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Pia Caroline Adamič[1,2], Tom Levanič[1,3], Mihail Hanzu[4], Matjaž Čater[1,5]

Growth response of European beech (*Fagus sylvatica* L.) and silver fir (*Abies alba* Mill.) on climate factors along the Carpathian massive

KEYWORDS: climate change; dendrochronology; radial growth response; meteorological parameters.

Introduction

We focused on beech (*Fagus sylvatica* L.) and fir (*Abies alba* Mill.), which are likely to be the two most important tree species for a large part of Europe's mid- and high-altitude forests in the future (Dobrowolska et al., 2017). In study at the Balkan Peninsula along the Dinaric high karst, where different and well-expressed ecological factors intertwine at relatively short geographical distance (approx. 1000 km) (Bohn et al., 2000), response of beech and fir from the southern, warmer and dryer sites already served successfully as a most probable future prediction for the same species response on currently less-extreme sites northward (Čater and Levanič, 2019). Carpathians as more complex site comprise sufficient latitudinal and longitudinal gradient connected with significant differences in temperature/precipitation as well as differences in their seasonal pattern (Micu et al., 2016). The quality and future of fir-beech forests is in tight connection with our understanding of tree-response to environmental parameters. Dendrochronological analysis of stand growth provides a historical retrospective of the response to climatic factors in different time series of mature trees (González et al., 2003). In predicting the consequences of climate change on tree species, studying the response of species on a geographic gradient may highlight the crucial parameters important for tree growth on a larger scale, help to predict future response and optimize future forest management. In the presented study, we were interested if there is a similar response between tree species along the Carpathian arc. The aim was to determine the influence of climate on the growth of beech and fir along the geographical gradient (a), to find similarities or differences between the two species (b) and to compare response in time for eventual change in the growth response (c).

Methods

Along the Carpathian Mountains, seven sites with mature fir-beech stands located between 820 and 1038 m above sea level were selected and analyzed (Figure 1 and Table 1). At the study sites, the average temperature is 7.3 °C and the average temperature in the growing season

[1] Department of Yield and Silviculture, Slovenian Forestry Institute, Večna pot 2, 1000 Ljubljana, Slovenia

[2] Department of Forestry and Renewable Forest Resources, Biotechnical Faculty, University of Ljubljana, 1000 Ljubljana, Slovenia

[3] Faculty of Mathematics, Natural Sciences and Information Technologies, University of Primorska, Glagoljaška 8, 6000 Koper, Slovenia

[4] Semper Silva Proiect SRL, Lânii street 21, 550019 Sibiu, Romania

[5] Department of Silviculture, Faculty of Forestry and Wood Technology, Mendel University, Zemedelska 3, 613 00 Brno, Czech Republic

Corresponding author: Pia Caroline Adamič - pia.adamic@gozdis.si

(from May to August) is 15.8 °C. The average precipitation is 60.7 mm per month and 91.5 mm per month from May to August. The meteorological data were calculated for the years 1950 to 2020. At each site, 15 mature dominant healthy fir and beech trees were double cored, which gave in total 105 sampled trees for fir and 105 sampled trees for beech. Tree cores were packed into plastic straws, marked, and transported to the dendrochronology laboratory. The cores were dried, mounted and glued on a wooden support and sanded with progressively finer sandpaper. The cores were then scanned with an ATRICS (Levanič, 2007) image capturing system, and annual radial increments were measured to within 0.01 mm using CooRecorder and CDendro software, which also served as quality control for the measured tree-ring width (TRW) sequences. TRW sequences were visually and statistically synchronized with PAST-5. Quality control was also performed by checking and correction. We calculated correlations between trees in CDendro and created a plot chronology that we compared to individual trees. Any tree ring width sequence that did not fit well into the plot chronology were corrected in CooRecorder and returned into data pool. Individual TRW were standardized to remove long-term trends using a cubic smoothing spline of 67 % with a frequency cutoff of 50 % in R program's dplR library (Bunn, 2008). Indexed TRW chronologies were compared to monthly mean temperatures, maximum temperatures, monthly sum of precipitation, and two drought indexes using the boot-strapped resampling method and calculating the correlation coefficient in the Treeclim library (Zang and Biondi, 2015) of the R program. Temporal correlation between tree-ring proxies and combinations of monthly and seasonal variables was examined using monthly gridded temperature, precipitation, and drought data (0.5 × 0.5° grids) from the CRU TS and CSIC database, available online in KNMI Climate Explorer (http://climexp.knmi.nl). Each tree-ring proxy was tested against monthly meteorological data or different combinations of seasonal variables to find the best possible combination of influencing climate variables. We analyzed the period from 1950 to 2016. To show whether trees along the Carpathians respond similarly to meteorological data, correlation coefficients above 0.2 and below -0.2 were considered. If such a value was confirmed in at least three studied sites, we marked a particular month with a climate parameter as important for certain species. The sites on different sides of the Carpathians were grouped into three clusters: southern group - sites 1, 2, 3; eastern group - sites 4, 5, 6 and northern site number 7. We calculated the average TRW for fir and beech by decades from 1950 on.

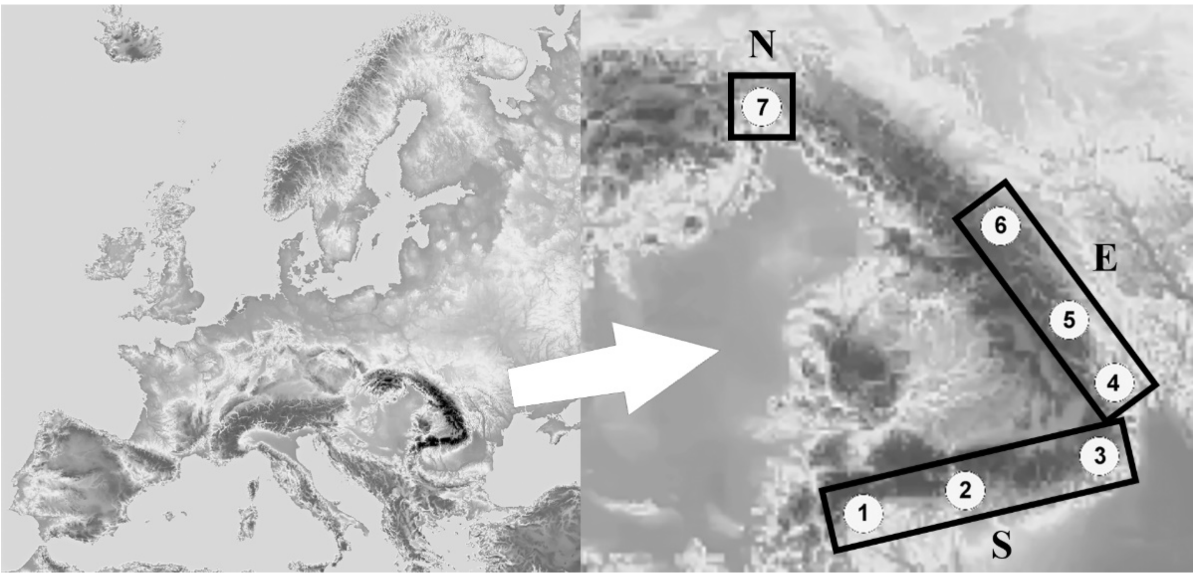

Fig. 1. Research site location.

Table 1. Locations, forest label, altitude, and coordinates of research site locations.

	County	Plot	Managed/old growth forest	Altitude (m)	E (DMS)	N (DMS)
1	Gorj	Tismana	managed	985	22°55'1.00"	45°10'10.00"
2	Arges	Arefu	managed	995	24°39'4.00"	45°27'37.00"
3	Buzau	Zagon	old growth	1038	26°13'44.00"	45°36'51.00"
4	Vrancea	Soveja	managed	830	26°36'14.00"	46° 0'5.00"
5	Neamt	Tarcau	managed	950	26°10'6.00"	46°51'15.00"
6	Suceava	Frumosu	managed	850	25°40'60.00"	47°28'6.00"
7	Bardejov	Livovska huta	managed	880	21°0'59.62"	49°15'17.06"

Results

The study showed a more significant correlation between tree growth and seasonal variables was observed on the eastern side of the Carpathian arc, while it was less evident or absent at sites on the southern side (sites 1,2,3). In comparable studies, the response to different climatic variables was decreasing or was absent in the south side of the studied transect due to genetic adaptability, phenotypic plasticity, or both (Čater and Levanič, 2019). The reason for the different response could also be that the eastern side of the Carpathians is affected by a climate with continental nuances and Baltic influences (Nechita et al., 2017). Fir and beech on northern sites react differently to meteorological parameters. Above-average precipitation in July had a positive effect on radial growth in both species, and in beech also in June. In the course of climate change, we don't expect above-average precipitation in summer; on the contrary, we expect more summer drought. In the study, we showed that fir responds negatively to above-average temperatures in June and in September of the preceding tree ring formation, with above-average summer temperatures likely to become more frequent under climate change, while warmer winters increase fir radial growth. Above average maximum winter temperatures from January to March have an even more significant positive influence on fir growth than above average temperatures. Fir, as an evergreen tree species, enjoys warm winters, while beech, as a deciduous tree species, is not as affected by warm winter temperatures. Mihai et al. (2018) showed high genetic variability within the silver fir studied in the Carpathians. They confirm that climate change could increase fir productivity at higher elevations while climatically marginal environments and low elevations, such as edges of the Eastern Carpathians and the Banat region may be exposed to higher risk (Mihai et al., 2018), due to higher temperatures and lack of moisture. Current fir populations have well-preserved genetic resources and relatively high genetic variability (Konnert and Bergmann, 1995) but are threatened by pressure from herbivores, large-scale reforestation of old fir stands, inappropriate management practices (Dobrowolska et al., 2017), reductions in population density that can lead to fragmentation, self-pollination, and genetic drift (Jump et al., 2006), and predicted climate change, particularly increases in temperature and lack of precipitation (Cailleret et al., 2013). Beech does not like too hot summers during the active growth phase, while this is not so pronounced in fir. Above-average temperature in the summer months had a negative effect on radial growth, so the higher summer temperatures may cause disturbances in beech growth. In the Eastern Carpathian region, changes in beech forests have been noted in recent decades (Durak, 2010), while old-growth beech forests in the Northwestern Carpathians were considered stable (Kucbel et al., 2011). Martinez del Castillo et al. (2022) predicted a substantial decline in beech growth across Europe, ranging from -20% to more than -50% by 2090, depending on the region and climate change scenario (CMIP6 SSP1-2.6 and SSP5-8.5). A comparison of average TRW over decades shows better growth of fir at the northern and eastern sites and slight decrease at the southern sites. Beech demonstrates more consistent radial growth in the south; but growth increases less than in fir on the eastern and northern studied sites. The effects of global warming becomes evident in comparison of fir and beech response in time. Since we wanted to know the recent growth trend due to climate change, we calculated the average TRW for fir and beech by decades from 1950 on. Fir on the southern side shows a decreasing trend in TRW over time, signaling that these sites are gradually becoming unfavorable for fir. At the same time, the eastern and especially the northern sites are becoming more favorable for growth of both species. Of particular concern is the negative effect of above-average summer temperatures on beech growth, which is becoming more significant over the years, while July precipitation indicates an increasingly positive effect radial growth of fir. We may expect more frequent above-average summer temperatures and the absence of summer (July) precipitation, reflecting along both latitude and longitude, so also future differences in seasonal responsiveness of beech and fir may be expected. Extreme weather events and increasing average temperatures will influence future demographics of fir, as mentioned by Tinner et al. (2013) and Klopčič et al. (2017) to higher elevations and northward. At the same time a similar response of beech at the expense of fir and its general spread in Central Europe was observed by Šamonil (2008), Vrška (2009) and Janík (2014). Our results confirm increasing dependence of trees on precipitation over the past century and coincide with the increasing drought events after 1951. The likely response of species to climate change will vary, affecting their competitiveness, their existence, and consequently forest management decisions and measures (Brang et al., 2014). In southwestern Europe fir is more resilient to climatic extremes compared to other tree species (Bošela et al., 2018). At the same time, two fir populations have been distinguished in the Carpathian region: the eastern one, which is similar to the Balkan population, and the western one, which is less sensitive to summer droughts (Bošela et al., 2018). In the south-exposed areas of Eastern Carpathians, fir was the least sensitive of studied tree species (Bouriaud and Popa, 2008); its growth rate increased continuously and remained at a high level even in old individuals compared to Scots pine or Norway spruce. Firs growth was significantly and positively correlated with December temperatures and spring precipitation in April and May (Bouriaud and Popa, 2008). Although growing under the same conditions, European beech and silver fir have shown remarkably different growth patterns over the past half century. While fir has responded positively to recent warming, beech growth has declined at all examined sites, suggesting that fir is less susceptible to warmer and drier conditions than beech (Bošela et al., 2018). Long-term growth patterns and growth-climate sensitivity of fir and beech did not differ significantly between managed and unmanaged forests.

Conclusions

Predicted forest productivity loss is mostly pronounced at the southern limit of beech natural distribution, where drought intensity is expected to increase (Martinez Del Castillo, 2022). Our study confirmed different responses depending on species and location. A more pronounced response of tree growth to climate was observed on the eastern side of the Carpathians, while it was less pronounced or absent at the southern sites. Both beech and fir show better radial growth with higher precipitation in July and slower growth with higher average and maximum temperatures in June of the current year. Fir shows a positive correlation between radial growth and temperature in winter, while beech shows a negative correlation between radial growth and temperature in summer. In 1950, average tree ring widths for fir and beech were largest at southern sites compared to other sites, but after 2016, the increase is smallest at southern sites while it is greatest at northern sites. Despite the adaptive diversity of beech populations, the survival of beech and other temperate tree species in the future is uncertain, as the rate, uniformity, and intensity of climate change vary among different sites. We may expect strong climate future variability in southern forest ecoregion, while northern sites still exhibit stability and structural resistance. Temporal changes in species composition led to minor fluctuations in stand parameters that do not threaten the long-term coexistence of beech and fir (Petritan et al., 2015). Beech populations at the edge of the species range have great adaptive potential, and their persistence appears to contribute to forest stability throughout Europe, requiring adaptation of forest management and conservation policies (Mátýas et al., 2009; Lefèvre et al., 2014; Fady et al., 2016).

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