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Influence of climate on Scots pine growth on dry and wet soils near Lake Engure in Latvia

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Abstract. Tree-ring width chronologies provide a retrospective record of the past tree growth, which allows scientists to infer the past history of environmental change. These types of studies have already been conducted throughout Europe for Scots pine (*Pinus sylvestris* L.) growing in dry conditions, but there is little knowledge about pine growth on organic soils. Scots pines were cored on dry and wet soils near Lake Engure to obtain tree-ring widths and to determine climate–growth relationships. Scots pine growth response to precipitation differed between the wet soil and dry soil sites. On the wet soil Scots pine was more sensitive to precipitation in the previous year and in October while yearly precipitation (previous-year October to present-year September) and growing-period precipitation (April–September) positively influenced pines growing on the dry soil. Yearly temperature and dormant-period temperature (January–March) showed a positive influence on tree growth on both sites. The explained variation of tree-ring width was very low: 5.9% for the dry site and 14.8% for the wet site. Therefore, unknown other abiotic and also biotic factors (e.g. competition) may have had a strong influence on the radial growth of the trees in this study.

Key words: dendroclimatology, Scots pine, tree rings, dry soil, wet soil, fen.

INTRODUCTION

The distribution of trees is generally determined by their ecological characteristics. Both internal and external factors, e.g. climate, influence the growth of trees. Many dendroclimatological studies have shown that climate explains a relatively large part of the temporal variability in tree-ring width (Fritts, 2001). The relationship between climate and tree-ring width occurs because plant growth is affected by specific conditions in the habitat environment. In addition, the nature of soil where trees grow may affect their response to climate (Linderholm, 2001; Linderholm et al., 2002; Vitas & Erlickytė, 2007; Weber et al., 2007).

Scots pine (*Pinus sylvestris* L.) has a very wide ecological amplitude and successfully occupies dry habitats and sandy soils as well as peatland habitats. Therefore, it has a wider geographical distribution than any other pine species (Ohlson, 1995; Richardson & Rundel, 2000).

Tree rings of Scots pine have been successfully used in dendroclimatology, mainly regarding trees growing on dry soils. Dendroclimatological investigations of tree rings in Latvia (Špalte, 1975, 1985; Skudra, 1982; Elferts, 2007a, 2007b), Lithuania (Bitvinskas, 1978; Vitas, 2004; Vitas & Erlickytė, 2007), Estonia

(Läänelaid, 1982; Läänelaid & Eckstein, 2003), Poland (Cedro, 2001, 2006), and Scandinavia (Linderson, 1992; Linderholm, 2001; Linderholm et al., 2002) show that Scots pine growing on dry soil is sensitive to cold winters in the area around the Baltic Sea. Several studies treat the growth of Scots pine on peatlands. These have focused mainly on bogs and little is known about Scots pine growth on fens. Most of the previous studies examine relationships of pine growth on drained fens from a wood production improvement perspective (Pyateckij, 1963; Zalitis, 1967, 1968). There are only a few studies where the age and size of Scots pine as well as some habitat factors (nutrient characteristics of the peatlands and climate) are examined in relation to the natural regeneration of this tree species on fens (Ågren et al., 1983; Ohlson, 1995).

In pristine peatlands, e.g. fens, the most important differences in comparison to mineral soil sites are a high water table level (Boggie, 1972; MacDonald & Yin, 1999), poor soil aeration, and low nutrient availability and uptake, which control seedling survival (Ågren & Zackrisson, 1990; Ohlson & Zackrisson, 1992; Sarkkola et al., 2004), and extremely slow growth of trees (Ohlson, 1995; MacDonald & Yin, 1999; Fritts, 2001; Hökkä & Ojansuu, 2004). Water table depth is regulated by several factors, of which temperature and precipitation are the most important in controlling seasonal and yearly variation. This means that both of these factors influence tree growth directly and indirectly through regulation of the water table by evapotranspiration (Fritts, 2001; Linderholm et al., 2002). Climatic amelioration has been of great importance with regard to the comparatively successful regeneration of pine and spruce on peatlands (Ågren et al., 1983).

Ohlson (1995) observed that on fen sites the growth rate of Scots pine is greater and much more variable than on bog sites. Therefore, we suggest that Scots pine growing on fens can be more useful in dendroclimatology compared to pine growing on bogs. The aim of this study was to determine the climatic factors influencing the radial growth of Scots pine growing on dry and wet soils near Lake Engure in Latvia.

MATERIAL AND METHODS

Study sites

Lake Engure is situated at the western coast of the Gulf of Riga, from which it is separated by a 1.5–2-km wide dune area. It is the largest relict lake in the coastal area of Latvia and has remained there since the time of the Litorina Sea (Vīksne, 1997; Pakalne & Kalnina, 2005). It is a protected nature area, founded in 1957 as a restricted ornithological area (nowadays a nature park). Since 1989, the area has been on the European list of most significant bird habitats and, since 1995, it has been included in the Ramsar Convention on Wetlands of International Importance list (Vīksne, 1997). Lake Engure is connected to the Gulf of Riga through a canal, which was built in 1842. The water level in the lake then dropped by about two metres. To the east, on the higher ridges of the exposed area, Scots pine forests developed. In lower areas an extremely rich fen community of *Schoenetum ferruginei* is found (Pakalne & Kalnina, 2005).

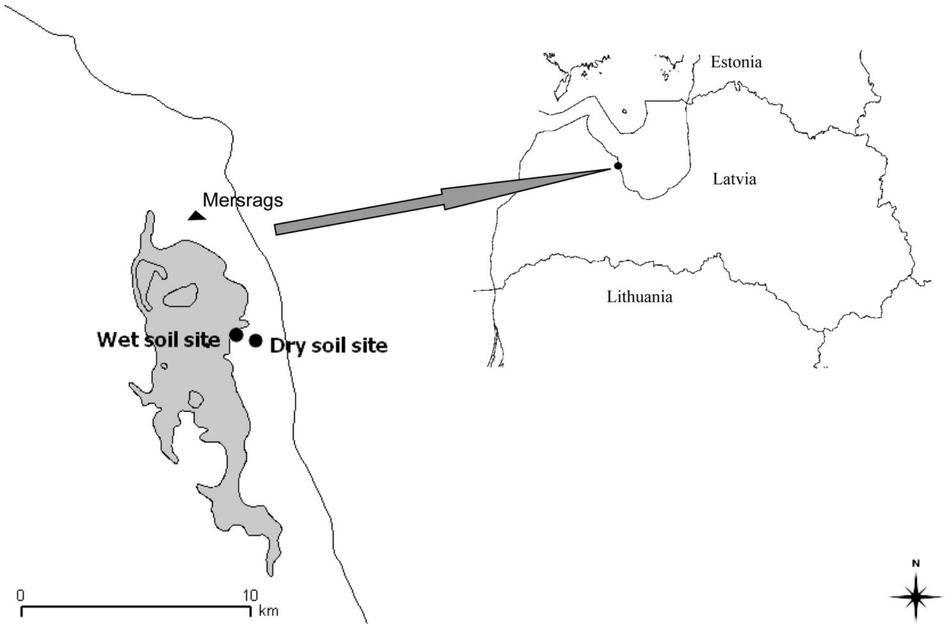

Fig. 1. Location of the wet and dry soil sites near Lake Engure and the Mersrags Meteorological Station (triangle). The bar scale refers to the map on the left.

Scots pine trees were sampled from two sites (a dry soil and a wet soil site) near Lake Engure, Latvia (Fig. 1). On the dry soil cores were collected from trees growing in a Scots pine dominated forest on dry, well-drained, podzolic sandy soil, corresponding to *Vacciniosa* site type (Latvian typology, *see* Bušs, 1981). On the wet soil cores were collected from trees growing at the edges of a wet depression covered by fen vegetation. The soil at the edges of the fen was organic. The pine around the edges of the fen probably invaded the site after the water level in Lake Engure dropped due to the drainage project. The forest growth conditions at the fen edge correspond to *Caricosa–Phragmitosa* site type (Bušs, 1981) in the Latvian typology, or a tall-sedge pine fen in the Finnish peatland classification (Vasander, 1996).

Climatologic data

Climatologic data (mean air temperature and precipitation sum; Fig. 2) were obtained from the Latvian Environment, Geology, and Meteorology Centre for the Mersrags Meteorological Station. The analysed period was 1896–2005.

In total, 32 climate parameters were used. These included 16 temperature and 16 precipitation sum parameters: mean monthly, yearly (from previous-year October till current-year September), previous-year, dormant-period (from previous-year October till current-year April), and growing-period (from current-year April till September) temperature and precipitation.

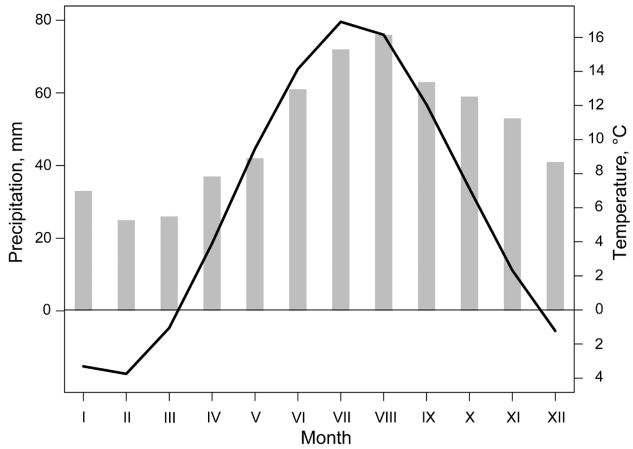

Fig. 2. The 1896–2005 monthly temperature means (black line) and precipitation sums (grey bars) calculated from meteorological records at the Mersrags Meteorological Station.

Sample collection, measurement, and chronology development

The Scots pine samples were collected in 2006. Tree-ring width samples (wood cores) were taken from the oldest trees, based on visual appearance such as tree height, stem diameter, and shoot and crown shape. Two tree-ring samples per tree were taken with an increment borer from opposite directions; in total 20 trees on the dry site and 60 trees on the wet site were sampled. If trees were tilting, samples were taken 90° from the tilting direction (Schweingruber, 1988). For the tree-ring width measurement a LINTAB 'measuring table' connected with TSAP software (Rinn, 1996) was used. Cross-dating and quality control of tree-ring measurement were performed using the program COFECHA (Holmes, 1983). After tree-ring width measurement and quality control, the mean tree-ring width was calculated for each tree. To analyse the relation between climate parameters and radial growth the long-term growth trends were removed by detrending using the ARSTAN program (Holmes, 1999). After detrending all tree-ring series from one site were summarized to one site chronology (using ARSTAN). For climatic analysis a residual chronology was used. The residual chronology was obtained by double detrending and auto-regressive modelling (Holmes, 1999).

Statistical analysis

Pearson correlation analysis was performed using SPSS (linear regression method) (Morgan et al., 2004) to determine statistically significant (at $\alpha = 0.05$) relations between data. The residual chronology and all climate parameters (precipitation sums and mean temperatures) were used in the analysis.

Multiple regression analysis was performed to determine the part of chronology value variation explained by climate parameters. For multiple regression analysis

SPSS was used for all chronologies. The predictors (factors) that were included in the regression equation were selected using 'response function' analysis in the program Dendroclim2002 (Biondi & Waikul, 2004).

RESULTS

For the dry site 18 of the 20 cored trees were measured and used for the chronology building. For the wet site the residual chronology was built from 25 trees. The length of the dry site chronology was 201 years and of the wet site chronology, 98 years (Fig. 3). Some of the samples from the dry site had very narrow and undistinguishable tree rings in the last 60 years due to declining growth. This part of the cores also easily developed cracks during coring. In these cases, the later part of the series was removed because cross-dating was impossible. This resulted in a decreasing sample depth (Fig. 3). Correlation between the two chronologies was statistically significant (0.369).

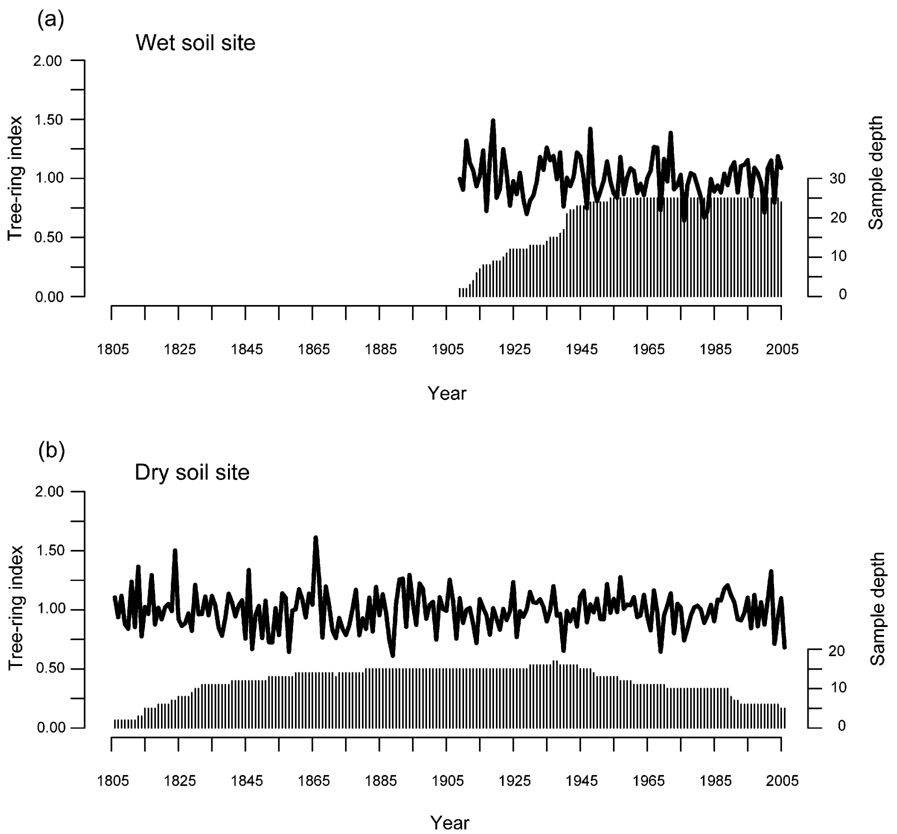

Fig. 3. Standardized tree-ring width chronologies from Lake Engure Nature Park: (a) wet soil site and (b) dry soil site.

Table 1. Correlation between climate parameters and dry and wet soil site chronologies. Only statistically significant ($\alpha = 0.05$) correlation coefficients (r) are shown

Parameter	Dry soil site	Wet soil site
Precipitation		
Previous year		−0.297
October		−0.264
February	0.193	
Yearly	0.197	
Growing period	0.200	
Temperature		
January	0.220	
February	0.256	0.249
March		0.296
July		0.206
Winter	0.279	
Yearly	0.309	0.256
Dormant period	0.280	0.229
Growing period	0.203	

Both chronologies have a significant correlation with February, yearly, and dormant-period mean temperatures, but the chronologies have no common significant precipitation parameters (Table 1). In addition, temperatures in January, during the whole dormant period, and in the growing period at the dry site and in March and July at the wet site were significant. Response to precipitation was lower than to temperature on the dry site, being positive and significant in late winter (February), during the whole season, and the growing period. Precipitation sum prior to the growing period negatively and significantly affected the subsequent pine growth on the wet site.

On the wet site climate parameters (February temperature and precipitation sum of the previous year) explained 14.8% of tree growth but for the dry site only 5.9% (February temperature).

DISCUSSION

As previous studies have shown (Bridge et al., 1990; Pilcher et al., 1995; Linderholm et al., 2002), there are difficulties with measurement and cross-dating of trees growing on wet soils (peatlands) not only among trees but also between radii from a single tree. This has been explained by the formation of compression wood in varying directions within the tree (Schweingruber, 2007) due to wind and unstable ground (i.e. peat), as well as ethylene-induced formation of reaction wood in flooded trees. Flooding also induces the formation of short, thick-walled rounded tracheids (generally resembling those in compression wood), surrounded by intercellular spaces (Kozlowski, 1997). A clear boundary can exist between earlywood and latewood, representing a false tree ring (Fritts, 2001). Also, most coniferous tree species produce resin ducts as a reaction to environmental stress (Gärtner, 2007; Schweingruber, 2007). Resin duct density is an indicator of water stress, where irrigation increases the proportion of resin ducts in earlywood (Rigling et al., 2003), complicating the distinguishing of tree rings. For these reasons, in the study of tree-ring series only the best cores, i.e. those from 25 of the 60 cored trees, were measured and used for building the chronology. For the dry site only two trees were not included in further studies.

The sites were located rather close to each other and thus climatic factors could be expected to be similar. However, there are only a few cases when both chronologies showed a significant correlation with the same climate parameters. A significant influence of yearly mean temperature is a characteristic feature for pines growing in northern regions (Lindholm et al., 2000). Another characteristic feature is a significant positive influence of February mean temperature on pine growth, which has been observed in previous studies in Latvia (Elferts, 2008; Zunde et al., 2008), Poland (Cedro, 2001), Estonia (Pärn, 2003), and Lithuania (Vitas, 2004). Scots pine is susceptible to winter and spring frosts. The significant relation with February temperature could be explained by a deeper frozen soil layer, which can increase the time period needed for the soil to thaw in spring. The same explanation might be offered for a positive influence of dormant-period mean temperature (Rydin & Jeglum, 2006) on pines on the dry and wet sites.

The influence of precipitation on pine growth on dry and wet soil is of dissimilar character. Pines growing on dry soil are positively influenced by yearly precipitation and growing-period precipitation. In the growing period, when temperatures are higher, especially in June and July (Fig. 2), transpiration is intensified and there is a need for additional moisture. Also in Southern Finland (Lindholm et al., 2000) and Poland (Cedro, 2001) pines growing on dry soils showed a positive relation to precipitation sum in summer months. Lack of a relationship between precipitation of most months and dry soil chronology might be explained by optimal moisture conditions for pine growth in a particular site (Linderholm, 2001).

The same explanation might be true for the trees growing at fen edges, which showed a positive response to July temperature. The high July temperature probably favours evapotranspiration and therefore the growth of trees, as observed for the Scots pines growing on alluvial terraces along Alpine rivers (Polacek et al., 2006).

Trees growing on peatlands are highly dependent on the depth and fluctuations of the water table, and precipitation and temperature regulate the water table depth. In addition, there might be a lag in the response of the water table to changing climate conditions (Linderholm, 2001). The growth of Scots pine is much more dependent on prior growth, especially for pines affected by water stress (Weber et al., 2007). Thus, pines growing on the wet soil showed negative responses mainly to previous-year and October climate parameters. A negative response can occur via bud and needle formation for the next year and therefore affect photosynthesis. A high yearly water level suppresses needle formation in coniferous trees and often inhibits bud initiation. Under anaerobic conditions, the activity of several metabolic pathways is suppressed or altered. Soil inundation affects not only the synthesis of carbohydrates but also their transport to meristematic sinks and their utilization in metabolism and production of new tissues. Shifts occur also in protein, organic acid, and lipid metabolism (Kozlowski, 1997). Especially October is a very important month for peatland pines, because at that time sugars are splitting to lipids in the tree (Lebedeva, 1967). The lag effect, which is characteristic of evergreen coniferous tree species in temperate climates, can obscure the response of pine to current moisture conditions (Weber et al., 2007). The low growth response to precipitation during the growing period may also suggest that there is sufficient water available.

In the analysis of peatland pine growth response to climate it is very important to examine water level data. Unfortunately, for the Engure fen sites this type of data are lacking. Water level records in Lake Engure cover only a 30-year period (from April to October, in some years to August), which is too short for reliable interpretation of results.

CONCLUSION

Despite the fact that the two chronologies had a significant correlation with climate parameters (seven for the wet site and nine for the dry site), the explained variation of tree-ring width was very low: 5.9% for the dry site and 14.8% for the wet site. As Latvia is not on the distribution border of Scots pine where a higher relation with climatic factors is expected (Schweingruber et al., 1990), other internal and external factors likely have a stronger influence on the radial growth of Scots pine.

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Kliima mõju hariliku männi kasvule kuival ja märjal pinnasel Engure järve ääres Lätis

Iluta Dauškane ja Didzis Elferts

Engure järve ääres võeti puurproovid *Vacciniosa*-kasvukohatüübi kuival pinnasel kasvavatest mändidest ja madalsood piirava *Caricosa-Phragmitosa*-kasvukohatüübi märjal turbapinnasel kasvavatest mändidest. Mändide aastarõngalaiuste standardiseeritud (jääkide) kronoloogiad korreleeriti kuude keskmiste õhutemperatuuride ja sademete summadega, kokku 32 meteoroloogilise parameetriga.

Nii kuiva kui märja kasvukoha mändide radiaaljuurdekasv oli statistiliselt olulises korrelatsioonis veebruari, aasta ja puhkeperioodi temperatuuriga. Sademete osas kahel kronoloogial ühiseid statistiliselt olulisi meteoroloogilisi parameetreid ei leidunud. Kuiva kasvukoha mändide kasvule olid lisaks eelnimetatuile olulised ka jaanuari, talve ja kasvuperioodi temperatuurid. Märja kasvukoha mändide kasvule olid olulised ka märtsi ja juuli temperatuurid. Kuivas kasvukohas oli puude juurdekasvu seos sademetega nõrgem kui temperatuuriga, kuid osutus siiski oluliseks (positiivseks) veebruaris, aastas ja kasvuperioodil. Märjas kasvukohas mõjutas mändide kasvu oluliselt (negatiivselt) kasvuaastale eelneva aasta sademete hulk.

Märja kasvukoha mändide radiaalkasvust selgitasid kliimaparameetrid 14,8%, kuiva kasvukoha mändide juurdekasvust aga ainult 5,9%. Autorid oletavad, et mändide kasvu Lätis limiteerivad enam muud sisemised ja välised tegurid.