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Original Article

Effects of precipitation and temperature on the growth variation of Scots pine—A case study at two extreme sites in Finland

Pekka Nöjd[a,*], Mikko Korpela[b], Pertti Hari[c], Üllar Rannik[d], Mika Sulkava[e], Jaakko Hollmén[f], Harri Mäkinen[a]

[a] Natural Resources Institute Finland (Luke), Tietotie 2, 02150 Espoo, Finland
[b] University of Helsinki, Department of Geosciences and Geography, P.O. Box 14 68, FI-00014, Finland
[c] University of Helsinki, Department of Forest Sciences, P.O. Box 27, 00014, Helsinki, Finland
[d] University of Helsinki, Department of Physics, P.O. Box 48, 00014, Helsinki, Finland
[e] Natural Resources Institute Finland (Luke), Statistical Services, P.O. Box 2, 00791, Helsinki, Finland
[f] Aalto University, Department of Computer Science, P.O. Box 15400, 00076, Aalto, Espoo, Finland

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ABSTRACT

Site properties have received limited attention in analyzing the weather-growth relationship of trees. We analyzed the annual growth variation of Scots pine on two extreme sites in southern Finland: a dry hill top site and a moist patch of mineral soil surrounded by a large peatland. The effects of daily precipitation and temperature were related to growth variation using correlation analyses. In addition, the common signal and the difference of ring-width indices from the dry and moist sites were studied via principal component analysis and related to the daily weather measurements. All possible time intervals longer than 14 days from current year April 1st to August 31st were tested. We also modeled daily photosynthetic production of Scots pine using two parameter sets, one describing limited stomatal closure and the other one easily triggered stomatal closure. Growth variation at the dry site was linked with variation of precipitation during early and middle parts of growing season, while growth at moist site was correlated with temperature during the middle part of growing season. Daily photosynthetic production, modeled with parameters describing mostly open stomata produced a rather strong negative correlation with ring-width indices from the dry site, possibly indicating that the parametrization overestimated growth during dry years. Other than that, the modeled photosynthetic production was relatively weakly correlated with the ring-width indices. Evidently, the mechanisms controlling Scots pine growth at drought-sensitive sites in southern Finland are complex. Overall, the results indicate that site properties, especially water retention capacity, need to be considered in dendroecological research.

1. Introduction

In the boreal region, climatic changes, especially the warming of growing season, are expected to enhance tree growth and forest productivity (Hari et al., 1986; Kellomäki et al., 2008; Seppälä et al., 2009; Hari and Kulmala, 2011). The variability of precipitation has also been predicted to increase (Jylhä et al., 2009), which would involve an increased drought risk to forests. Recent examples of the magnitude of drought induced damage occurred in the Amazon region both in 2005 and 2010, wiping out a decade's worth of Amazonian carbon sequestration (Marengo et al., 2010; Bellassen and Luyssaert, 2014). The rainfall deficit and extreme summer heat in 2003 caused an estimated 30% reduction of gross primary production over Europe (Ciais et al., 2005).

Dendroecological studies based on tree rings have a long tradition in Finland. In most studies, weather data for complete calendar months have been compared to ring width variation. A strong temperature signal was observed in early studies analyzing Scots pine (*Pinus sylvestris* L.) rings at northern Finland, (northern boreal zone), where warm July temperatures were observed to promote growth (Hustich, 1948; Mikola, 1950). The approach of using complete calendar months could fail to adequately describe the connection between weather and tree growth, especially in regions where growing season is short. However, subsequent studies using daily temperature data have shown that the period with the most significant temperature impact virtually coincides with the month of July in northern Finland (Salminen et al., 2009; Korpela et al., 2011). Helama et al. (2013) also observed a positive correlation between ring width and July soil temperature and a

* Corresponding author.
E-mail address: pekka.nojd@luke.fi (P. Nöjd).

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negative correlation with May snow depth (cf. Vaganov et al., 1999).

For southern Finland, (southern boreal zone) temperature has been reported to correlate less strongly with growth variation of Scots pine (e.g. Mikola, 1950; Helama et al., 2005). However, using daily weather data, Henttonen et al. (2014) found no systematic change in the magnitude of correlations between Scots pine ring-widths and temperature across a north-south gradient extending from northern Finland to Estonia (hemi-boreal zone). In the southern part of the gradient, the most influential period occurred considerably earlier and would have been difficult to recognize using monthly weather data. However, also in their results southern Finland was an exception: the observed correlations between Scots pine growth and temperature were lower than in the northern and southern ends of the gradient.

Earlier studies using precipitation sums of complete calendar months have observed a relationship between May precipitation and Scots pine growth both in northern and southern Finland (e.g. Lindholm, 1996; Helama et al., 2005). Using periods not restricted to complete calendar months, Henttonen et al. (2014) found positive correlations between growth and precipitation across the gradient from northern Finland to Estonia, but the correlations were stronger in the southern part of the gradient. No clear latitudinal trend was observed in the timing of the influential period, which usually started in late May. In addition, Henttonen et al. (2014) also discovered a correlation between Scots pine growth and modeled soil water content of previous year late summer and autumn.

Mäkinen et al. (2002), studying the relationship between weather and Norway spruce (*Picea abies* K.) growth across a gradient from Northern Fennoscandia to Central Europe, discovered that the effects of precipitation were more pronounced at the southern sites. Mäkinen et al. (2001) analyzed the growth of healthy and damaged Norway spruce stand in southern Finland, and discovered that abrupt and intensive growth reductions during dry years were typical for the damaged stands. Jyske et al. (2010) studied the effects of artificially induced drought on Norway spruce growth at two fertile sites in southern Finland. The treatment reduced both radial and height growth and also had minor effects on tracheid properties. Kalliokoski et al. (2012) observed an exceptionally early termination of the tracheid formation of Norway spruce in southern Finland during the dry summer of 2006.

Site properties have received limited attention in studies on the effects of precipitation on Scots pine growth. Linderholm (2001) analyzed growth variation of Scots pine at two high altitude sites, a dry (530 m a.s.l.) and a peatland site (528 m a.s.l.) in Central Sweden. Temperature had the strongest influence on growth at both sites. Precipitation during growing season was weakly correlated with growth at both sites, but at the dry site, the influence of late-winter–early-spring precipitation was significant.

The phenomenon could be analyzed further, as sites occupied by Scots pine in Scandinavia are highly varying. The species is commonly found on both fertile and highly nutrient-deficient sites (Finnish Statistical Yearbook… 2014). It is able to occupy rocky sites with a shallow soil and a very low water holding capacity, but it is also the most common tree species on peatlands (Finnish Statistical Yearbook… 2014), where tree growth is limited by excessive amount of water, not lack of it. The tolerance for widely varying conditions suggests that the species has developed effective adaption mechanisms. Extensive ecophysiological research analyzing the metabolism of Scots pine (e.g. Hari and Nöjd, 2013; Hari et al., 2013) has provided additional tools for analyzing the growth variation of the species.

We analyzed the growth variation of Scots pine on two extreme sites in southern Finland. The first one (DRY) was a rocky hill top site and the second one (MOIST) a small patch of upland mineral soil surrounded by a large peatland. The soil at the first site is very shallow, corresponding to low water retention capacity and frequent drought episodes, while at the second site the ground water level is continuously high due to the surrounding peatland. We analyzed the precipitation and temperature signals in the radial growth of Scots pine at both sites. We hypothesize that (1) growth variation of Scots pine is mainly controlled by growing season temperature at the MOIST site, (2) water availability dominates the growth response at the DRY site. These hypotheses were tested by analyzing correlations between daily weather measurements and the ring-widths of Scots pine at the two sites. In addition, we hypothesize (3) that the trees have acclimated, and, to a lesser extent, adapted to the prevailing conditions at the DRY and MOIST sites by adjusting the mechanism of controlling evapotranspiration via stomatal closure. The third hypothesis' was tested using modeled daily photosynthetic production, produced by the PhenPhoto-model (Hari and Nöjd, 2009), with special emphasis on model parameters describing the sensitivity of stomatal closure.

2. Materials and methods

2.1. The ring-width chronology – sampling and processing the material

The tree-ring material was collected from two sites at Hyytiälä, Ruovesi, southern Finland. The region represents the southern boreal zone with annual mean temperature 3.3 °C and annual precipitation 713 mm (Drebs et al., 2002). The first site (DRY) was on top of a rocky hill, where the soil layer is shallow and the water holding capacity limited (61°51′135/24°17′248). The second site (MOIST) is a flat small patch of upland mineral soil surrounded by a large peatland, where ground water level can be assumed to be continuously high even during periods of low rainfall (61°49′635/24°11′075). The distance between the DRY and MOIST sites was 6.1 km and they were situated 0.7 km and 5.8 km from the local meteorological station at Hyytiälä (HMS), respectively.

We selected and cored (one core per tree) from 43 trees (89–285 rings at breast height) from the DRY rocky site and 35 trees (124–280 rings) from the MOIST site with a Suunto increment borer (Vantaa, Finland). The ring-widths were measured to the nearest 0.01 mm. The ring-widths were visually cross-dated and the cross-dating checked with the aid of COFECHA (Holmes, 1983) software and further checked with the dplR software (Bunn, 2010).

2.2. Standardizing the ring-width chronologies

Severe dry episodes could have caused growth recessions lasting several years at the DRY site. In order to reduce the risk of removing weather related variation, we standardized the ring-width series of individual trees with a relative stiff smoothing spline with a fixed 50% frequency cutoff in 60 years (Cook and Peters, 1981) using the dplR software (Bunn, 2008; Bunn et al., 2015). The annual increment indices for DRY and MOIST sites were computed as the bi-weight mean of the individual, prewhitened series. The analysis was repeated using a more flexible spline with a 50% cut-off frequency in 20 years, but the results were essentially similar (results not shown).

We calculated the expressed population signal (EPS) and the signal-to-noise ratios (SNR) for both chronologies. The degree of similarity between the chronologies was compared by calculating the correlation coefficient and the Gleichläufigkeit (Schweingruber, 1988).

2.3. Pointer-year analysis

Pointer years were computed using the R package pointRes (van der Maaten-Theunissen et al., 2015). To detect event years in individual series, a moving window method (Cropper, 1979) with a window length of 13 years was used. Event years were divided into three intensity classes using thresholds of 1, 1.28, and 1.645 standard deviations during a 13 year period for weak, strong, and extreme event years, respectively (Neuwirth et al., 2007). The intensity class of a positive (negative) pointer year, as computed by pointRes, is the most common intensity class of the positive (negative) events in that year. The threshold for declaring a pointer year was set at 50%, i.e., at least half