in Artificial Intelligence (AI) have the potential to facilitate various new research methods in ecology. In particular, Deep Learning algorithms and Convolutional Neural Networks (CNNs) have been shown to outperform other approaches in automatic image analyses. This makes them suitable for quantitative wood anatomical investigations, where the main challenges reside in the detection of a high number of cells, and in the intrinsic variability of the wood material.

To properly classify and interpret images, algorithms need to undergo a training stage. We performed the training on some of the most common species in NE Germany: Scots pine (*Pinus sylvestris* L.), Oak (*Quercus robur* L.), Beech (*Fagus sylvatica* L.) and Black alder (*Alnus glutinosa* L). Alongside, we created a user-friendly interface for the algorithm that also provides results on the accuracy of the output of automated cells detection.

Our results showed that, the algorithm can detect and measure cell areas with high accuracy. As expected, the algorithm best performs with oak (96%), since the large vessels are easier to detect. Beech and alder share a similar wood structure, therefore show a similar performance (95%). Cell area recognition of scots pine is close to the broadleaved species (95%), despite the higher ratio of cell per unit area. In general, the number of undetected cells is very low (1.8-2.5%), and it is particularly associated with small vessels or tracheids. Our research demonstrates that future software tools for quantitative wood anatomy would greatly benefit from using deep learning CNNs for the detection of tracheids, vessels or other xylem features.

SLOCLIM: A new high-resolution daily gridded precipitation and temperature dataset for Slovenia

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We created a daily gridded dataset SLOCLIM, containing minimum and maximum temperatures and the amount of precipitation with a resolution of 1 x 1 km for the period 1950 to 2018 for Slovenia. We applied the methodology previously developed to create precipitation and temperature gridded datasets SPREAD and STEAD for Spain. A comprehensive quality control process based on the spatial coherence of the data was applied to the original dataset obtained from 174 meteorological stations, and missing values were estimated independently for each day and location. The methodology proved to be useful to provide a high-quality climate data in the region with great geographical and climatic variability on the crossroads between the Mediterranean, Alpine and continental climate regimes and altitudes ranging from 0 - 2864 m a.s.l.
The dataset is publicly available on Zenodo https://doi.org/10.5281/zenodo.4108543. For the needs of various studies, including the dendroecological and dendroclimatological ones, we will present a web-page with a user-friendly data transfer which enables downloading of climatic data per selected grid point and time span. We will demonstrate the use of gridded data in the forest sites for which official meteorological records are not available and discuss the advantages of using the modelled daily climatic data of precise location instead of a monthly ones from available meteorological stations.

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