Agricultural and Forest Meteorology 252 (2018) 283–295

Contents lists available at ScienceDirect

Agricultural and Forest Meteorology

journal homepage: www.elsevier.com/locate/agrformet

Spatio-temporal variability in Scots pine radial growth responses to annual climate fluctuations in hemiboreal forests of Estonia

Sandra Metslaid*, Maris Hordo, Henn Korjus, Andres Kiviste, Ahto Kangur

Chair of Forest Management Planning and Wood Processing Technologies, Institute of Forestry and Rural Engineering, Estonian University of Life Sciences, Kreutzwaldi 5, Tartu 51014, Estonia

ARTICLE INFO

Keywords:
Dendrochronology
Climate-growth relationships
PCA
Ecological site conditions
Moving correlation
Summer water deficit

ABSTRACT

In this study, we used a comprehensive tree-ring network from Estonia and investigated Scots pine (*Pinus sylvestris* L.) radial growth responses to changing climate conditions, considering differences in site conditions and local climates. To assess whether climate influences Scots pine radial growth consistently across the country, we developed thirteen tree-ring width chronologies for pine populations growing in four forest site types – *Cladonia*, *Calluna*, *Myrtillus*, and *Rhodococcum* – in four sub-regions of Estonia and compared these to climate data. A correlation analysis between ring-width indexes and monthly resolved temperature and precipitation applied over the period of 1955–2006 revealed significant positive correlations with winter/early spring temperatures and the total precipitation of late summer in the year prior to growth. High mean temperatures in August of the year prior to growth were negatively related to pine growth, particularly on islands and in the Northeast of Estonia. Scots pine growth on mesic and medium fertile *Myrtillus* and *Rhodococcum* sites in the Southeast exhibited greater sensitivity to mean February – April temperatures, while high temperatures and low precipitation at the end of the summer of the previous growing season limited radial growth of pine on the islands and in the North-eastern sub-region. A principal component analysis conducted on mean index chronologies and a hierarchical cluster analysis performed on bootstrapped correlation coefficients showed that local climate is the main driver of common growth, followed by ecological site conditions. A moving correlation analysis, performed over the period of 1955–2006, using 30-year windows shifted by one year showed that climate-growth relationships are not stable in changing climatic conditions. Associations between Scots pine tree-ring width and winter temperatures are getting weaker.

1. Introduction

Since the middle of the last century, the growth and productivity of hemiboreal forests in North-eastern Europe have been subjected to rapid changes in climatic conditions, arising as a result of global climate warming (Serreze et al., 2000; HELCOM, 2013; Rutgersson et al., 2015). According to Giorgi (2006), North-eastern Europe is among the top hotspot regions in Europe where the greatest shifts in thermal and precipitation regimes are expected by the end of this century. Considering that trees are long-living organisms, concerns arise regarding the possible impact of climate change on the functioning and productivity of forest ecosystems in the region. According to growth model predictions, climate warming will have a positive influence on the boreal forest growth with an expected increase in productivity (Karjalainen and Kellomäki, 1995). However, the impact of climate warming in a hemiboreal vegetation zone, which is a transition zone between boreal and temperate zones, is suggested to depend on site conditions (Lindner et al., 2010) and can be both positive and negative.

In the Baltic Sea region, increases in mean annual air temperature have been observed since the beginning of meteorological measurements in 1871 (BACC Author Team, 2008). The temperature rise for the region is of 0.08 °C per decade, which is greater than at the global scale. The North Atlantic Oscillation (NAO) during wintertime (Niedźwiedź et al., 2015) has a strong influence on the weather conditions in the region. Since large-scale circulations are characterized by interchanging cycles of cool (severe) and warm (mild) phases that last for several decades (Hagen and Feistel, 2005), the warming process has been fragmented and had several cooling and warming periods (Rutgersson et al., 2015). For several recent decades, all areas around the Baltic Sea experienced a distinct warming and changes in precipitation regimes, which in turn have already altered the seasonal water balance and river run-off in the Baltic States (Kriauciuniene et al., 2012).

* Corresponding author.
E-mail addresses: sandra.metslaid@emu.ee (S. Metslaid), maris.hordo@emu.ee (M. Hordo), henn.korjus@emu.ee (H. Korjus), andres.kiviste@emu.ee (A. Kiviste), ahto.kangur@emu.ee (A. Kangur).

https://doi.org/10.1016/j.agrformet.2018.01.018
Received 25 March 2017; Received in revised form 10 January 2018; Accepted 13 January 2018

The magnitudes of the climatic change and seasonal timing in the region are not equally distributed and depend on the geographical location (Lind and Kjellström, 2009; BACC II Author Team, 2015). In Estonia, the most pronounced warming has been taking place in winter and early spring (Jaagus, 2006; Tarand et al., 2013; Jaagus and Mändla, 2014). Winters have become milder and shorter, as the number of very cold days has decreased (HELCOM, 2013). The duration of snow cover has become shorter by 17–35 days, with the greatest changes in coastal areas (Jaagus, 2006). Therefore, the growing season starts earlier (Ahas and Aasa, 2006). Higher temperatures together with changes in precipitation patterns have already been altering seasonal hydrological regimes (Graham, 2004; Koprowski et al., 2012), which may affect forest growth (Tullus et al., 2012; Rosenvald et al., 2014; Sellin et al., 2017) and productivity in the region (Lindner et al., 2010). Because the growth and wood production of trees are closely related to temperature fluctuations (Schmitt et al., 2004; Rossi et al., 2008), the question arises as to what the growth response to altered annual weather fluctuations is and what consequences it will have on the growth dynamics and functioning of forest ecosystems in the region. Therefore, a better understanding of interactions between tree growth and shifting climatic conditions is greatly needed.

Scots pine (*Pinus sylvestris* L.) is the most abundant (Navasaitis, 2004; Eckenwalder, 2013) and economically important (e.g., Kaimre, 2010) coniferous tree species in North-eastern Europe. In addition to wood and non-wood products, hemiboreal pine forests provide a number of other ecosystem services, including soil and water protection (Wiśniewski and Kistowski, 2015), carbon sequestration and storage (Karjalainen, 1996; Vucetich et al., 2000; Kolari et al., 2004), provision of habitats for wildlife (Marmor et al., 2013; Laarmann et al., 2013), recreational opportunities (Riepšas, 2012), as well as aesthetic and cultural values. Because of the great importance for the region and local communities, a profound understanding of interactions between tree growth and climate variability and responses to change is needed to promote sustainable forest development.

The annual radial growth of trees, including that of Scots pine, has been extensively used to study growth responses to past climate (e.g., Kirchhefer, 2001; Linderholm, 2002; Friedrichs et al., 2008; Büntgen et al., 2012) and to assess possible impacts of environmental change on the studied populations (e.g., Bauwe et al., 2013). An understanding has developed (based on previous spatially fragmented studies) that the radial growth of Scots pine populations in the northern latitudes (boreal forests) is limited by low temperatures during the growing season (Briffa et al., 1990; Babst et al., 2013), while the growth of pine populations at their southern range limit can be related to received precipitation. However, recent studies (e.g., Sánchez-Salguero et al., 2015; Hellmann et al., 2016) have used tree-ring networks and found that, on the spatial scale, responses are much more diverse. In the central part of the tree species distribution, climatic responses are more complex and depend on both local climatic and local site conditions. In hemiboreal forests, cold winters (Bitvinskas, 1974; Lõhmus, 1992) and low spring temperatures (Läänelaid and Eckstein, 2003; Hordo et al., 2009, 2011) have been previously identified as climatic factors that limit Scots pine growth. Existing knowledge about the climate influence on Scots pine growth in Estonia originates from climate-growth relationships established between regional Scots pine master chronology and climate data (Lõhmus, 1992; Läänelaid and Eckstein, 2003) or smaller-scale dendrochronological studies (Pärn, 2003, 2008; Metslaid et al., 2016). When regional chronologies are used, the effects of ecological site conditions are commonly neglected, while small-scale tree-ring studies are restricted to certain locations assuming that established climate-growth relationships are valid for a larger area (e.g., the whole country). Lõhmus (1992) used a large set of tree-ring data collected across Estonia and studied climate influences on Scots pine growth considering the fertility gradient of sites but did not focus in more detail on regional differences in local climates. Thus, a comprehensive understanding of the climate influence on Scots pine growth on the spatial scale in the country is still limited (Hordo et al., 2009, 2011). Several recently conducted spatially explicit dendrochronological studies in Estonia, which investigated Norway spruce (Helama et al., 2016), common oak (Sohar et al., 2014) and also Scots pine (Hordo et al., 2009), showed that climate-growth relationships for the same tree species tend to differ between populations growing on inland areas and close to coastal areas, suggesting that local climatic conditions are diverse enough to result in contrasting responses, as reported for other geographical regions (e.g., Mazza et al., 2014). In addition to spatial variation in climatic conditions, the dominance on the growth control of the climatic variables or seasonal timing may also shift due to temporal changes in climatic conditions (Moir et al., 2011; Büntgen et al., 2012). To improve our understanding of climate influences on Scots pine growth on the spatial scale in Estonia, to define climatic variables that could be further used for future growth modelling, and to assist climate-sensitive empirical forest growth models, we used a tree-ring network distributed across Estonia, which includes a range of climatic and site conditions (Kiviste et al., 2015). Since soil conditions are shown to be important in mediating climate influences (Moir et al., 2011), we studied the Scots pine response to climate variability based on growing conditions as defined by the classification into forest site types. A forest site type, in general terms, describes edaphic and hydrological site conditions and is the main classification unit used in forest management in Estonia (Lõhmus, 2004). Therefore, the aims of this study were 1) to assess the relationships between Scots pine radial growth and climatic variables, considering ecological site conditions and local climates; 2) to define similarly responding populations in terms of growth; and 3) to test if relationships remained stable since the second half of the last century when most of the warming has taken place.

2. Material and methods

2.1. Study area

The study was conducted in Estonia, a country in North-eastern Europe that spans between 59.5° N 28° E and 57.5° N 22° E. The area belongs to the hemiboreal vegetation zone, which is a transition area between boreal and temperate forests (Ahti et al., 1968). Coniferous tree species, including Scots pine and Norway spruce, prevail in the forests and are the most relevant tree species for local forestry, followed by birch, aspen and alder species (Raudsaar et al., 2016). The topography of Estonia is relatively flat, with more hilly landscape (max elevation 318 m a.s.l.) in the South-eastern part of the country.

The climate in Estonia is temperate (Hordo et al., 2011), characterized by cold snowy winters and warm summers. The variation in air temperatures between different sub-regions of Estonia mainly arises due to the proximity of the Baltic Sea (Jaagus, 2006; Tarand et al., 2013). Along the coast and on the islands, maritime climate prevails, gradually changing to semi-continental when moving towards the inland. As a result, winters tend to be milder in the coastal areas and colder farther inward the country, with the opposite effect in early spring and summer. The mean annual temperature over our study period (1955–2006) ranged between 5.1 °C and 6.4 °C and was higher in the West Estonian Archipelago and lower in the South-eastern and North-eastern parts of the country (Table 1). The coldest month is February (mean air temperature −2.9 to −6.1 °C), and the warmest month is July (mean temperature +16.5 to +17.6 °C). The number of sunshine hours is higher on the islands and in coastal areas than in the inland, ranging from 1,600 to 1,900 h, respectively. Accordingly, the growing season (average for Estonia is 180–195 days) is longer in the coastal areas. However, seasonal change, with climatic seasons defined using constant thresholds of daily mean temperature (Jaagus, 2003), is slightly delayed in the coastal areas, first approaches the South-eastern part of Estonia and then gradually spreads across the other sub-regions. The climate in the Northeast tends to be slightly cooler and the growing