

White pine and Scots pine tree-ring chronologies as indicators of climate-related non-native and native tree growth patterns in Estonia

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Abstract

Three tree-ring chronologies of white pine (*Pinus strobus*), a species which are non-native to Europe, were constructed for Suuremõisa, Jädivere and Järvselja sites in Estonia. These chronologies were related to instrumental climate records and Scots pine (*P. sylvestris*) chronologies from nearby sites. Growth rates of *P. strobus* exceeded those of *P. sylvestris*. The chronologies of the non-native and native pine species relatively well correlated with each other. Moreover, tree-ring growth of both species correlated positively with late-winter and spring (February–May) temperatures and negatively with spring (April) precipitation. While *P. strobus* growth was positively associated with summer precipitation, the growth of *P. sylvestris* remained positively related to the growing season temperatures. Both species exhibited a negative growth anomaly from 1939 to 1942.

Keywords: *Pinus strobus*, *Pinus sylvestris*, dendroclimatology, Estonia

Introduction

Pinus strobus is native to north-eastern North America with distribution from Newfoundland to northern Georgia (Mirov 1967). In its native land, the species is called eastern white pine, northern white pine, northern pine, soft pine, pumpkin pine, and simply white pine. There are multiple ways to explain the introduction of this species to Europe. In 1605, Captain George Weymouth of the British Royal Navy explored Maine and carried home with samples of magnificent timber. This timber represented *Pinus strobus* and, as a result, the species became known as Weymouth pine in England (Wilson and McQuilkin 1963). According to Hugh Johnson (1973: 71), a British author, *P. strobus* ‘was introduced to Britain in the 18th century by Viscount Weymouth, who planted it at Longleat’, while Owen Johnson (2004) says that the species was brought to Great Britain in 1705 by Lord George Weymouth.

First notifications of the introduction of *P. strobus* in Estonia are known from the second half of the 18th century. Forest cultures with white pine were established in

several localities, e.g. in Vigala manor and Viimsi manor in the first half of the 19th century, as well as in Karksi manor at the end of the 19th century (Sander and Meikar 2004). While in the stocktaking of 1954–1960 white pine was recorded growing in 127 sites over Estonia (Sander 2006), then in the inventory of 1983–1985 big trees of white pine were recorded growing in about 50 old parks in Estonia (Roht, in press). Alongside with Blister rust (*Cronartium ribicola*), anthropogenic influence is the probable reason for the decline of the white pine population in Estonia. Nevertheless, there are some stands of big healthy specimens of white pine that survived in several places.

Although *P. strobus* is not among the economically important tree species in Estonia, statistical analyses of its climatic determinants may be of value for assessing its growth variability, with comparisons to similarly estimated tree-ring growth of its native counterpart, *P. sylvestris*.

Previous studies have detailed the tree-ring growth patterns of non-native conifers in Estonia (Hordo et al. 2016, Läänelaid and Helama 2019). While these studies have focussed on introduced larch and Sitka spruce, the

purpose of this study is to contribute here to this literature with an analysis of *P. strobus* tree-ring growth. In Europe, tree-ring growth patterns of non-native *P. strobus* trees have been previously studied in the Czech Republic (Máková 2001, 2008). Moreover, *P. sylvestris* growth variations have been previously detailed and related to climatic factors with tree-ring data from several Estonian sites (Läänelaid and Eckstein 2003, Hordo et al. 2011, Metslaid et al. 2018). These studies form the basis of our interpretations of tree-ring growth patterns of these non-native and native pine species and their relation to climatic variations as observed in the Estonian sites with new *P. strobus* tree-ring data.

Materials and methods

Field sites

P. strobus growing in three localities in Estonia were taken under investigation for this study, along the transect line from northwest to southeast: Suuremõisa, Jädivere, and Järvselja (Figure 1).

In Suuremõisa Forest Park (coordinates 58.87° N, 22.94° E) in the Hiiumaa Island, there are about 15 big trees of *P. strobus* growing in *Vaccinium myrtillus* forest site type of III quality class, densely in a small patch of 30 × 30 metres. The site was visited in May 2018 when increment cores were extracted from the trunks of three trees of white pine at 1.0 m height above ground from the west side.

In Jädivere (58.70° N, 24.44° E) in West Estonia, nine big white pines grow in the nature-protected forest park. This is an abandoned manor park, now classified as of *Oxalis* forest site type of II quality class. Eight of them (one was missed as decayed inside) were sampled with increment borer at 1.2 m height from the north side in October 2019.

In Järvselja (58.27° N, 27.31° E) in East Estonia, there are remarkable specimens of white pine growing in several places. Four trees were sampled in the Dendro-park at Järvselja, Agali Arboretum, Haavametsa forester's homestead and the forest quarter No. 301 nearby, all at 1.3 m height from different directions of the trunk. One more tree was sampled from the remained stump on the border



Figure 1. A map showing the *Pinus strobus* (PIST, blue dots) and *P. sylvestris* (PISY, green dots) sites in Estonia. See Table 1 for the site codes.

of the forest quarter No. 75 at 0.4 m height from N and W sides. These white pines were sampled in November 2019.

Through this paper, the acronyms PIST and PISY are used for *P. strobus* and *P. sylvestris*, respectively. This usage follows the nomenclature common in tree-ring research for these species (Grissino-Mayer 1993). Accordingly, the *P. strobus* and *P. sylvestris* tree-ring chronologies from the seven sites are referred to as PIST1, PIST2, PIST3, PISY1, PISY2, PISY3a, and PISY3b (see Table 1 for the descriptions of site chronologies).

Tree-ring analyses

Ring widths were measured from the increment cores to the preciseness of 0.01 mm by Lintab measuring device (Rinntech). Ring-width series of two radii were synchronised for each tree and the tree averages then dated by graphs against Estonian chronology of Scots pine (Läänelaid and Eckstein 2003).

Long-term growth variations were removed from the tree-ring series using a two-phase detrending technique carried out using the Arstan software (Holmes et al. 1986). First, the long-term trends pertaining to the tree ageing were eliminated from each tree-ring series by fitting either a modified negative exponential curve or a regression line with negative or zero slope (Fritts 1976) to the series of

Table 1. A list of *Pinus strobus* (PIST) and *Pinus sylvestris* (PISY) sites investigated in this study, with latitude (°N) and longitude (°E) of the sites, the total number of radii with tree-ring data (N_{series}) and the number of cored trees (N_{tree}), the median tree age at sampling height (1.0–1.3 m) (ASH; years) at the time of sampling, and the meteorological stations nearest to the tree-ring sites and used for dendroclimatic comparisons

Site code	Site name	Latitude	Longitude	N_{series}	N_{tree}	ASH	Station
PIST1	Suuremõisa	58.87	22.94	5	3	122	Ristna
PIST2	Jädivere	58.70	24.44	16	9	161	Kuusiku
PIST3	Järvselja	58.27	27.31	17	5	98	Tartu
PISY1	Kärdla	58.96	22.69	13	12	212	Ristna
PISY2	Velise	58.78	24.53	10	8	125	Kuusiku
PISY3a	Järvselja forest block 261	58.27	27.33	14	14	218	Tartu
PISY3b	Järvselja forest block 274	58.27	27.31	12	12	181	Tartu

tree-ring widths and obtaining tree-ring indices as ratios between the observed and modelled ring width. As the series of tree rings may contain growth pulses caused by ecological disturbances (Cook 1987), a second curve was also applied as a spline curve (Cook and Peters 1981) to the series of ratio-based indices. The growth variations modelled by this curve were eliminated from the data by dividing the ratio-based index value by the value of the curve. A previously suggested rigidity of the spline (see Cook et al. 1990a) was chosen to represent two-thirds (67%) of the length of each series (50% frequency response cut-off). Then, the series of tree-ring indices were further pre-whitened in order to remove the autocorrelation from the series using autoregressive-moving average models (Cook et al. 1990b). Arithmetic mean was used to compute the site chronologies. In so doing, the series of tree-ring indices of different radii from the same tree were averaged, after which the tree-specific index series were averaged to represent the tree-ring growth variability at each *P. strobus* and *P. sylvestris* site. Comparisons among and between the *P. strobus* and *P. sylvestris* chronologies were made visually and statistically using Pearson correlations. Following a previous study (Helama et al. 2016a), the correlations were averaged subsequent to Fisher’s *z* transformation (Fisher 1921). Comparison of the two means was made using *t*-test. Mean correlations were reported subsequent to the inverse of the Fisher transformation. The regional mean chronologies were calculated by averaging the time-series of the sites’ chronologies. In so doing, the two *P. sylvestris* chronologies from Järvelja sites were averaged before the calculation of the regional chronology (to avoid weighting the data towards this sub-region). The relatedness between the tree-ring chronologies and climatic records was quantified using Pearson correlations. The series of pre-whitened tree-ring indices were correlated with the series of monthly mean temperatures and precipitation sums as obtained from Ristna (58.94° N, 22.06° E), Kuusiku (58.99° N, 24.73° E) and Tartu (58.27° N, 26.47° E) meteorological stations each locating near one of the tree-ring sites (see Table 1). These data were linearly detrended, scaled to a mean of zero and standard deviation of one, and averaged prior to dendroclimatic correlation analysis in order to avoid flawed relationships. A previously suggested approach (Helama et al. 2016b) to produce a new time-series as the difference between two investigated tree-ring chronologies to further illustrate their deviating growth patterns was used by applying the following equation:

$$d_t = \bar{i}_t^{PIST} - \bar{i}_t^{PISY} \quad , \quad \text{Eq. 1}$$

where d_t is the difference between the \bar{i}_t^{PIST} and \bar{i}_t^{PISY} , the mean indices of *P. strobus* and *P. sylvestris* chronologies, respectively, in year *t*.

Also, this time-series was correlated with climatic records similar to the actual *P. strobus* and *P. sylvestris* chronologies.

Results

Tree-ring data

Cumulative plots visualised the growth rates as a function of tree age (Figure 2). Growth rates were clearly higher in the *P. strobus* data. All the three site-specific curves of cumulative growth for this species exceeded those obtained for *P. sylvestris* trees. Moreover, *P. strobus* and *P. sylvestris* chronologies portrayed tree-ring growth variations on inter-annual and longer scales (Figure 3a–b). The period common to full datasets was 1922–1998 (Figure 3c). Calculated over this period, the correlations among *P. strobus* chronologies were slightly higher (0.39) in comparison to those among *P. sylvestris* (0.38) chronologies. Overall, these correlations (i.e. intraspecific) averaged 0.38, which was somewhat higher than the mean (i.e. interspecific) correlation calculated between the chronologies of the two species (0.32) (Table 2). Even these correlations did not exhibit a statistically significant difference in their means, as indicated by *t*-test ($t = 1.36, p = 0.20$). It appeared that the site chronologies of the two species were

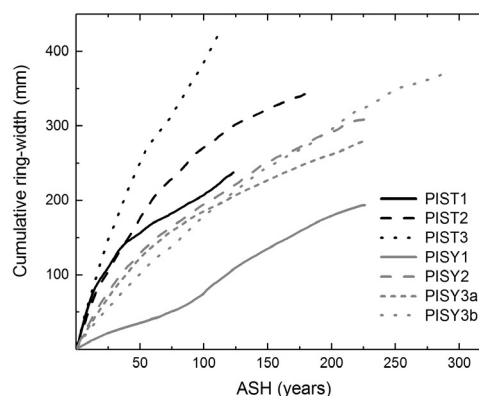


Figure 2. Cumulative plot of tree rings

Growth rates computed for the *Pinus strobus* (PIST) and *P. sylvestris* (PISY) sites as a function of age at sampling height (ASH). See Table 1 for the site codes.

Table 2. Correlations between the *Pinus strobus* (PIST) and *Pinus sylvestris* (PISY) site chronologies over the 1922–1998 period

Statistical significance at the 0.05, 0.01 and 0.001 levels are denoted by one (*), two (**) and three (***) asterisks, respectively. Here, the site code PISY3 refers to the mean of PISY2a and PISY2b chronologies. See Table 1 for the descriptions of site codes.

	PIST1	PIST2	PIST3	PISY1	PISY2	PISY3
PIST1	1.00					
PIST2	0.44***	1.00				
PIST3	0.34**	0.39***	1.00			
PISY1	0.25*	0.23*	0.44***	1.00		
PISY2	0.18	0.34**	0.35**	0.33**	1.00	
PISY3	0.17	0.38***	0.47***	0.29*	0.51***	1.00

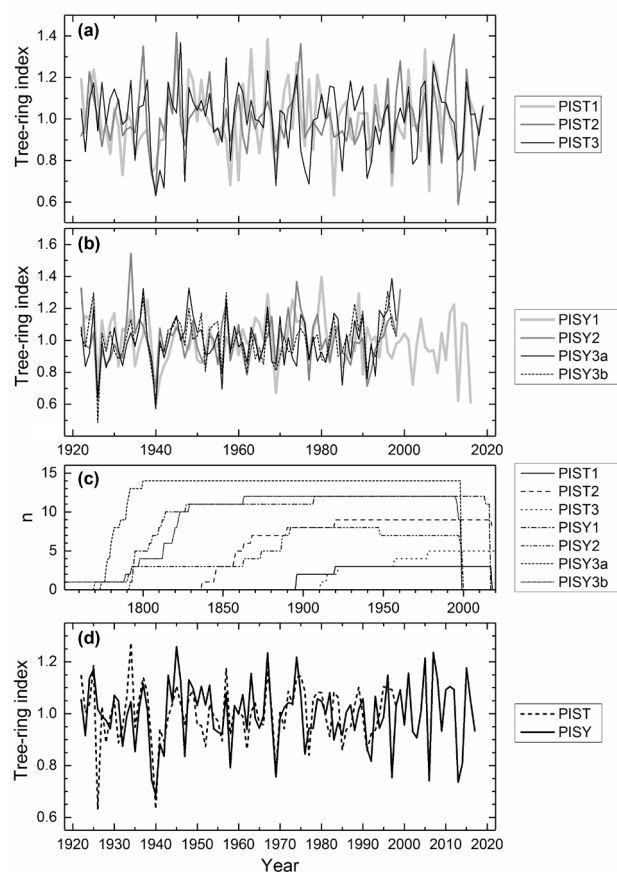


Figure 3. Site chronologies showing the *Pinus strobus* (a) and *P. sylvestris* (b) tree-ring growth variability, the replication (number of trees) of the chronologies (c), and the regional *P. strobus* and *P. sylvestris* chronologies (d)
See Table 1 for the site codes.

equally related to each other. Correlation between the regional mean chronologies of the two species was markedly higher (0.53) than the foregoing correlations between the site chronologies. Also, visual inspection of the records revealed considerable similarity between the chronologies (Figure 3d).

Dendroclimatology

Climatic determinants of *P. strobus* and *P. sylvestris* tree-ring growth were analysed from the regional chronologies. The temperature data from Ristna station were available since 1945 (April), and the correlations were calculated over the 1946–1998 period common to the full dataset of tree-ring and climate data. Correlations with climatic records indicated that the growth variability could be related to both temperature and precipitation records (Figure 4a–b). The growth of *P. strobus* was positively associated with late-winter and spring (Feb–May) temperatures, negatively with precipitation in April, and positively with summer (Jul–Aug) precipitation. Like this

species, the *P. sylvestris* growth was positively related to winter/spring temperatures. By contrast, the *P. sylvestris* growth remained positively associated with the growing season temperatures. Moreover, the growth of this species was relatively insensitive to summer precipitation. These differences were revealed by the correlations between the climatic records and the d_t time-series (Figure 4c). That is, the differentiated pine growth responses to growing season precipitation and temperature conditions were signified by the statistically significant ($p < 0.05$) negative and positive correlations, respectively, with July temperature and August precipitation.

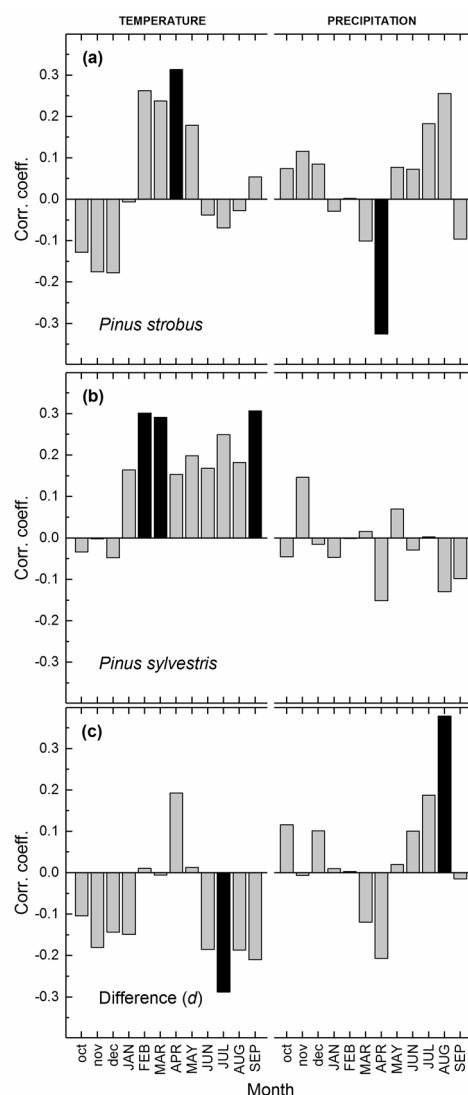


Figure 4. Correlations between the *Pinus strobus* (a) and *P. sylvestris* (b) chronologies and the monthly mean temperatures and precipitation sums of previous (small letters) and concurrent (capital letters) to growth year, and the climatic correlations of the difference (Eq. 1) between two investigated tree-ring chronologies (c)

Statistically significant relationships (0.05 level) are indicated as filled histograms.

Discussion and conclusions

Higher growth rates observed for *Pinus strobus*, in comparison to *P. sylvestris*, concurs with American silvicultural literature citing the former species among the more rapid growing northern forest conifers (Wendel and Smith 1990). Moreover, *P. strobus* can attain a very large size (Wilson and McQuilkin 1963). According to the latter authors, the dominant *P. strobus* trees ordinarily grow at the rate of 5–10 rings per diameter-inch to an age of 250 years, whereas in fully stocked stands tree diameter increases on average sites at the rate of 1 inch every 5–7 years. The growth rates of the studied *P. strobus* showed radius of ca. 200–400 mm for their first 100 years (Figure 2). This means that the growth rates obtained for Estonian sites reach the upper range or even exceed the values described for the average American *P. strobus* trees. Possibly, the Estonian sites are more favourable to *P. strobus* than those reference (average) sites. Also, the studied *P. strobus* trees have not yet reached the age of 250 years. As the radial increment tends to decrease as trees age, as also indicated by the concavity of the illustrated growth curves (Figure 2), it is likely that the growth rate estimates for the Estonian and reference sites are not fully comparable.

Our results demonstrate the regional chronologies of the two pine species, *P. strobus* and *P. sylvestris*, to correlate relatively well with each other (Figure 3d). Previously, the *P. strobus* and *P. sylvestris* were exemplified as two pine species which are ecologically dominant in nutrient-poor soils in cool temperate regions in the north-eastern USA and central Europe, respectively; in comparison, however, *P. sylvestris* extends to much colder habitat in high latitudes (Rundel and Yoder 1998). With these regards, the similarity of their growth patterns as demonstrated here for the Estonian sites may not be too surprising, especially given the central role of climatic factors potentially driving the common growth variability. Focussing on *P. sylvestris* tree-ring growth in Estonia, Metslaid et al. (2018) showed that the growth responses to climate variability were more similar in this species within the same sub-region (inside Estonia) than for the same forest site types in different regions, suggesting that climatic properties could precondition the differentiation between the growth responses. In our study, the growth variability expressed by the *P. strobus* and *P. sylvestris* site chronologies could not be statistically distinguished from each other purely by linear (Pearson's) correlativity, which could also suggest that the climatic properties exert a profound influence on the pine growth variability thus leading to observed (intra- and interspecific) similarity in growth. On the other hand, the growth responses to some of the climatic factors were dissimilar, thus explaining the remaining growth patterns that deviate between the species.

The positive growth response of *P. sylvestris* to late-winter and spring temperatures (Figure 4b) has been

previously demonstrated in Estonia (Läänelaid and Eckstein 2003, Hordo et al. 2011, Metslaid et al. 2018). Using much longer *P. sylvestris* tree-ring chronologies, Läänelaid et al. (2012) showed that climatic variations in association with such a winter response could indeed lead to spatially extending synchrony between the chronologies around the Baltic region over the past millennium. Here, this climatic factor was found to influence also the *P. strobus* growth variability (Figure 4a). Like these findings, tree-ring growth of *P. sylvestris* was positively related to winter (February) temperatures in the Czech Republic where, however, *P. strobus* did not exhibit such a response (Máková 2001, 2008). With regards to *P. sylvestris* growth responses, Metslaid et al. (2018) connected this factor to several potential physiological explanations including frost damage to fine roots, defoliation in the following spring and reduced photosynthetic recovery, delayed snowmelt and restricted water and nutrient uptake, with delays in a cambial activity. We see these influences as likely candidates to drive both the *P. sylvestris* and *P. strobus* growth in the studied Estonian sites. Previous analyses have also revealed the negative (non-significant) correlation between the *P. sylvestris* tree-ring growth and precipitation in April (Läänelaid and Eckstein 2003). Here, this correlation was statistically significant and stronger for *P. strobus* (Figure 4a). It is known that developing foliage of *P. strobus* acts as a strong carbon sink in the spring stimulating photosynthetic production in the older foliage (Rundel and Yoder 1998). With these regards, it may not be ruled out that the negative correlation to April precipitation relates to photosynthetic reductions during rainy springs when fewer photosynthates are available to radial growth during the forthcoming growing season. While both climatic factors, the late winter/spring temperature and April precipitation/cloud cover appear common to both species, dissimilar growth responses between the species were observed particularly in connection to growing season conditions.

Our results demonstrate the dependence of *P. strobus* and *P. sylvestris* growth on moist and warm summer conditions, respectively (Figure 4c). That is, the deviating growth patterns in their regional chronologies could likely be attributed to variations in these climatic factors. Similar to these findings, *P. sylvestris* tree-ring growth is positively related to summer temperatures in some parts of Estonia (Metslaid et al. 2018) and southern Finland (Helama et al. 2012), and commonly over much-extended areas with increasing correlations towards the northern limit of the species range (Helama et al. 2005). In accordance with our findings (Figure 4a), tree-ring growth of *P. strobus* was related to summer (May–July) precipitation variability in the Czech Republic, where this response remained stronger for this species than for *P. sylvestris* (Máková 2001, 2008). Moreover, the adverse effects of water deficits during growing season have been documented for the annual increment of native *P. strobus* trees

(Clinton et al. 1997). By contrast, we find no correlations to relate *P. sylvestris* growth similarly with precipitation (Figure 4b). Previous findings indicate that early-summer (June) precipitation could indeed influence *P. sylvestris* growth, at least during restricted time intervals, also in Estonia (Läänelaid and Eckstein 2003). Positive correlations between the *P. sylvestris* tree-ring growth and June–July precipitation were evident also in southern Finland (Helama et al. 2012). To conclude, the dendroclimatic results from the Czech Republic concur with our findings to indicate that *P. strobus* remains more sensitive than *P. sylvestris* to summer droughts. Climate change scenarios for Estonia show warming in all months, however, the projections of precipitation are more variable, with increases predicted for the cold seasons, decreases in precipitation being possible for summer and autumn (Jaagus and Mändla 2014). In such a situation, the projected climatic change could lead to the differentiated future growth of the two pine species with adverse effects from droughts becoming more likely to limit *P. strobus* growth.

An eye-catching feature of the tree-ring chronologies (Figure 3) was a growth curtailment observed for both pine species ca. 80 years ago, with tree-ring index values remaining below 1.0 from 1939 to 1942. The most substantial growth reduction was observed in 1940 when the tree-ring indices of both species dropped below 0.7. We note that this growth anomaly overlaps with three years of unusually cold winter (Jan–Mar) conditions as recorded by more than 6°C colder (−11.3°C) than average (1901–2000) temperatures (−5.1°C) at the Tartu meteorological station. This event postdates, however, the start of the growth anomaly by one year and could not explain the low growth values in 1939. In Estonia, a coinciding anomaly of low tree-ring growth was previously observed for *Picea abies* in connection to dry summer conditions (Läänelaid et al. 2015), in keeping with the indications of *P. sylvestris* tree-ring growth in Finland where the drought lasted for the 1939–1942 period (Helama 2004). A similar growth anomaly appears as previously illustrated for Sitka spruce growing in Estonia (Läänelaid and Helama 2019). The summer (Jun–Aug) of 1939 was also one of the driest (84 mm) in the context of long-term (1901–2000) precipitation level (220 mm) as recorded at the Tartu meteorological station and could, at least tentatively, serve as a candidate for low growth value in 1939, especially for *P. strobus*. The case of *P. sylvestris* remains more open as this climatic factor did not show in the dendroclimatic correlations for this species. Eventually, it seems plausible that a rare occurrence of overlapping events likely of climatic origin may result in coinciding tree-ring growth anomalies both in native and non-native conifers.

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