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Report on the Ph.D. thesis by Jiří Mašek entitled "Response of tree rings and NDVI of Central-European conifers to extreme climatic events"

To whom it may concern,

The thesis by Jiří Mašek assesses the climate sensitivity, growth responses to drought events, and correlation between tree-ring width as a proxy of stem biomass and the Normalized Difference Vegetation Index (NDVI), a spectrometric data as a proxy for leaf biomass of two widely distributed conifer species in central Europe: the Scots pine (*Pinus sylvestris* L.) and Norway spruce (*Picea abies* (L.) H. Karst.).
The three main objectives of this doctoral thesis are:
1) Understand how Scots pine and Norway spruce respond to climate and extreme events in Central Europe.
2) Identify the spatial variability in these responses from landscape to regional scales.
3) Compare climate-growth responses of tree-ring width and NDVI.

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The PhD-thesis by Jiří Mašek is written as a cumulative thesis comprising four peer-reviewed research papers, three published and one under review to renowned academic journals:

1. Treml, V., Mašek, J., Tumajer, J., Rydval, M., Čada, V., Ledvinka, O., & Svoboda, M. (2021). **Trends in climatically driven extreme growth reductions of Picea abies and Pinus sylvestris in Central Europe.** Global Change Biology. https://doi.org/10.1111/gcb.15922.

2. Mašek, J., Tumajer, J., Lange, J., Kaczka, R., Fišer, P., & Treml, V. (2023). **Variability in Tree-ring Width and NDVI Responses to Climate at a Landscape Level.** Ecosystems. https://doi.org/10.1007/s10021-023-00822-8.

3. Mašek J., Dorado-Liñán I., Treml V. (2024 in review). **Responses of stem growth and canopy greenness of temperate conifers to dry spells.** International Journal of Biometeorology.

4. Mašek, J., Tumajer, Jan, Lange, J., Vejpustková, M., Kašpar, J., Šamonil, P., Chuman, T., Kolář, T., Rybníček, M., Jeníček, M., Vašíčková, I., Čada, V., Kaczka, R., Rydval, M., Svoboda, M., Nedělčev, O., Hais, M., & Treml, V. (2024). **Shifting climatic responses of tree rings and NDVI along environmental gradients.** Science of the Total Environment. https://doi.org/10.1016/j.scitotenv.2023.168275.

All four publications are from very good to excellent contributions that helped improve our understanding of these two species' drought sensitivity, the spatial diversity in their climate responses, and the still challenging part of combining tree growth and remote sensing.

As such, **Treml et al.** (**2021, Global Change Biology**) discuss the impact of climate change, particularly the increase in extreme climatic events on two temperate conifer species, *Pinus sylvestris* and *Picea abies* distributed at the margins of their elevation distribution, at low and high-elevation sites throughout the Czech Republic and Slovakia. However, despite ongoing warming trends benefiting cold-limited forests, there's high spatial variability in growth and extreme events. The study aims to analyse trends in extreme growth reductions (EGRs) over 118 years (1901-2018), hypothesising increased EGRs at drought-limited sites due to more frequent droughts and decreased EGRs at temperature-limited sites due to rising temperatures. It also explores species-specific trends in EGRs between warm and cold ranges. In their paper, the authors use quite an innovative approach to quantify the EGR based on relative growth changes calculated from tree-ring width data. They account for individual tree sensitivity to extreme events, identifying years with exceptionally high growth reductions for each tree. The study uses the relative growth change method to quantify abrupt growth changes in tree-ring width series, considering age trends. To identify exceptionally high growth reductions, the study applies a recurrence interval method, considering the sensitivity of individual trees to extreme events. Finally, generalized additive mixed effect models analyse the proportion of trees exhibiting EGRs over the study period, considering site categories (high and low elevation), climatic drivers, and calendar years.

Mašek et al. (**2023, Ecosystems**) investigate the link between ring-width chronologies and remote sensing data, specifically the Normalized Difference Vegetation Index (NDVI) derived from high-resolution satellite data, as a proxy respectively for stem and leaf biomass of two conifer species: *Pinus sylvestris* and *Picea abies* located in two study areas in the Czech Republic. The correlation between stem and leaf biomass increments and the potential for linking information from both data sources is noted. However, the authors tried to cover the gap related to combining tree-ring width and NDVI analyses across distinct topographic features (south and north-facing slopes, plateaus, and valley bottoms) and investigating the influence of topography on the climatic signal and the relationship between NDVI and tree rings. In total, the authors sampled 20 sites in each of the two study areas to cover the variability of the landscape in terms of moisture availability and solar irradiation. The statistical method used was quite conservative; the authors performed a principal component gradient analysis (PCGA) to assess the coherency of growth patterns in tree-ring indices chronologies (TRI) and NDVI data. Climate-growth responses are analysed using Pearson's correlations between TRI/NDVI, monthly mean temperatures, and the standardized precipitation evapotranspiration index (SPEI). Differences in climate-growth correlations are compared between site categories using ANOVA, and linear models are used to examine the influence of topography on climate sensitivity. Finally, the relationship between wood and leaf biomass is quantified by correlating TRI and NDVI time series for each site. Their study highlights the complex patterns in the climatic responses of TRI and NDVI. They found notable species-specific differences in the climatic limitations of stem and leaf biomass. While *Pinus sylvestris* sites showed higher correlations between TRI and NDVI, reflecting a common climatic driver (mainly drought), *Picea abies* sites exhibited heterogeneity in the climatic signals of TRI and NDVI. Most important is the role of topography in shaping the climatic responses of both TRI and NDVI, particularly for Pinus sylvestris sites. Tree-ring widths showed a stronger climatic sensitivity than NDVI, indicating that wood formation is more strongly driven by climatic constraints than leaf biomass production.

Mašek et al. (**2024, International Journal of Biometeorology in review**) focus on the impact of severe drought events on the above-ground biomass components of Pinus sylvestris and Picea abies in the same two study areas in the Czech Republic of the paper Mašek et al. (2023, Ecosystems). The authors analysed the responses of stem growth as tree ring chronologies and canopy greenness as Normalized Difference Vegetation Index (NDVI) to dry spells. ERA5 climatic data were utilised to obtain monthly temperature, precipitation, surface solar radiation, soil moisture, and the Standardized Precipitation-Evapotranspiration Index (SPEI). Pearson's correlations are calculated between tree-ring indices (TRI), NDVI chronologies, and climatic variables, and a Superposed epoch analysis (SEA) and linear mixed-effect models are used to explore the response of TRI and NDVI to dry spells. The main finding is the different responses between the two species, the microenvironment, and TRI and NDVI. The differences in response to dry spells may be partly due to species-specific rooting strategies, with deep-rooting species exhibiting greater resilience. TRI shows a more pronounced and persistent reduction compared to NDVI after dry spells. Stem growth reduction persists for two years post-drought, while NDVI increases during the same period. This suggests a stem-leaf biomass trade-off: trees allocate more resources to their leaves to recover from drought-induced damage.

Mašek et al. (**2023, Science of the Total Environment**) aim to investigate how the tree growth measured using tree-ring chronologies downloaded and from the TreeDataClim database and canopy vigour as time-series of NDVI derived from Landsat imagery respond to climate variations across different environmental gradients in temperate forests mainly composed of Picea abies. They calculated correlations between tree-ring indices chronologies (TRI), NDVI, and climate variables such as growing season temperature and standardized precipitation evapotranspiration index (SPEI). They evaluated how these climate responses varied with stand age, aridity index (as total annual precipitation divided potential evapotranspiration), soil category (fertility and moisture), and topographical factors (mean slope inclination, topographic wetness index, and heat load index). The important finding is the climate-growth responses of tree rings shifted from positive to negative for SPEI and from negative to positive for temperature as environmental conditions transitioned from dry (warm) to wet (cold) areas. However, this trend was not registered using NDVI data with contrasting responses: NDVI showed a consistent negative response to temperature across the entire climatic gradient, likely influenced by drought effects in warm areas and the impact of cloudy conditions on foliage greenness in wet areas. Moreover, the aridity index was the main predictor of climate sensitivity, with variability between TRI and NDVI, the latest more influenced by topographical and soil variables. Stand age also influenced the climatic response of TRI, with older stands exhibiting higher sensitivity to low temperatures and juvenile stands being more sensitive to drought. The findings suggest caution in upscaling TRI observations using NDVI derived from satellite imagery, particularly in areas with climatically optimal growing conditions and towards the colder part of the species' range.

Overall evaluation and recommendation

Overall, the thesis is a comprehensive work laid out in 132 pages, including the four original publications, related appendices, and a reference list of 20 pages related to chapters 1-7. I found some references somewhat outdated, particularly regarding the climate sensitivity of the two studied species. In Chapter 6, I would have expected more of a review of the growth trends and climate sensitivity of the two study species in central Europe, for example, showing in a table format the most critical months for their growth, the most relevant environmental factors, and the years with negative (or positive) growth.

Furthermore, what seems lacking in the initial chapters is a link to the four published papers, which are the core of this thesis. For instance, when discussing topographic factors potentially influencing climate-growth responses, it would be beneficial to reference the key findings and highlight key insights. Moreover, when addressing negative pointer years, it would be expected to establish connections with the documented drought years from the

papers. Similarly, in the conclusion, when listing warm and dry years negatively affecting the tree growth for the two species, coherence could be enhanced by aligning these findings with the research outlined in the published papers. Sections throughout the thesis occasionally exhibit disconnection; for instance, transitioning abruptly from plant physiology to climate change impacts and subsequently to European conifer biomass (e.g., see page 6). Despite these points, the thesis is well written. It demonstrates the PhD candidate's acquisition of ecological knowledge of the two studied species and achieves its primary objectives. Furthermore, the interdisciplinary approach, combining remote sensing with dendrochronology, quite advanced statistical analysis, along with extended fieldwork and management of extensive and different datasets, is evident.
Overall, the thesis contributes significantly to advancing our understanding of forest ecology concerning two key conifer species in central Europe, emphasizing the importance of accounting for species-specific traits, environmental gradients, and climate-ecosystem interactions in climate change assessments.

In summary, the Ph.D. thesis by Jiří Mašek is a great contribution to the research community. I recommend that the thesis be accepted and moved forward for a PhD defence in accordance with the procedures of the Faculty of Science of Charles University, Czech Republic.

Sincerely,

Dr Alma Piermattei