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Effect of climate on extreme radial growth of Scots pine growing on bogs in Latvia

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Abstract. Tree rings are one of the most important indicators for reconstructing past history of climate variability as well as anthropogenic and ecological processes. The climatic signal for the past centuries recorded on tree rings is well known in regions of Europe for Scots pine growing in dry conditions, but little knowledge is available regarding pines growing on peatlands. Extreme changes of environmental conditions limit the radial increment of trees and influence the formation of very wide or very thin tree rings. Usually, these extreme events (pointer years) are best explained by climatic factors. The study was carried out on five bogs with variable evidence of past human disturbance. A large number of pointer years common between study sites were identified (positive 1913, 1916, 1917, 1934–1939, 1957, 1967, 1968, 1972 and negative 1865–1867, 1926, 1928–1931, 1947–1949, 1951, 1990, 2000, 2002). Correlation analysis between climatic variables (maximal, minimal, and mean air temperature and precipitation sum) and pointer years indicated that the response to precipitation sum was mainly local and low compared to the response to air temperature. The main climatic variables influencing the development of pointer years were the mean air temperature in the growing season (May–September) and minimal air temperature in February, as well as the precipitation sum in February (positive response) and in the growing season (negative response). However, pointer year development of Scots pine on bogs is mainly determined by local factors.

Key words: Scots pine, peatland, pointer year, climate.

INTRODUCTION

Tree rings are a unique source of proxy data for information about changes in the environment. Extreme changes of environmental conditions cause the formation of tree-rings that are much wider or narrower compared to neighbour tree-ring width (Schweingruber, 1996) or cause other conspicuous features such as missing rings, reaction wood, traumatic zones, etc. (Kaennel & Schweingruber, 1995). If these events are recorded in one and the same year in many individuals of a group of trees, they are designated as pointer years (Schweingruber et al., 1990). Pointer years indicate both regional and local influence of environmental changes (Schweingruber et al., 1990). Tree growth response to a particular environmental condition can be at a local scale (e.g. insect outbreak) and at a regional scale (e.g. climate), and it depends on tree species, bioclimatic regions, and site characteristics (Oberhuber et al., 1998; Desplanque et al., 1999; Rolland et al., 2000; Elferts, 2007). Pointer years are particularly useful for dendrochonological dating and they can be a powerful tool for dating the reaction of trees to climatic influences, particularly regarding extreme events (Desplanque et al., 1999; Vitas & Erlickytė, 2007) and at sites located at the ecological limits of the tree species (Rolland et al., 2000; Čejková & Kolář, 2009).

Scots pine (*Pinus sylvestris* L.) has a very wide ecological amplitude. This tree species successfully occupies dry habitats with coarse rocky and sandy soils as well as peatland habitats. Therefore, Scots pine has a wider geographical distribution than any other pine species. It is one of the dominant forest tree species within the boreal zone in Europe and Asia (Ohlson, 1995; Richardson & Rundel, 2000). Tree rings of this species have been successfully used in dendroclimatology, mainly regarding trees growing on dry soil sites. Comparatively few studies have considered the dendroclimatology of Scots pine growing on pristine peatlands or peatlands showing small signs of anthropogenic activities (Zālītis & Bambe, 1991; Stravinskiene & Juknys, 1998; Linderholm, 2001; Linderholm et al., 2002). The relative roles and interactions of climatic variables regarding the growth of Scots pine on peatlands are still not fully understood and, as previous studies have shown (Glebov & Litvinenko, 1976; Vaganov & Kachaev, 1992; Linderholm & Leine, 2004), these trees are better climate indicators at a local scale than the global scale. Dendroclimatological research of Scots pine in peatlands has demonstrated a low response of pines to climatic factors like temperature and precipitation, as growth is limited by depth and fluctuation of the local water table (Boggie, 1972; Glebov & Litvinenko, 1976; Jātnieks, 1987; Vaganov & Kachaev, 1992; MacDonald & Yin, 1999; Linderholm, 2001; Linderholm et al., 2002; Rydin & Jeglum, 2006). Water table depth controls regeneration and survival of seedlings, determines pine stand structure and dynamics (Ågren & Zackrisson, 1990; Ohlson & Zackrisson, 1992; Sarkkola et al., 2004), and shallow water table depth causes extremely slow growth of trees (Ohlson, 1995; MacDonald & Yin, 1999; Hökkä & Ojansuu, 2004). However, while water table depth as the main limiting factor intrinsically determines the effect of climate on growth, climate can control seasonal variation of water table depth, mainly by balance of precipitation versus evapotranspiration (Mannerkoski, 1991; Vaganov & Kachaev, 1992).

Previous research has shown that extreme radial growth patterns differ depending on climatic region, altitude (Rolland et al., 2000), and tree species (Desplanque et al., 1999; Vitas, 2004a; Lebourgeois et al., 2005). We hypothesized that extreme tree rings of Scots pine growing on peatlands can be a good proxy to explain the climate–growth relationship. The purpose of this study was to determine the main climatic variables influencing extreme radial growth of Scots pine on bogs, both regionally and locally.

MATERIAL AND METHODS

Study sites and climatological data

The study was carried out on five peatlands, which are specially protected nature areas (nature reserves) in Latvia and are included in the European network of protected territories *Natura2000* (Fig. 1). Three of them (Cena Mire, Lielais Kemeri Mire, and Gulbju-Platpirovas Mire) are also included in the list of Internationally Important Bird Areas. All of the study sites have evidence of human disturbance. The main anthropogenic activity in bogs has been ditching for peat harvesting and forestry carried out in the 20th century, particularly between 1960 and 1980 (Prieditis, 1999). In Cena Mire this influence is presently most visible as peat extraction is conducted about 1 km from the study site. The study sites were chosen as far as possible from ditches to minimize the human impact.

Climatological data were obtained from the Latvian Environment, Geology, and Meteorology Centre for the Ainazi, Rezekne, Riga, and Ventspils meteorological stations. Unfortunately, in Latvia the majority of meteorological records cover only short periods, mostly less than 100 years. The Riga meteorological record is the longest (1851–2006), but it is not possible to use these data for all study sites because the climate, especially total monthly precipitation in summer, significantly differs across Latvia. Therefore, climate data were obtained from the closest meteorological stations that had data for a sufficiently long period (Fig. 1, Table 1).

The data used were minimal, maximal, and mean monthly temperature and precipitation sum from the current and the previous year. A year was considered to start in the October of the previous year and end in September. Monthly data for the growing season (from May to September) and dormant season (from the previous October till the current-year April) were also used.

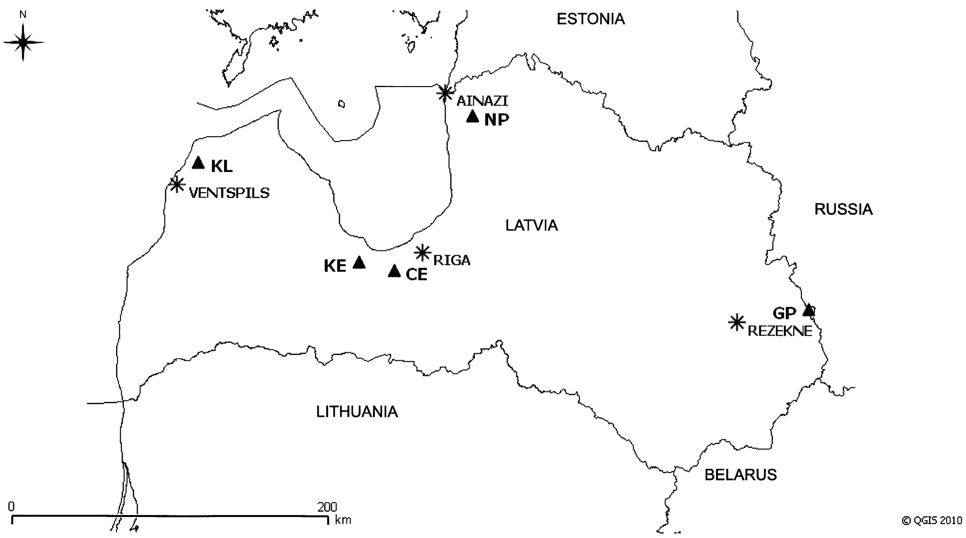

Fig. 1. Map showing the locations of the meteorological stations (marked with asterisks) and study sites (marked with triangles): **KL** – Klanu Mire, **KE** – Lielais Kemeri Mire, **CE** – Cena Mire, **NP** – Niedraju-Pilkas Mire, **GP** – Gulbju-Platpirovas Mire.

Table 1. Climatic variables and the length of meteorological records for the stations used in data analysis (Latvian Environment, Geology, and Meteorology Centre)

	Study site				
	Klanu Mire	Lielais Kemeri Mire	Cena Mire	Niedraju-Pilkas Mire	Gulbju-Platpirovas Mire
Latitude (N)	57°27′	56°54′	56°50′	57°44′	56°34′
Longitude (E)	21°45′	23°27′	23°49′	24°38′	28°05′
Meteorological station	Ventspils	Riga	Riga	Ainazi	Rezekne
			Temperature, °C		
Annual	6.6	6.2	6.2	5.8	5.2
July	16.8	18	18	17.2	16.9
December	−0.1	−2.6	−2.6	−1.8	−4.1
Time span for mean monthly	1923–2005	1851–2006	1851–2006	1927–2006	1948–2005
Time span for max and min monthly	1924–2005	1924–2000	1924–2000	1927–2006	NA
			Precipitation, mm		
Annual	647	614	614	595	586
July	63	78	78	65	72
December	62	44	44	45	41
Time span for total monthly	1923–2005	1851–2006	1851–2006	1927–2006	1948–2000

NA – data not available.

Sample collection and measurement

Samples were collected in 2005 (Klanu Mire, Cena Mire) and 2006 (Lielais Kemeri Mire, Niedraju-Pilkas Mire, Gulbju-Platpirovas Mire). Wood cores were taken only from the oldest trees, based on visual appearance of shoot and crown shape and bark (thickness and roughness). Two cores were taken from each tree with an increment borer from two opposite directions, as close as possible to the base of the tree, i.e., close to the bog surface. The pines were generally short and the base was overgrown by moss. If trees were tilting, samples were taken 90° from the tilting direction (Schweingruber, 1988).

In the laboratory the cores were dried and gradually sandpapered. A LINTAB ‘measuring table’ connected with TSAP software (Rinn, 1996) was used to measure tree-ring width. All curves from each site were checked using a combination of visual, graphic, and statistical cross-dating techniques. Visual and graphic techniques were used to correct misdated samples. Dating accuracy was checked with COFECHA software (Holmes, 1983). After tree-ring width measurement and quality control, mean tree-ring width was calculated for each tree that had two cross-dated cores.

Statistical analysis

Analysis was performed for different time periods for the study sites (Table 1). Pointer year intensity values for each study site were determined by the modified Skeleton-plot method (Neuwirth et al., 2004) where intensity values were defined as extreme positive or negative deviations from the average tree-ring width measurement in a single tree-ring series. Tree-ring width of each tree was compared to the mean tree-ring width of the previous five years. According to the intensity of a single growth deviation, five intensity classes from 'weak' to 'extreme' were used. The 5th intensity class is the maximum intensity class when a tree ring is at least 85% narrower or wider than the mean of the neighbouring rings, and the 1st intensity class refers to a 'weak' intensity when the difference is less than 20% (Neuwirth et al., 2004). Site pointer year intensity (I) was calculated using the formula:

$$I = \frac{100}{k \cdot n} \sum_{j=1}^{k} h_j \cdot i_j \ (\%),$$

where k – number of intensity class; n – total number of trees; h_j – number of trees in intensity class; i_j – value of intensity class.

Correlation analysis (Spearman correlation coefficient) was used to test extreme growth response to climate (maximal, minimal, and mean air temperature and precipitation sum). It is necessary to consider that trees growing on bogs are very sensitive to the influence of various environmental factors (e.g. wind, water table fluctuation) that can affect the formation of reaction wood (Schweingruber, 1996; Schweingruber et al., 2006). Therefore, pointer year analysis was conducted in two ways: (1) using only pointer year intensity values that were greater than 40% or less than –40% (in the case of negative pointer years); (2) using pointer year intensity values that were greater than 40% or less than –40%, plus values greater than 20% or less than –20% if these pointer years were common for at least three study sites. In this way, an attempt was made to obtain regional signals by filtering out local effects with low impact.

RESULTS

The number of successfully cross-dated Scots pine samples was quite low (Table 2). Discarded samples usually contained many missing rings (especially in Cena Mire) and rings with compression wood. The proportions of cross-dated samples were higher in Klanu Mire and Gulbju-Platpirova Mire, where mean tree-ring widths were wider than in other sites. The oldest trees were from Klanu Mire (mean tree cambial age 184 years) and Niedraju-Pikas Mire (mean tree cambial age 180 years).

In the period from 1803 to 2006, the number of pointer years differed between sites. A total of 45 pointer years (23 positive and 22 negative years in which pointer year intensity exceeded 20%) were synchronous in at least three sites (black bars in Fig. 2). Of these, 13 positive and 15 negative years were synchronous

Table 2. Basic data of the Scots pine samples

Study site	Sampled trees/ Cross-dated trees	Mean cambial age of cross-dated trees, years	Mean ring width of cross-dated trees, mm/year
Klanu Mire	15/11	184	1.19
Lielais Kemeri Mire	40/21	101	0.51
Cena Mire	80/19	147	0.55
Niedraju-Pilkas Mire	30/20	180	0.69
Gulbju-Platpirovas Mire	30/22	119	0.77

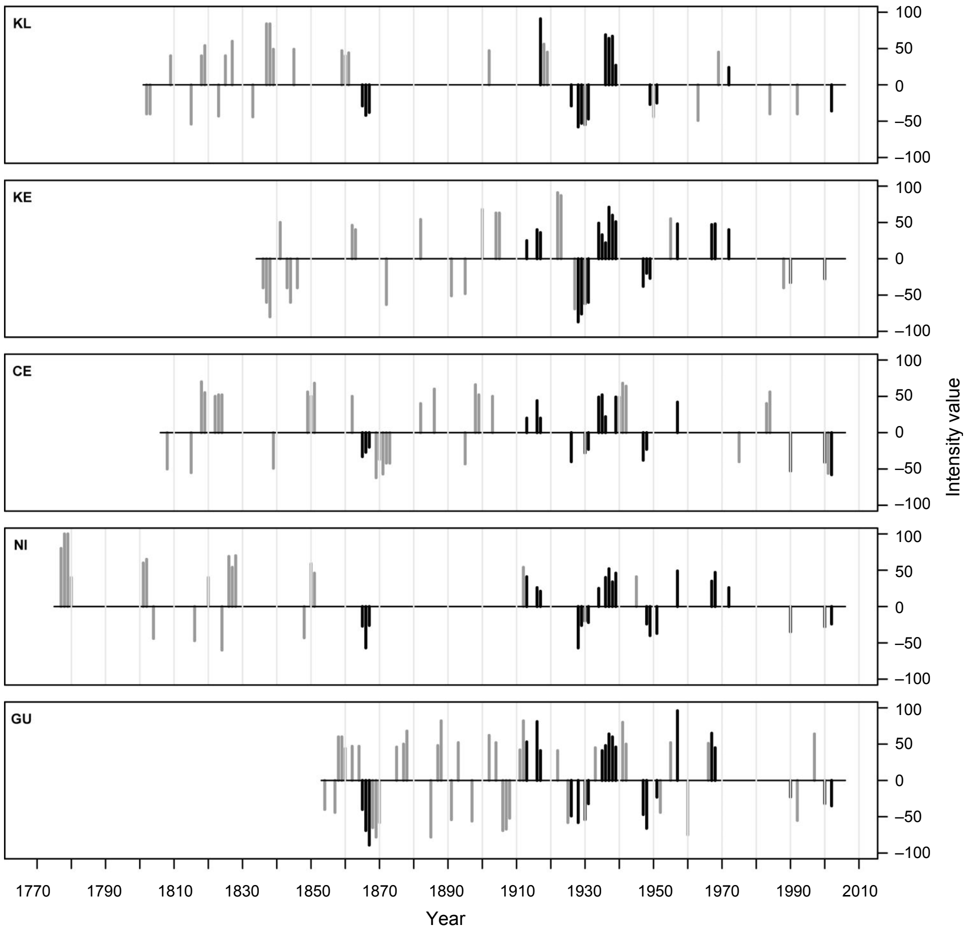

Fig. 2. Pointer year intensity values (upper 40% and lower –40% plus upper 20% and lower –20% if pointer year was significant at least for three study sites) at the studied sites: KL – Klanu Mire, KE – Lielais Kemeru Mire, CE – Cena Mire, NI – Niedraju-Pilkas Mire, GU – Gulbju-Platpirovas Mire. Pointer year intensity values in black are common for at least three sites. The length of the *x*-axis shows the length of the chronology for each site.

in four or all study sites: positive 1913, 1916, 1917, 1934–1939, 1957, 1967, 1968, and 1972 and negative 1865–1867, 1926, 1928–1931, 1947–1949, 1951, 1990, 2000, and 2002.

Correlation analysis between climatic data and pointer year intensity values greater than 40% or less than –40% suggests that the effect has a more local than regional character (Table 3). The addition of pointer year intensity values with a

Table 3. Significant correlations (Spearman correlation coefficient at α = 0.05) between climatic variables and pointer year intensity values. (1) Only pointer year intensity values greater than 40% or less than –40% (if negative pointer year) and (2) pointer year intensity values greater than 40% or less than –40%, plus values greater than 20% or less than –20% if these pointer years were common for at least three study sites were used. The latter correlations are marked with an asterisk

Study site	Klanu Mire	Lielais Kemeru Mire	Cena Mire	Niedraju-Pilkas Mire	Gulbju-Platpirovas Mire
			Mean air temperature		
March			–0.43		
April					–0.73*
June	0.50			0.51*	
	0.58*				
July	0.60	0.52*		0.50	
	0.62*			0.52*	
August	0.53	0.64*			
	0.60*				
September		0.48*			
PY					–0.81
GP	0.51	0.55*			
	0.69*				
			Maximal air temperature		
June	0.74	0.53*		0.53*	
	0.66*				
July	0.58*	0.52*	0.56	0.46	
August	0.58*	0.54			
		0.54*			
September		0.61			
		0.59*			
December			–0.51		
			Minimal air temperature		
February	0.58*	0.47*			
March			–0.51		
July				0.47*	
August		0.46			
		0.59*			
			Precipitation sum		
February		0.38	0.36		
April			0.50*		
May	–0.51				
	–0.66*				
June				–0.45	
July				–0.53*	
GP	–0.55	–0.43			
		–0.46*			

lower threshold (greater than 20% or less than –20%) but with synchrony in at least three sites increased the number of significant correlations.

However, even with the attempt to remove local influence from the analysis, only three climatic variables (mean air temperature in June and mean and maximal air temperature in July) had significant correlations in at least three sites. Thus, at a regional level, summer air temperature appears to be the main factor positively affecting pointer year growth of Scots pine on bogs. The effect of mean, maximal, and minimal air temperature in August and September was significant only in one or two sites. Minimal air temperature in February and March affected pointer year tree growth locally at two and one sites, respectively, but this effect was both negative or positive. Maximal December air temperature had a negative effect at one site. Precipitation sum in February and April positively affected growth at one or two sites, and that in May–July and in the growth period negatively affected growth at one site.

In general, the response to precipitation was much lower than to air temperature for extreme growth of Scots pine on bogs. Interestingly, the two westernmost sites (Klanu Mire and Lielais Kemeru Mire) had more significant correlations between climate and pointer year growth. The lowest response of pointer years was in Gulbju-Platpirovas Mire, located at the eastern border of Latvia.

DISCUSSION

As previous studies show (Bridge et al., 1990; Pilcher et al., 1995; Linderholm et al., 2002), there are difficulties with measuring and cross-dating trees growing on peatlands, not only among trees but also between radii from a single tree. This was explained by missing and extremely narrow rings, formation of compression wood in varying directions within the tree, wind, and unstable ground like peat, as well as ethylene induced formation of reaction wood in flooded trees (Schweingruber, 2007). In Cena Mire, the Scots pine trees had an extreme number of missing rings: as many as nine rings could be missing. These trees were most strongly suppressed by wind and fluctuation of the lake water level, and many were tilted.

In previous studies, for a given tree species pointer years are usually common over a large scale, such as over Central Europe, since the extreme conditions and the response are more global (Neuwirth et al., 2004). Some of the identified pointer years for pine on bog sites in Latvia have been also identified in studies across northern Europe. For example, the negative pointer year of 1928 in Sweden, identified from pine on bogs, was associated with a very rainy May and June and low air temperature in June and July (Linderholm & Leine, 2004). A cool and wet spring to summer can influence the rate of evapotranspiration, a key component of the water balance in peatlands (Rydin & Jeglum, 2006). Flooding during the growing season has a greater effect than during the dormant season because it can cause injury, inhibition of seed germination and vegetative and reproductive growth, changes in plant anatomy, and mortality (Kozlowski, 1997).

Some of the identified pointer years in this study are common with pointer years of Scots pine growing on dry soil sites. Such coincidence was recorded not only in Latvia (Elferts, 2007), but also in Lithuania (Vitas, 2004b) and Estonia (Läänelaid & Eckstein, 2003; Zunde et al., 2008). Synchronous positive pointer years of pine growing on bogs and dry sites in Latvia and on dunes in Lithuania were 1938 and 1967, positively associated with high air temperature in February, and in 1929, negatively associated with low air temperature in February (Vitas, 2004b; Zunde et al., 2008). Scots pine is an ecologically plastic tree species and, compared with the effect of habitat type, genetic impact is a main factor controlling reaction of trees to climate influence (Schweingruber, 1996).

For Scots pine growing on bogs, the pointer years often formed a series of a number of years, for example the years 1934–1939. This suggests the effect of an environmental factor with high autocorrelation. As trees growing on peatlands are limited by depth and fluctuation of the water table, the pointer year series may be caused by a lag in the response of the water table to changing climate conditions (Kilian et al., 1995; Linderholm, 2001). A period of wet and cool climate can cause a raised water table, which remains high for a number of years (Rydin & Jeglum, 2006).

The strength of pointer years of a site is related to the effect of climate variation, local moisture supply as well as stand factors such as insect outbreaks (Neuwirth et al., 2004; Vitas, 2004a,b). Pointer year development of Scots pine in Latvia on dry soil sites, like in our study on peatlands, is determined by local factors, except in years when abrupt changes in climatic conditions are observed (Elferts, 2007). The climatic factors correlated with pointer year values at three or more sites indicate a common response to a regional environmental change. Growing season temperature seems to be of greater importance than precipitation for bog pine radial growth in a regional context in Latvia, as previously observed on peatlands in Sweden (Linderholm, 2001; Linderholm et al., 2002) and on dry soil sites in Latvia (Elferts, 2007). Precipitation mainly controls water table variation. On the other hand, temperature influences tree growth directly but also affects the water table level through evapotranspiration. A high growing season temperature keeps the water table from rising to a level where pine growth is suppressed (Linderholm et al., 2002).

Air temperature in February is an important factor, not only for bog pines in western Latvia and Sweden (Linderholm, 2001), but also for pines on dry sites in Latvia (Elferts 2007), Poland (Cedro, 2001), Estonia (Läänelaid & Eckstein, 2003; Hordo et al., 2009; Pärn, 2009), and Lithuania (Vitas, 2004b). The coldest month in Latvia is February, and interaction of air temperature with precipitation in this month may be significant for growth. Higher air temperature in February may mean less winter damage to roots, and less growth limitation. On the other hand, a deep snow pack in late winter was shown to effectively reduce radial growth rates by maintaining low soil temperatures and delaying initiation of cambial expansion (Pederson et al., 2004). Conifers can have an effective photosynthesis on warm winter days when their needles are not frozen (Havranek & Tranquillini, 1995), but this makes them more sensitive to damage from freezing, snow and ice accumulation, or winter desiccation.

The different response of pointer years to climate at the study sites might be explained by a west–east gradient. One of the most important factors determining air temperature and precipitation amount is the prevailing air masses. The mean range of variation in seasonal air temperature within the region is 1.9 °C in winter and spring seasons, 1.8 °C in autumn, and lowest in summer: 0.9 °C. Also the seasonal distribution pattern of precipitation differs: in the continental part, maximum precipitation occurs in the middle of summer (July), while in coastal areas the highest precipitation is usually observed in the second half of summer and in autumn (Zunde et al., 2008). However, due to the low number of study sites, we do not know if our results represent a real trend. Another reason for the differences might be the shortness of climatic data series, i.e. the Rezekne meteorological station used for the easternmost site (Gulbju-Platpirovas Mire) had the shortest data series, which might also explain the low number of significant correlations.

A major problem in the study of the radial growth of pine on bogs is the absence of long series of water table level measurements, as on bogs this is the limiting factor for growth. We also lacked data on the past human disturbance at the sites, but the sites were chosen as far as possible from visible ditches. However, the ditches in Cena Mire were closer to the study site than in other areas, which might have affected the pointer year response.

To conclude, the identification of pointer years that are synchronous across sites does suggest some regional climatic effect, which may interact with water table level. Nevertheless, the climatic effect observed was mostly local. Further work (in preparation) is being focused on a bog where the water level has been monitored in wells for about 40 years.

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Kliima mõju hariliku männi ekstreemsele radiaalkasvule Läti rabades

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Autorid võtsid radiaalse juurdekasvu puurproovid viies Läti rabas kasvavatest mändidest (vähemalt 15 puust igast rabast) ja uurisid ekstreemselt kitsaste ning ekstreemselt laiade aastarõngaste korrelatsiooni näitaastatel (*pointer years*) kuude õhutemperatuuri ja sademetega igas rabas. Selgus, et uuritud rabade mändide kasvus esineb mitmeid ühiseid näitaastaid (positiivsed 1913, 1916, 1917, 1934–1939, 1957, 1967, 1968, 1972 ja negatiivsed 1865–1867, 1926, 1928–1931, 1947–1949, 1951, 1990, 2000, 2002). Näitaastate aastarõnga laius on kõige enam korrelatsioonis kasvuperioodi (mai-september) keskmise õhutemperatuuri ja veebruari miinimumtemperatuuriga. Sademete hulgaga on juurdekasvu seos näitaastatel üldiselt nõrgem kui temperatuuriga, kuid oluline korrelatsioon esineb siiski veebruari (positiivne) ja kasvuperioodi (negatiivne) sademetega. Kokkuvõttes on järeldatud, et rabas kasvavate mändide ekstreemsed juurdekasvud näitaastatel tekivad suurel määral lokaalsetel põhjustel.