Late Winter-Early Spring Thermal Conditions and Their Long-Term Effect on Tree-Ring Growth in Hungary

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Abstract

Similar to international trends, late winter-early spring climatic conditions have changed significantly in the last 100 years in Hungary. Thermal circumstances have a remarkable role on the onset of spring and hereby on the dynamics of tree-ring growth at the beginning of the vegetation period. Since investigations about the effect of increasing temperature in February and March on annual increment have never been done in Hungary we set as our aim to study how and how much the changing conditions affect the climate-growth relationship on long-term timescale. During our work, we analysed earlywood, latewood and total tree-ring separately and determined their correspondence with climate data using bootstrapped correlation. To evaluate the changes in climate-growth connection we calculated 25-year moving window correlation values between the residual indices and temperature data. According to our results, thermal conditions of February and March have significant positive effects on tree-ring growth but this effect has changed a lot during the past 100 years. In parallel with the intensive warming, which has started in the middle of 1960's, the role of temperature in formation of different tree-ring parameters has decreased dramatically. As it was reported in Poland as well, the stable and strong correlation, which typified the connection of early spring temperature and tree-ring growth, has totally ceased at the beginning of the century.

Keywords: Scots pine, dendroclimatology, earlywood, latewood, moving window correlation, increasing temperature.

Introduction

Since the Carpathian Basin is seriously affected by the negative impacts of global warming (Parry et al. 2007, Bozó 2010, Náfrádi et al. 2013), it is particularly important to investigate how trees respond to the changing climatic conditions. In addition, which factors are the most favourable for the growth of trees and how these factors will alter in the future? The best way to understand and estimate upcoming events better is the investigation of past processes with different methods of paleoclimatology (e.g. Bradley 1999). As it is widely known, tree-rings are important records of former environmental (Schweingruber 1996) and climatic (Fritts 1976) conditions, as well as central elements of paleoclimatological reconstructions thanks to their annual resolution.

Though Scots pine (*Pinus sylvestris*) is among the most frequently used species in dendrochronology (e.g. Eilmann 2006, Pärn 2009, Michelot et al. 2012, Panayotov et al. 2013, Stravinskiene 2013, Pritzkow 2014), Hungarian studies have focused on oak (Babos 1984, Grynaeus 1997, 2004, Horváth 2004, Szabados 2006, Dávid and Kern 2007, Kern et al. 2009, Kern et al. 2012) and beech (Garamszegi and Kern 2014) so far dealing with climate-growth relationship and climate reconstruction, but the effect of increasing temperature on tree-ring formation in the late winter-early spring period has never been investigated on pine trees.

The current warming trend that hits the European continent (Xoplaki et al. 2005) has a significant effect on extension of the growing season (Menzel and Fabian 1999). In Poland due to the higher temperature in February and March, the onset of spring has shifted to earlier by more than two weeks (Kożuchowski and Degirmendžić 2005). The rapidly changing conditions have heavy impact on the ecosystem and cause different responses on tree growth inside and outside of the natural range (Koprowski, 2013). Since the currently investigated stand is out of Scots pine's natural range, we defined three major aims for our study: (1) to identify which climate parameters affect mostly the growth of Scots pine outside its natural range using separate analyses of earlywood, latewood and total tree-ring width; (2) to investigate how climate-growth relationship responds to changing climatic conditions; and (3) is there any significant effect of increasing temperature in late winter-early spring period to tree-ring formation?

Materials and Methods

Study site and climate data

The current study site (Fenyőfő Pine Forest, N47°21', E17°45') is situated in the northern part of Western Hungary, on the northern slopes of the Bakony Mts. (Figure 1). The forest has been growing on secondarily evolved dune sand and weakly humic sandy soil, which were formed on calcareous sand bedrock (Borhidi 2003). Due to the thick sand layer, intensive summer evaporation usually subsides the groundwater level below the roots that causes poor water management and unfavourable conditions to tree growth. This process eventuates that while the forest is mixed with oak (*Quercus cerris*, *Quercus robur, Quercus petraea*), silver birch (*Betula pendula*) and ash (*Fraxinus ornus*), they cannot tolerate well the soil's low nutrient level; hence they could not supplant Scots pine. The canopy is ruled by the pine population, which varies widely in age. Though younger individuals dominate, it is not difficult to find more than 100-year-old trees with over 2.4-m trunk perimeter. Low number of black pine (*Pinus nigra*) can also be found in the forest.

The area is nearly flat, the relative fall is around 20 m and mean elevation is 270 m a.s.l. The climate of the region is moderately warm (Köppen code: Cfbx), and highly affected by Bakony Mts (Majer 1988). The long-term annual average temperature of the area is 10.3 °C while the total long-term average annual precipitation is 652 mm (Figure 1a). The warmest month is July (20.6 °C), the coldest is January (-1.1 °C). The wettest period of the year is late spring/early summer (May–July) with precipitation maximum in July (75 mm), the driest month is January (36 mm).

Taking notice of the fact that in Hungary available instrumental meteorological data series are not long enough and stations are far away from our study site we used CRU TS 3.22 0.5° × 0.5° (Harris and Jones 2014) gridded monthly and seasonal temperature and precipitation data for the period of 1914–2013. The dataset we needed was extracted for the area encompassed by the coordinates 47°–47.4°N and 17.5°–18°E using the KNMI Climate Explorer web page (http://climexp.knmi.nl). To check the reliability of grid data, we compared it to shorter instrumental data we already had from nearby stations of the study site and we found high correlation for the overlapping periods.

Since the purpose of climate analysis of the past century was not to provide a detailed picture about the climatic situation, but to investigate generally long-term processes, we made 25-year long averages of February and March temperature anomalies and illustrated them on maps using KNMI Climate Explorer field function (Figure 2).

Sampling and chronology building

To ensure the sufficient length of our chronology we selected old, dominant and healthy trees for sampling. In total 48 individuals were drilled at breast height during two sampling periods (1st: in 2011, 29 trees, 1 core/tree; 2nd: in 2014, 19 trees, 2 cores/tree). All of the samples were air-dried, then sanded and polished with 8 different sandpapers to enhance tree ring structure. Measurements

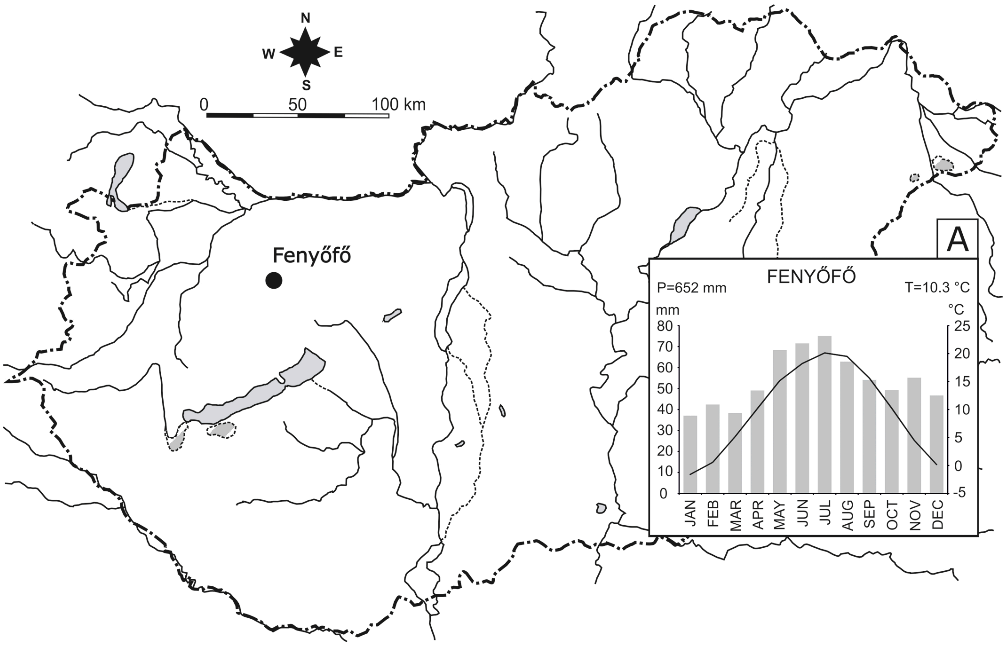

Figure 1. Location and long-term (1914–2013) monthly precipitation totals and mean temperature values (A) of the study site

of total tree-ring (RW), latewood (LW) and earlywood (EW) width were done with LINTAB Measurement Station in 0.01 mm precision, from the pith to the bark (Rinn 2003). Designation of earlywood-latewood borders was performed according to visual assessment using the considerably different cell structure of the two growing periods. In case of samples exceeding our study period, we deleted rings, which were formed before 1914. On-screen crossdating of individual series was done by program TSAPX; series intercorrelation, missing ring identification and detection of possible dating errors were checked by program COFECHA (Holmes 1983).

Climate signal

Since several non-climatic trends preserved in tree-rings (because of tree's age, size and effect of stand dynamics) needs to be removed, all of the series were standardized fitting a cubic smoothing spline with a 50% frequency response at 67% length of the individual series (Cook and Peters 1981). Autocorrelation was removed from each individual index, then all detrended residual series were averaged to chronology using the biweight robust mean (Cook 1985).

For the examination of stability of climate-related signal preserved in the index series, Expressed Population Signal (EPS) calculation was applied with 25-year window lagged by 1 year using 0.85 as a widely accepted threshold (Wigley et al. 1984). Afterwards, mean inter-series correlation (Rbar) was computed with the same window and lag as EPS values. Standardization and index calculation procedure were carried out using software ARSTAN (Cook and Krusic 2006).

The relationship between residual tree-ring parameters and climate data for the entire study period was evaluated by bootstrapped correlation (*r*) calculation from May of the previous year (MAY) to October of the current year (Oct) of tree-ring formation. To analyse the alterations in climate-growth relationship during the last 100 years we computed 25-year moving window correlations of temperature and tree-ring data (RW, EW and LW).

All correlation calculations were carried out using DendroClim2002 (Biondi and Waikul 2004).

Results

Thermal conditions during the past 100 years

In accordance with international trends (Xoplaki et al. 2005, de Luis et al. 2014, Koprowski 2012), an increase in spring temperature values can be observed in Hungary during the last 100 years, especially in the

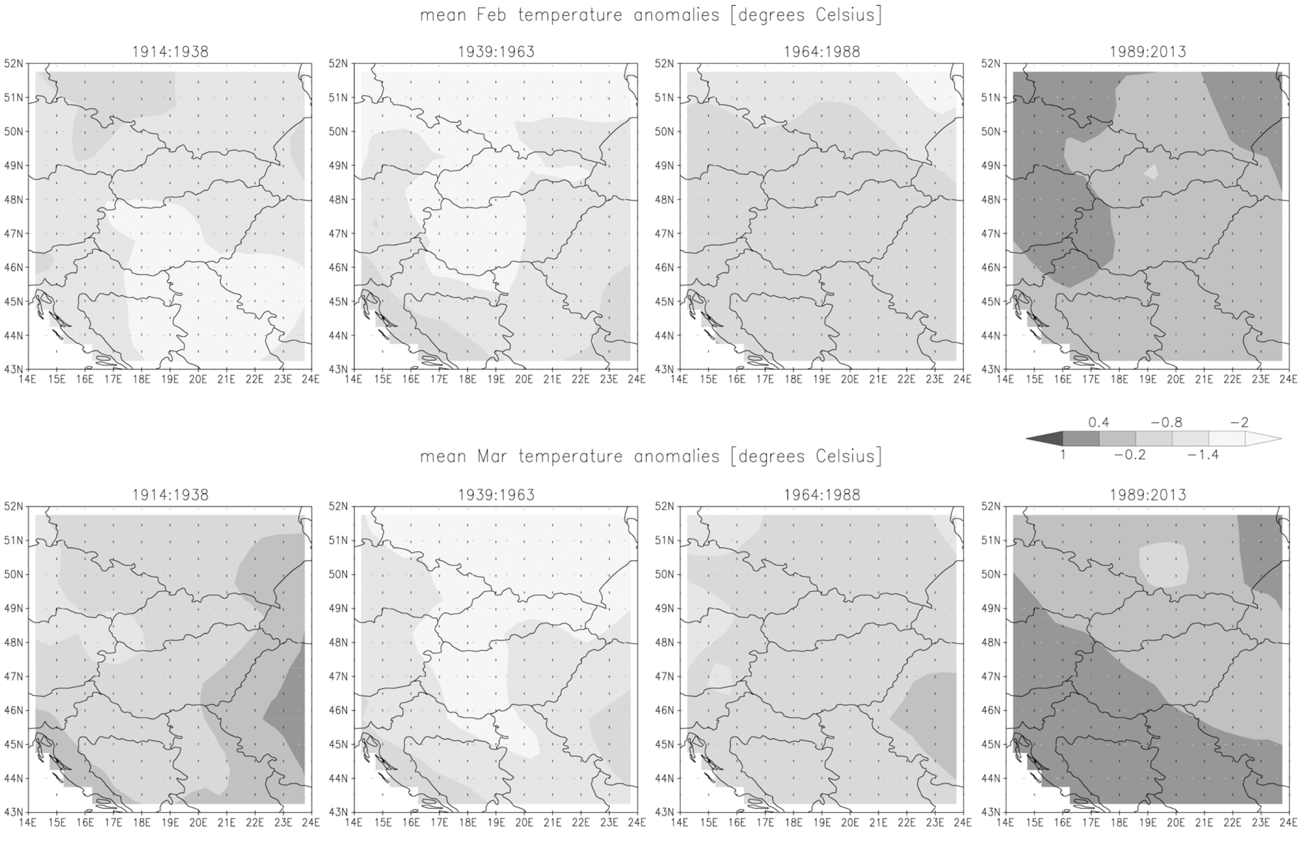

Figure 2. Changes in temperature anomalies of late winter-early spring in Hungary and in the surrounding areas. Reference period: 1971–2000

last two decades. In the first 25 years of our study period (1914–1938) mean spring (MAM) temperature was 10.4 °C that raised to 11.8 °C until the last quarter of the century (1989–2013) with fastest pace in April (0.43 °C / 25 years) and March (0.33 °C / 25 years). Winter conditions show more moderate warming in December and January but heavy increase occurred in February with 0.49 °C / 25 years on average.

In our study site, just like in the whole country, late winter-early spring temperature has significantly changed in the middle of the 1960's (Figure 2). After a long balanced period both February and March thermal conditions have started to rise. As a result of this process the average temperature in the last 50 years of the study period was higher by 1.4 °C in February and 1.2 °C in March than in the first one (Figure 3), which has effects on the onset of spring and on tree-ring formation undoubtedly.

Tree-ring chronology

In total, 3883 rings were measured to build up the final chronologies spanning from 1914 to 2013. The replication reaches its maximum between 1982 and 1994 with 48 samples, then it decreases to 19 samples after 2010, due to the lower amount of drilled trees during the second sampling period in 2014 (Figure 4). EW is the dominant part of the tree-ring. Its mean width exceeds LW value in every individual series. The maximum value of mean sensitivity was observed in LW chronology while RW chronology has the highest standard deviation (Table 1). The results of the correlations between RW/LW/EW indices show the best connection between LW/RW ($r = 0.85$), and EW/RW ($r = 0.83$) and weaker correspondence for EW/LW pairs ($r = 0.46$).

Climate response

EPS values of RW and LW show stable and high climatic signal for the entire period of the chronology. Although EW values demonstrate two clearly visible decreases, considering the whole time-span, their average is far above the widely accepted 0.85 level (Figure 4). In Rbar values similar trend can be seen: higher values of LW and RW, and less stable signal of EW.

According to the result of correlation analysis, summer precipitation has the main role in tree-ring formation with the highest influence in July (Figure 5). Temperature has a secondary effect in summer (JJA) with its influence on available precipitation for trees to utilize, and in the late winter-early spring period with supporting the onset of the growing season. The highest positive correlation observed in February between the residual chronology of earlywood and temperature. In March the relationship between EW formation and climate data slightly declines while the connection between total ring width (RW) and temperature values is increasing. It is also clearly visible

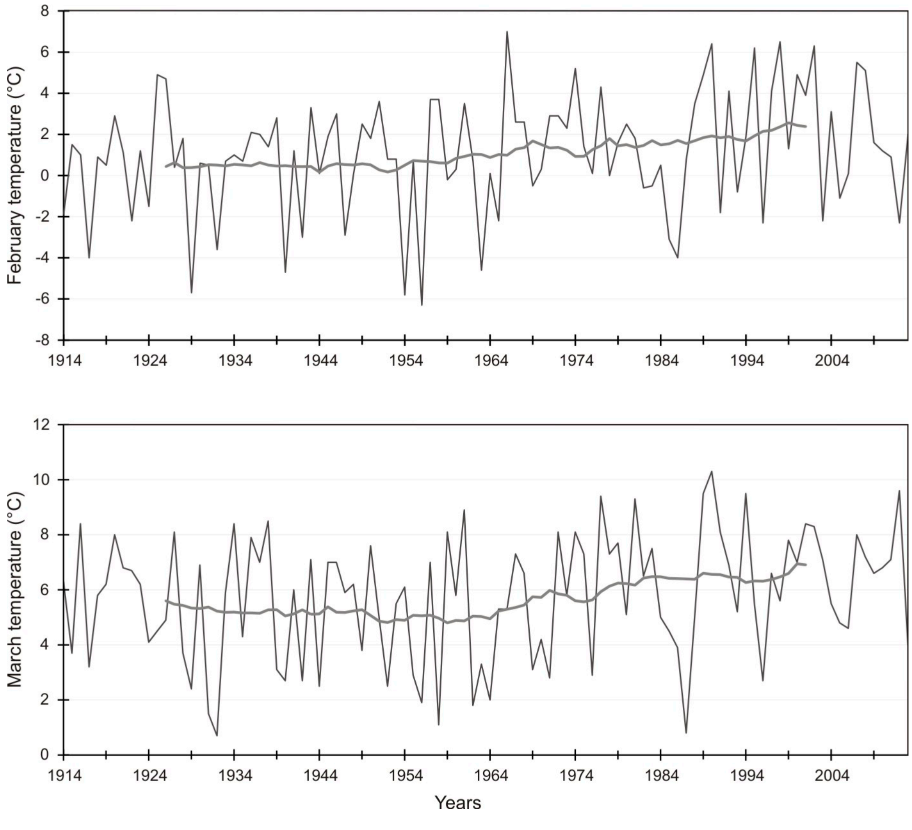

Figure 3. Thermal conditions of February and March (black line) with 25-year mean (grey line)

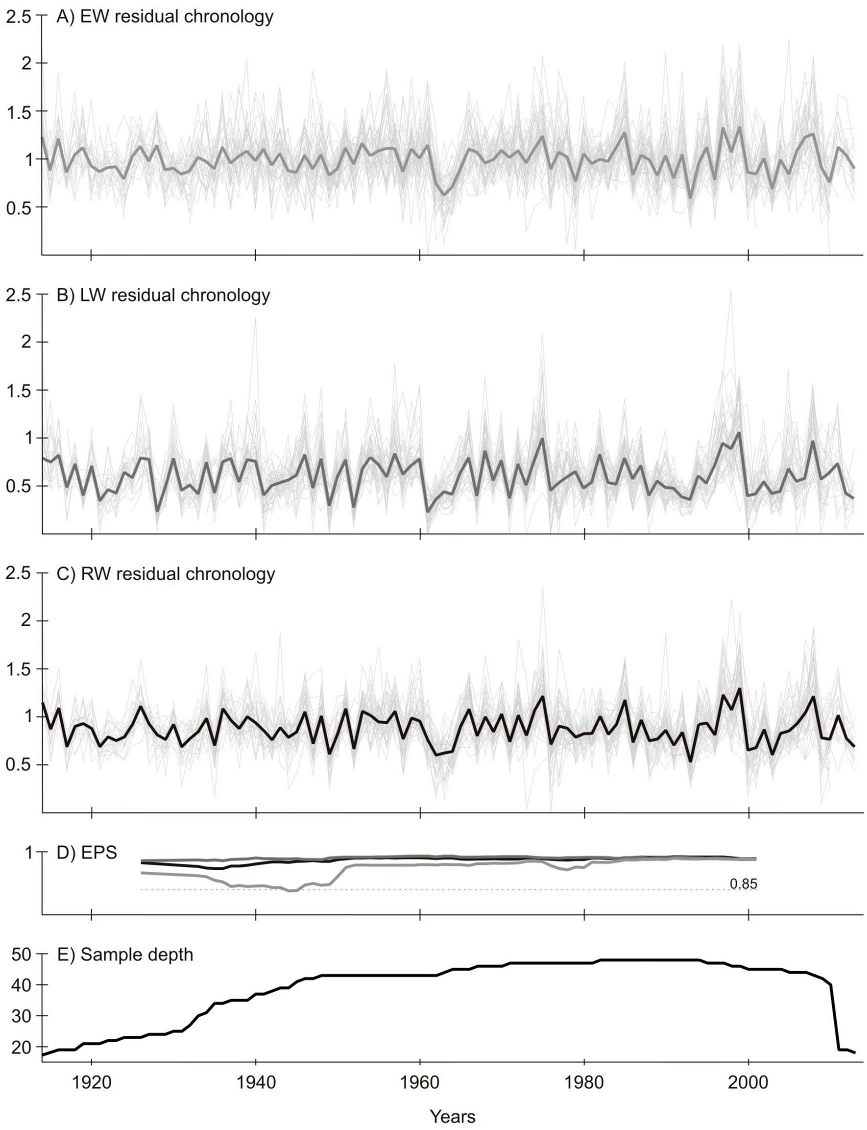

Figure 4. Residual chronologies of earlywood (EW), latewood (LW) and total ring width (RW); Expressed Population Signal (EPS) and replication

Table 1. Statistics of earlywood, latewood and total tree-ring chronologies: time span of the chronology, mean width (mm), series intercorrelation (*IC*), standard deviation (*SD*), mean sensitivity (MS), first order autocorrelation (AC1), Expressed Population Signal (EPS) and interseries correlation (*Rbar*)

Tree-ring parameter	Time span	Mean width	*IC*	*SD*	MS	AC1	EPS	*Rbar*
Earlywood	1914–2013	1.66	0.54	0.84	0.25	0.75	0.93	0.29
Latewood	1914–2013	0.79	0.68	0.49	0.40	0.58	0.98	0.5
Total tree-ring	1914–2013	2.45	0.65	1.16	0.23	0.79	0.97	0.44

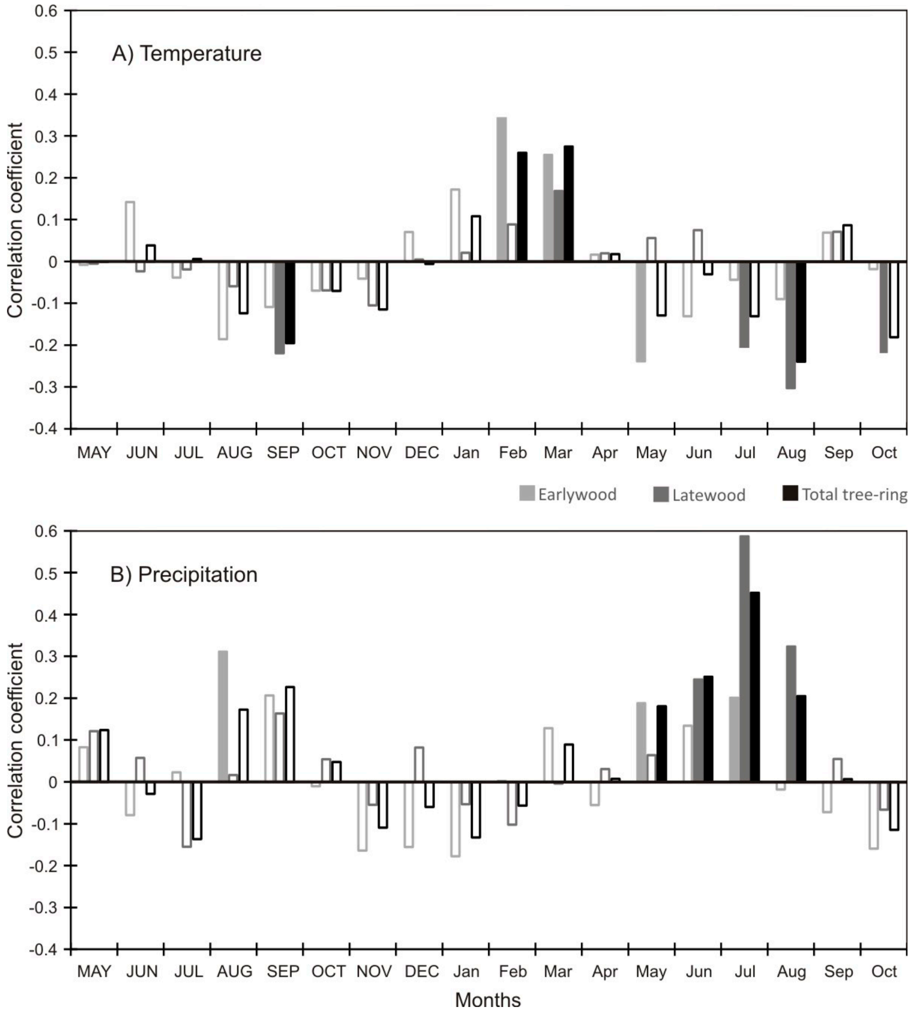

Figure 5. Bootstrapped correlation values between residual indices and climate data. Filled bars mark the significant correlations at 0.05 level

that previous year late summer and early autumn conditions have significant impact on tree-ring growth.

Moving window correlation shows wide scale variability in the role of temperature during the last 100 years (Figure 6). The effect of thermal conditions in February on earlywood is high and stable at the beginning of the study period, but is followed by a long depression in values between 1930–1954 and 1957–1981. After a few years above the significance level ($p < 0.05$) correlation drops down again and it increases anew only at the end of the study period. Total ring width formation has similarities to earlywood in moving correlation values at the beginning of the last century, but after 1927–1951, the significance of February temperature on RW growth ceases. Considering latewood, late winter thermal conditions have no effect on its formation.

In the relationship of March temperature and growth of different tree-ring parameters we found a more stable signal. Latewood development shows slightly higher connection with thermal conditions, but still cannot reach the significance level in most of the study period. Earlywood has strong bootstrap correlation in the middle of the last century, but the highest relationship between early spring temperature and tree-ring formation can be observed in RW values. Considering both months, their role in tree-ring formation dramatically decreased approaching to the end of the century. It is not that notable in February mainly due to the already weak and unstable signal, but much significant in March.

Discussion and conclusion

Effect of climatic conditions

As it was predictable, dynamics of tree-ring formation mainly depends on the available precipitation during the summer period. In case of both latewood and total tree-ring development July moisture has the highest positive impact, but precipitation of August and June has also

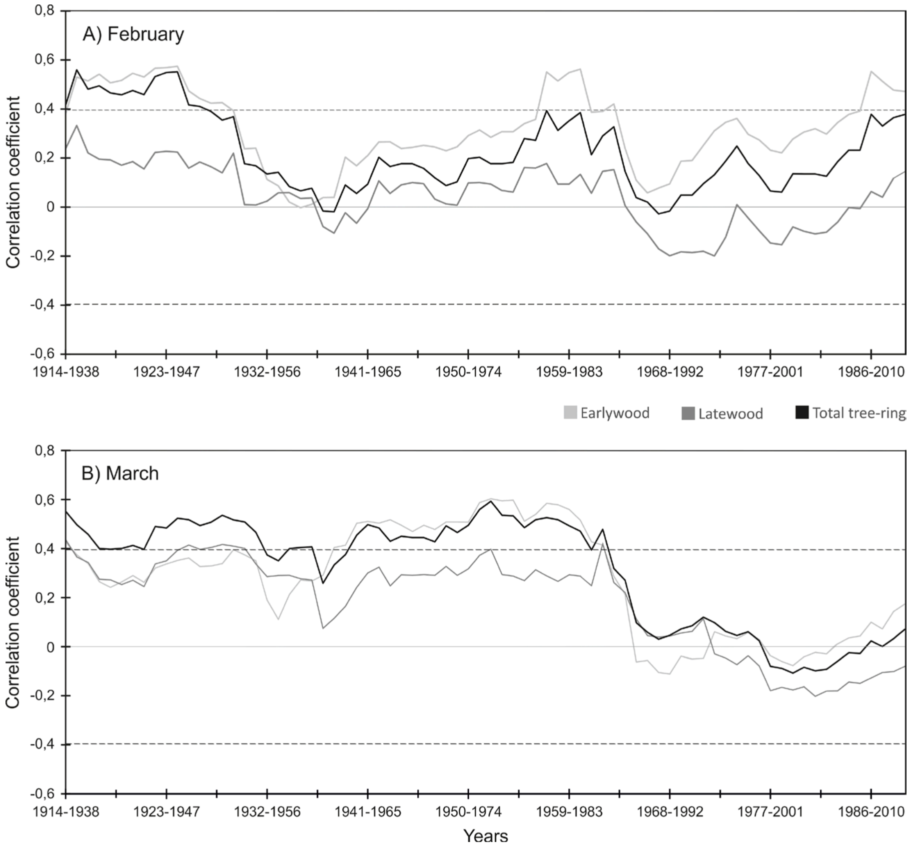

Figure 6. Changes in climate-growth relationship of Scots pine in February and March during the last 100 years. Dashed lines indicate the 0.05 significance levels

significant role. Still, considering precipitation, for the earlywood formation its amount is particularly important in May as well in prior August. Thermal conditions have a secondary, but remarkable role in tree-ring formation. The negative effect of temperature in August and July is dominant in latewood and in total tree-ring width, but warmer than average October, same as prior September, have also negative impact on their growth. The most significant positive influence of temperature on different tree-ring parameters occurs in the late winter-early spring period. The highest positive bootstrap correlation values between thermal conditions and annual increment were observed in February and March in both EW, LW and RW indices.

Similar correlation pattern to the above presented ones many times was described in other studies on pine (e.g. Michelot et al. 2012, Panayotov et al. 2013, Levanič 2015), on larch (e.g. Koprowski 2012) and on fir (e.g. Koprowski 2013) as well.

Effect of changing temperature

The effect of changing climatic conditions on tree-ring growth was reported several times (e.g. Carrer and Urbinati 2006, Pärn 2009, Koprowski 2013). In our study, we analysed the effect of increasing temperature on the onset of tree-ring formation in late winter-early spring period. According to our results, changing thermal situation has a significant long-term effect on earlywood and total tree-ring formation, but with different weight in February and March. As it was presented above, February temperature has significant role in both EW and RW growth, however, based on the 25-year moving window correlation the stability of this signal is weak, particularly between the 1930–1954 and 1957–1981 period (Figure 6). Correlation of earlywood index and temperature data reached the significance level ($p < 0.05$) only for three short periods during the last 100 years. Despite of the fact that temperature increase in February was remarkably high it had no effect neither on earlywood, on latewood nor on total tree-ring growth.

More stable and more significant role of March temperature has been observed in total tree-ring formation. Opposite to February, when no parallelism can be seen between the increasing trend of temperature and tree-ring growth, in March the tendency of alterations in the relationship between thermal conditions and annual increment development follows the trend of warming well. In most of the study period, until 1956-1980, March temperature had a balanced movement between 4.85 °C and 5.5 °C. Every time, when temperature decreased, earlywood and total tree-ring responded with better growth tendency. This pattern can be clearly seen in the period between 1937-1961 and 1962-1986. Nevertheless after this period the values of moving window correlation have decreased dramatically. This heavy shift in correspondence coincides with the warmest period of the last 100 years.

As it was many times emphasized, changing climatic conditions can cause altered climate-growth relationship and different seasonal reactions (e.g. D'Arrigo et al. 2008). In connection with the similar warming trend in Slovenia, de Luis (2014) noted that increase in winter temperature affects the onset of cambial reactivation and the onset of wood production, whereas long-term increase of spring temperature limit tree growth of most species hereby has negative impact on forest productivity. Analogous investigation to the current study has been done in the lowland area of Poland by Koprowski (2013) on spruce, where he found a similar decreasing trend in correlation values between late winter-early spring temperature and tree-ring growth, and draws attention to another negative effect of warming in February and March, namely, to the decrease of tree resistance to low temperature. It can happen because higher thermal conditions disturb the hardening of trees hereby they will become more vulnerable to late winter-early spring frost.

Koprowski also adds that in only one out of three regions a significant negative effect of increasing March temperature on tree-ring growth was observed. Comparing our results with findings by Koprowski, we can state that the shift in thermal influence occurred at the same time in Poland and in Hungary, around 1963–1987, which coincides with the onset of intensive warming in spring in Europe (Xoplaki et al. 2005). The origin of heavy temperature increase, which has been affecting the whole continent was most probably anthropogenic (Klein Tank et al. 2005) and due to its rapidity, it highly influences the European ecosystems. According to our results the relationship between the tree-ring formation of Scots pine and March temperature has significantly changed during the last decades in Hungary, which most probably was caused by the increasing thermal conditions in early spring. While in the beginning of the century March temperature was an important factor in tree-ring growth in the second half of the century, thanks to the continuous upward trend in temperature values its role completely ceased.

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