Norway Spruce in Estonia Reflects the Early Summer Weather in its Tree-Ring Widths

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Abstract

From Norway spruce (*Picea abies* (L.) H.Karst.) trees all over Estonia, increment cores were collected to study the relationship between tree-ring width and climate; particular emphasis was given to pointer years. Between 1871 and 2009, 34 negative and 31 positive pointer years were identified. As a limiting factor for the growth of spruce, June precipitation/temperature turned out to be most obvious, especially in pointer years. This dependence lost previous importance during the last decades while the amount of rainfall slightly increased.

Key words: Norway spruce, dendroclimatology, pointer years, Estonia, early summer rainfall/temperature

Introduction

Norway spruce (*Picea abies* (L.) H.Karst.) and Scots pine (*Pinus sylvestris* L.) are the most frequent conifers in North Europe, including the Baltic countries (Hallanaro and Pylvänäinen 2002). In Estonia, mixed hardwood-spruce forests form one of the few climax communities (Laasimer 1965, 1977). For many centuries, spruce and pine have been the main building timber in the region. In old Estonian buildings, spruce beams occur a little less frequent than pine beams even though many log houses and roof constructions are exclusively made of spruce timber. Moreover, spruce wood has been used to manufacture specific objects, from fences to violins.

As regards dendrochronological dating, spruce unlike pine often poses problems (e.g., Th. Bartholin, pers. comm., Läänelaid 2003). Spruce prefers fertile soils and demands sufficient moisture (Laasimer 1965, Lõhmus 2004), and due to its near-surface root system, it is sensitive to water-level changes. Whereas Estonian Scots pine has proven well-suited for dendrochronology and -climatology (Läänelaid and Eckstein 2003, Hordo et al. 2009, Pärn 2009), such systematic study is still missing for Estonian Norway spruce.

Therefore, we investigated living spruces all over Estonia (1) to see whether there is a uniform country-wide climatic signal recorded in their tree-ring widths, and (2) to consider whether this signal can be used as climate proxy.

Material and methods

For this project, seven ecologically similar sites (five of them are of the *Hepatica nobilis* forest type and two of them are of the *Vaccinium myrtillus* forest type), 30-120 m above sea level, with old-grown Norway spruce were selected all over Estonia (Fig. 1). From 10-16 trees per site, two increment cores, each, were taken with a conventional increment borer from opposite sides of the trunk at breast height. The transversal surfaces of these cores were smoothed to enhance the visibility of the tree-ring boundaries. Then, the tree-ring widths were measured to the nearest 0.01 mm using a LINTAB measuring device and the TSAP software (Rinntech 2006). The two tree-ring series per tree were visually cross-dated on the computer screen and averaged into one tree-ring series for each of the altogether 87 spruces. No missing rings or any other tree-ring anomalies were identified.

The tree-ring series were further processed with standard dendrochronological techniques (Fritts 1976, Cook and Kairiukstis 1990). At first, the age-trend had to be removed from the tree-specific mean tree-ring series, and the autocorrelation had to be minimized in order to focus on the climate-caused, year-to-year,

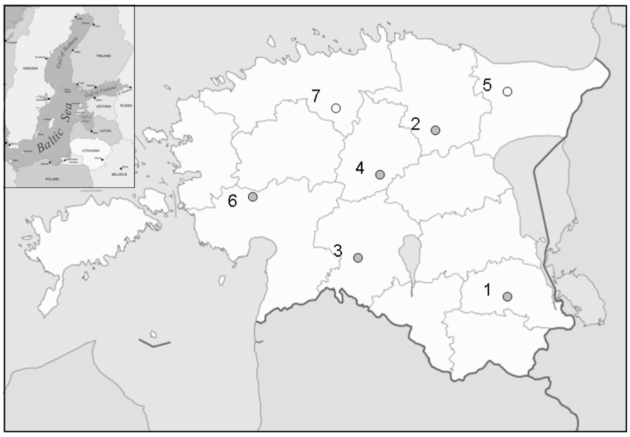

Figure 1. Map of the Baltic Sea area (inset) and location of the sample plots for Norway spruce in Estonia: 1 – Aarna, 2 – Äntu, 3 – Halliste, 4 – Imavere, 5 – Maidla, 6 – Pärnu-Jaagupi, 7 – Paunküla; the trees at sites 5 and 7 were excluded during the study

tree-ring width variability. This was done by program ARSTAN (Cook 1985) which was applying a two-step detrending technique, fitting (1) a negative exponential function or a linear regression function, and (2) a spline function preserving 50% of the variance at a wavelength of 128 years. After this transformation, ARSTAN has been assembling the tree-specific mean tree-ring index series into one chronology per site („residual“ tree-ring chronology). At the same time some statistical descriptors were computed, such as r_{bt} (correlation between the tree-ring series within each site), mean sensitivity (to measure the year-to-year variability of a tree-ring series), autocorrelation (to measure the persistence within a tree-ring series), and the percent value of common tree-ring width variability contained in the first principal component (Fritts 1976).

Based on these descriptors, the suitability for dendrochronology of the seven site chronologies was screened and inappropriate site chronologies eliminated from further analysis. The resulting regional tree-ring chronology was also qualified by statistical descriptors. In addition to the afore-mentioned ones, here also the expressed population signal (EPS) (Wigley et al. 1984) was given; if EPSe”0.85, the „sample depth“ of a chronology is considered to represent at least 85% of the common signal of a theoretically infinite number of trees. Finally, the tree-ring chronology was checked for its climatic signal(s).

The Estonian climate can be characterized being between maritime and temperately continental, with an annual mean temperature of +5 °C (the hottest and coldest months are July with +18 °C and February with -5 °C) and with an annual sum of precipitation varying from 550 to 800 mm of which 54% on average occur during the growing season from May to September. The annual mean temperature and the annual sum of precipitation were tested whether they vary around a constant long-term mean or a positive or negative regression line.

The climatic signal „archived“ in Estonian residual chronology of the tree-ring width was identified using program DendroClim2002 (Biondi and Waikul 2004). It correlates the regional tree-ring width chronology with monthly mean temperatures (recorded by the Meteorology Station of Tartu, beginning in 1866) and monthly sums of precipitation (averaged from more than 100 stations over Estonia, beginning in 1866 as well) from October of the previous year to September of the current year. This interval is based on early observations by Kairiūkštis (1963) and most recently by Vitas (2011) who found that Norway spruce (in Lithuania) started growing in the second half of May (1963)/early May (2011) and ended growing towards the end of August.

To check the stability of the climatic signal(s) over time, the whole period of instrumental weather records was divided into two sub-periods, 1875-1941 and 1942-2008. As a modification of the conventional approach, the regional tree-ring width chronology was additionally screened for years in which the growth of the trees showed the same downward or upward trend from the previous year independent from tree-ring width (Schweingruber et al. 1990). Such pointer years were identified by program Weiser (García-Gonzáles 2001) as long as the chronology was replicated by at least 12 trees (Eckstein and Bauch 1969). All other years were termed non-pointer years. Then, the tree-ring widths in pointer years and in non-pointer years were separately correlated with monthly precipitation and temperature.

Results

Statistical qualification of the tree-ring data

The statistical characteristics of the tree-ring data on the site-level were summarized in Table 1. The maximum tree age varied between 89 and 246 years and the mean tree-ring width between 0.73 and 2.70 mm. The persistence in the tree-ring site chronologies (expressed by the autocorrelation) was considerably high with values between 0.64 and 0.87 before standardization; in the standardized („residual“) chronologies the persistence is zero or nearly zero. The suitability of the seven site chronologies for dendroclimatology can roughly be estimated by the correlation between trees (r_{bt}) (0.27-0.51) and by the percent value of the variance explained by the 1[st] principal component (32.8-59.0%); both parameters quantify the common variance

Table 1. Statistical information for the seven site chronologies in Estonia; the chronologies of sites 5 and 7 are omitted from further analysis because of their poor statistical characteristics

No. and name of site	Trees [n]	Max. tree age and average [ ]	Mean tree-ring width [mm]	Auto-correlation of the raw data	Standardized chronologies		
					Correlation between trees [r_{bt}]	Mean sensitivity	% variance in the 1st eigenvector
1 Aarna	14	148 [82.6]	2.34	0.69	0.50	0.17	54.94
2 Äntu	12	182 [116.4]	1.91	0.74	0.43	0.21	49.43
3 Halliste	13	154 [121.5]	1.95	0.74	0.48	0.23	54.38
4 Imavere	11	148 [107.9]	1.91	0.75	0.51	0.18	58.96
5 Maidla	15	246 [206.7]	0.73	0.87	0.30	0.16	34.30
6 Pärnu-Jaagupi	14	143 [121.5]	2.08	0.85	0.45	0.18	49.33
7 Paun-küla	13	89 [60]	2.70	0.63	0.26	0.15	32.79

of the tree-ring widths within a site. The mean sensitivity ranged from 0.15 to 0.22.

Based on these statistical descriptors, the site chronologies for Maidla and Paunküla were exceptional in that they were the longest respectively the shortest, with the narrowest/broadest mean ring width and the highest/smallest autocorrelation. But even more exceptional were the by far smallest r_{bt}, mean sensitivity and percent variance in the 1st eigenvector making both site chronologies questionable for dendroclimatology. Therefore, the site chronologies for Maidla and Paunküla were excluded from further analyses.

Assembly of an Estonian spruce chronology

From the altogether 58 spruce trees at the remaining five sites a regional tree-ring widths chronology was assembled covering the period from 2009 back to 1828; from the year 1871 onward, the EPS was ≥0.85 and the chronology consisted of 12 or more trees (Fig. 2). Thus, the 182-year long chronology of living spruces contains a 139-year long, statistically reliable, part which is fully covered with monthly weather records.

Relationship between the continuous spruce chronology and climate

The climate/growth relationships for both sub-periods, 1875-1941 and 1942-2008, showed basically a similar pattern (Fig. 3) with an overwhelming positive influence of rainfall in June; therefore, June rainfall was furtheron considered as a robust climatic signal typical of Estonian spruce. The dependence of spruce growth from June rainfall appeared, however, to have slightly decreased towards the present while the amount of rainfall has been rising since about 40 years (Fig. 4).

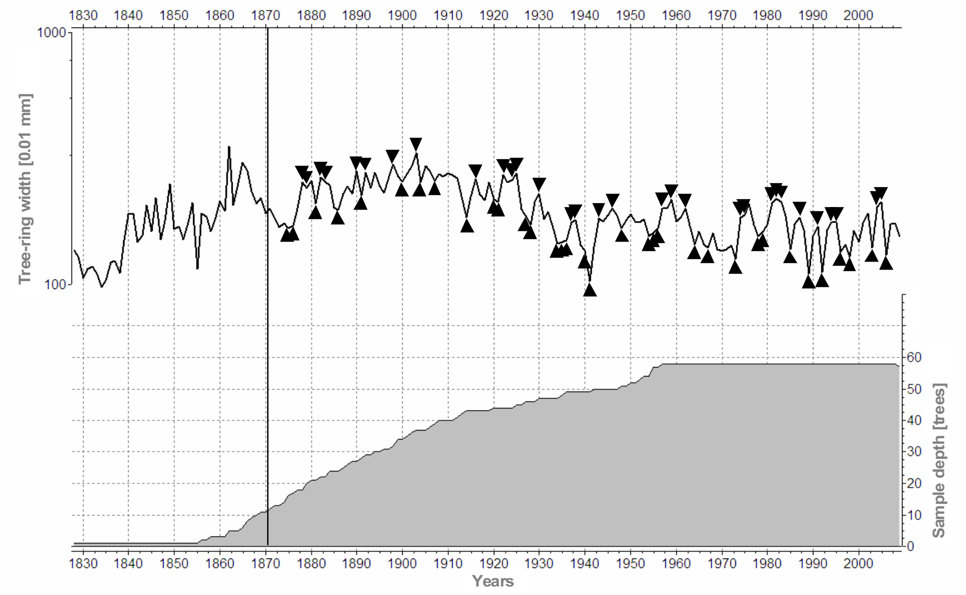

Figure 2. Estonian spruce chronology with sample depth (number of trees included); vertical line indicates EPS>0.85

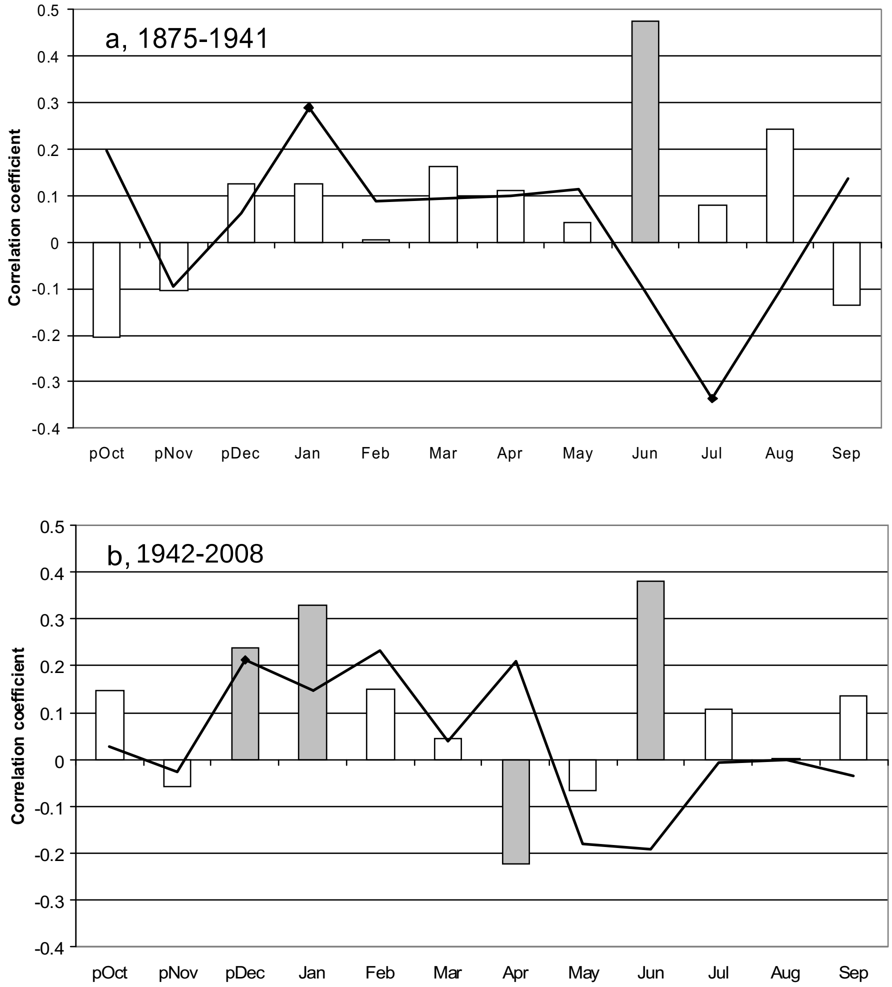

Figure 3. Correlation of the Estonian spruce chronology with monthly temperature and precipitation: a, 1875-1941, b, 1942-2008; significant correlation with precipitation marked by grey columns, with temperature – by rhomb marks; pSep, September prior to growth; Prec., precipitation; Temp., temperature

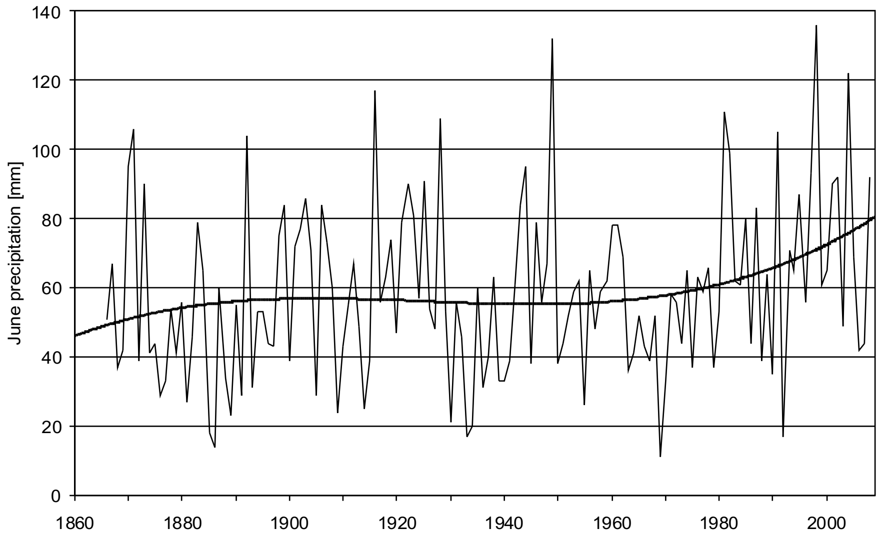

Figure 4. Variability of June precipitation in Estonia from 1866-2008, with a polynomial trend line superimposed

There were also two striking differences between the two sub-periods worth mentioning, (1) the highly significant negative influence of July temperature between 1875 and 1941, which disappeared lateron, and (2) a newly appearing influence of a warm/dry, respectively, a cool/moist April during the second sub-period which was not at all visible before.

The potential of the Estonian spruce chronology for being used as a climatic proxy is illustrated in Figure 5. We applied two qualifiers, the coefficient of coincidence ('Gleichläufigkeit') (Eckstein and Bauch 1969) as a measure of the year-to-year agreement between two time series, and the *t*-value (Baillie and Pilcher 1973) as a measure for how closely two time series approximate each other. The year-to-year variations of the chronology and of the amount of rainfall coincided in 62% of the years, that is to say, growth responded rather directly to changing water availability. The approximation between the two time series is expressed by a rather low *t*-value of 4.3.

years the climatic influence was concentrated on one single month; in other words, the overwhelming climatic signal contained in spruce was a wet/cool June. More detailed, June precipitation has the strongest influence on spruce growth in positive pointer years (Fig. 7a) whereas negative pointer years were primarily built by below-average temperatures from previous October to current September – even if not significantly throughout.

Discussion and perspectives

The Estonian Norway spruce chronology clearly reflects annually changing amounts of rainfall and – somewhat weaker – annually changing temperature, both in June. Since rainfall during summer is significantly negatively correlated with temperature (r=-0.24 in June, -0.32 in July, and -0.35 in August), the Estonian spruce chronology can thus be taken as a proxy for rainy/cool, respectively dry/warm, conditions in

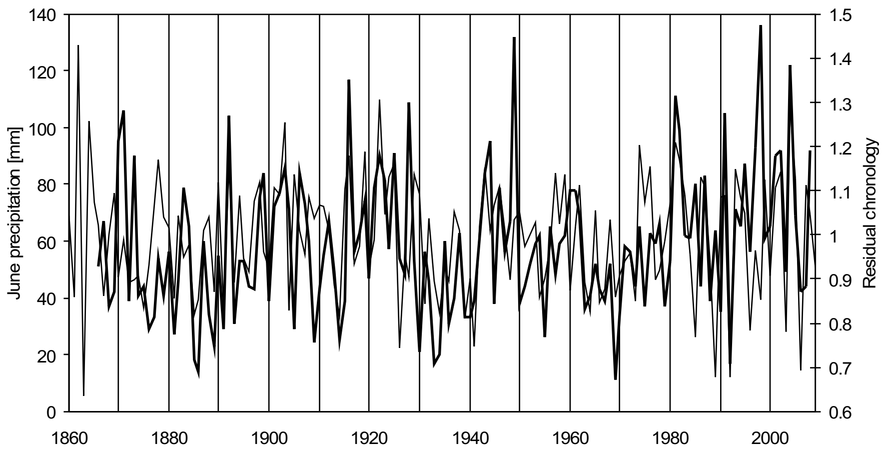

Figure 5. Estonian spruce chronology (thin line) vs. June precipitation (thick line) from 1866-2008; t = 4.3 (Baillie and Pilcher 1973), sign test = 62% (99.0 significance level) (Eckstein and Bauch 1969)

Relationship between the pointer-year respectively the non-pointer-year tree-ring widths and climate

Between 2009 and 1871, 31 positive and 34 negative pointer years were identified and marked along the spruce chronology (see Fig. 2). Their tree-ring widths correlated in the same way as the entire tree-ring chronology, however, much stronger. For example, June temperature during the early sub-period correlated with a value of +0.6 (as compared to +0.43 if the entire chronology is considered) (Fig. 6a).

The remaining 74 years were henceforth called non-pointer years (Fig. 6b) (see also Table 2). The most obvious characteristic for non-pointer-years was the beneficial influence of a dry and warm April, which was insignificant in the early sub-period, 1875-1941, of the whole chronology (see Fig. 3a) and not at all reflected by the pointer years. In contrast, in the pointer-

early summer (June). In contrast, the Estonian Scots pine chronology contains a late winter/early spring temperature signal (Läänelaid and Eckstein 2003). No wonder that the spruce and pine regional chronologies in Estonia do match only poorly to one another (r=+0.38 from 1871-2006). In Lithuania, there are also different patterns of tree-ring widths of spruce and pine and in consequence different responses to precipitation, as observed by Vitas and Bitvinskas (1998). Thirty years ago, Kask (1992) studied already the climate/growth relationships of spruce in Estonia; June precipitation, however, was not among the variables causing tree-ring width variation.

Around the Baltic Sea, Linderson (1992) reported that the radial increment of Norway spruce in southern Sweden is positively influenced by June precipitation. Furthermore, Vitas (2004) concluded for spruce

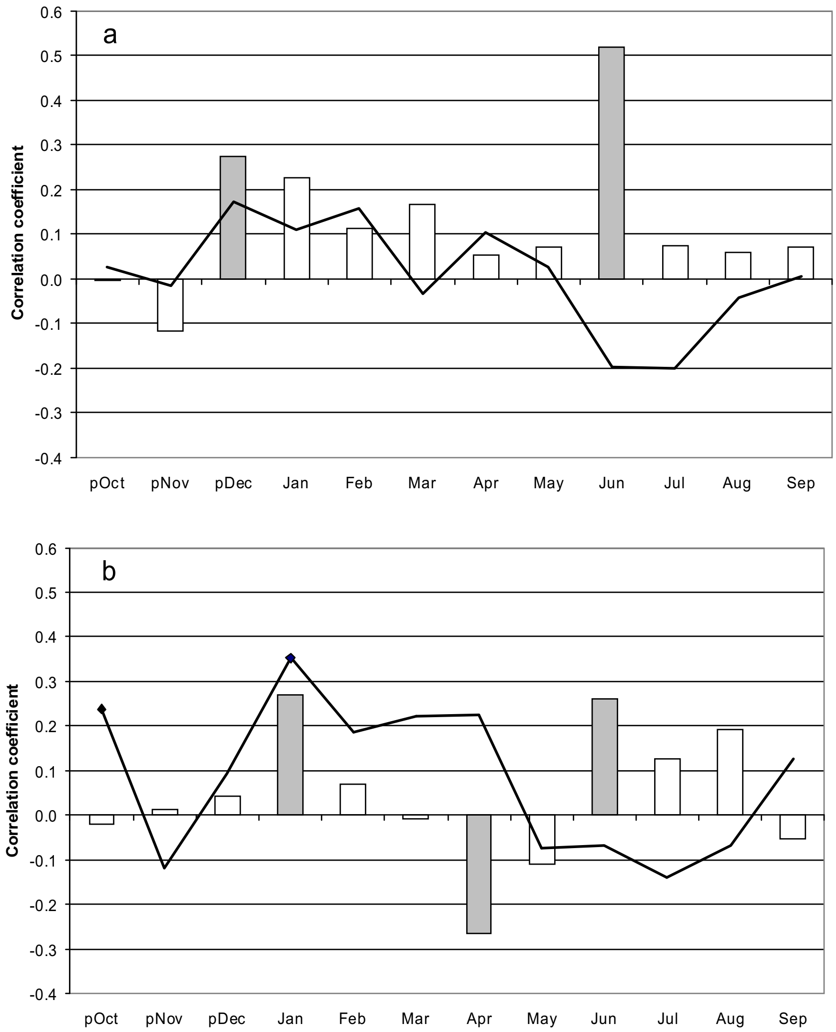

Figure 6. Correlation of spruce growth in non-pointer years (a) and pointer years (b), with temperature (line) and precipitation (bars) from pSep to August between 1875 and 2008; significant correlations are marked with gray bars and black markers on the line, respectively

Table 2. Correlation of June precipitation with the whole Estonian spruce chronology of five sites included and with the tree-ring index values in pointer years and in non-pointer years; significant correlations are marked in bold type

	Whole period 1875-2008	Early sub-period 1875-1941	Late sub-period 1942-2008
All years chronology	**0.41**	**0.47**	**0.38**
Pointer years	**0.52**	**0.60**	**0.48**
Non-pointer years	**0.26**	0.25	0.26

in Lithuania that a humid onset of summer is the most important factor. According to Koprowski and Zielski (2006), spruce growth on northern Polish sites is positively correlated with rainfall from May to July. Even in the lowlands of southeastern Norway, June precipitation turned out to be the main limiting factor for spruce growth (Andreassen et al. 2006). Furthermore, Selås et al. (2002) mentioned June-July precipitation as positively correlated with tree-ring width of spruce in southern Norway. Mäkinen et al. (2001) found that spruce growth showed a strongly positive correlation with June precipitation in damaged stands in southern Finland, whereas this relationship was much weaker in healthy stands. However, Henttonen (1984) has found that in southern Finland the decisive factor for the annual growth variation of Norway spruce is the effective temperature sum of the growing season, while precipitation from May-July had an effect only on two out of seven tree-ring width series. For northwestern Russia, high summer temperature was the most severe limiting factor for spruce growth, implying a summer soil moisture deficit for the trees (Aakala and Kuuluvainen 2011). Finally, for the southeastern Alps, Levanič et al. (2009) found that the sensitivity of Nor-

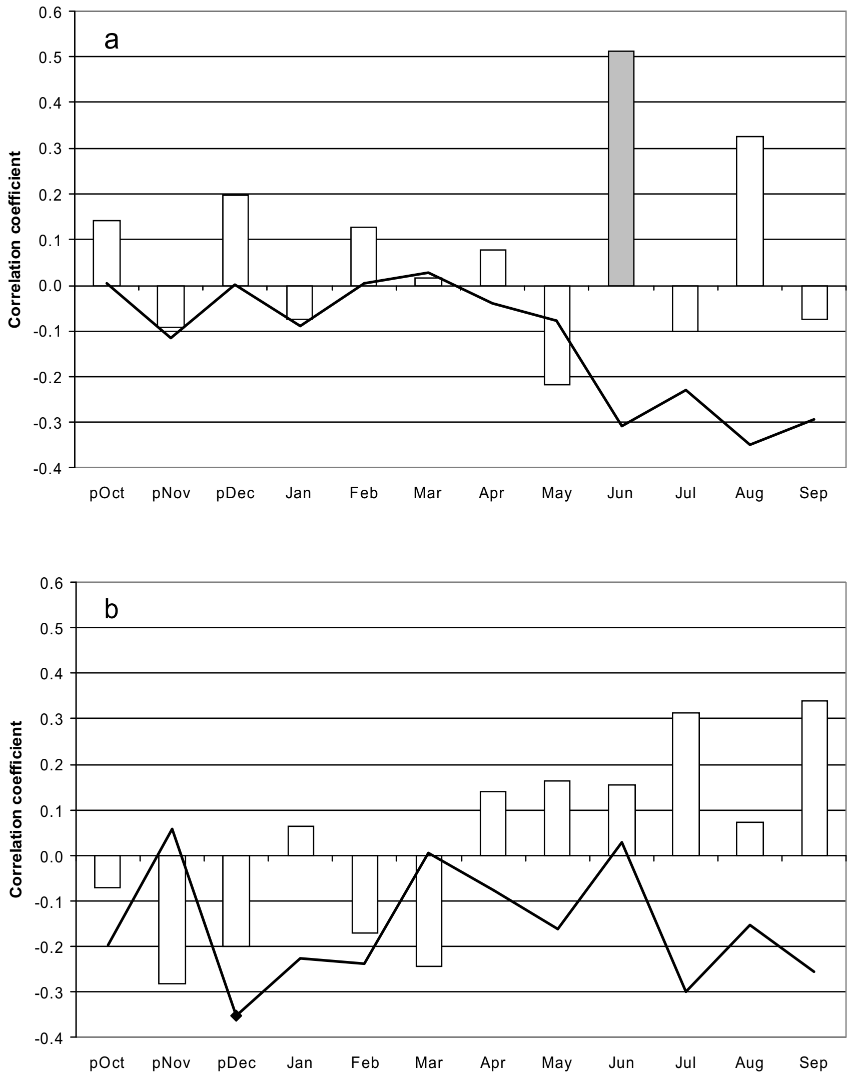

Figure 7. Correlation of spruce growth with monthly temperature (line) and precipitation (bars) in positive (a) and negative (b) pointer years

way spruce to summer temperature was site-dependent, sometimes even opposing from site to site.

The climate-growth relationship of spruce in pointer years provided a more reliable picture than the relationships in all years, and especially in contrast to non-pointer years. In future studies, the separation of pointer years from non-pointer years deserves more attention.

In conclusion, we could confirm a uniform country-wide climatic signal recorded in the tree-ring widths of Norway spruce, which even reaches out to surrounding countries from southern Finland through northern Poland to southeastern Norway. Due to its signal strength, the tree-ring widths of Norway spruce in Estonia could be taken as a proxy for early summer weather conditions; by additionally taking pointer years into account, climate reconstructions might become more reliable. The already existing Estonian Norway spruce chronology, composed from living trees and historic wood and at present covering the period from the present time back to 1576 (Läänelaid, unpubl.), could be taken for testing its dendroclimatic potential. For improving the datability of spruce timber, it is recommended to strengthen local tree-ring chronologies rather than rely on a single trans-regional one.

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ЕЛЬ ОБЫКНОВЕННАЯ В ГОДИЧНЫХ КОЛЬЦАХ ОТРАЖАЕТ РАННЕЛЕТНЮЮ ПОГОДУ В ЭСТОНИИ

А. Ляэнелайд и Д. Экштейн

Резюме

С целью сравнения мете орологических данных с шириной годичных колец ели обыкновенной (*Picea abies* (L.) H. Karst.), были отобраны керны соответствующих годичных колец. Из семи пробных площадей в Эстонии Особое внимание уделеноизучению связи годичного прироста с метеорологическими показателями в реперные годы, которых в интервале 1871-2009 годы оказалось 65, из них 34 были отрицательными и 31 положительным. Лимитирующими факторами в реперные годы для радиального роста ели оказались июнские атмосферные осадки и температура. Эта зависимость несколько ослабла в течение последних десятилетий, что в это время совпало с некоторым увеличинием суммы годичных осадков.

Ключевые слова: ель обыкновенная, реперные годы, дендроклиматология, раннелетние осадки/температура, Эстония.