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Increased tree establishment in Lithuanian peat bogs — Insights from field and remotely sensed approaches

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HIGHLIGHTS

- Vegetation shifts in peatlands point to environmental and/or climatic changes.
- Scots pine is establishing at accelerating rates in Northern hemisphere peatlands.
- Bog-tree spread is predominantly related to warmer and drier climatic conditions.
- Warm/dry conditions may turn peatlands from carbon sinks to carbon sources.

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ABSTRACT

Over the past century an ongoing establishment of Scots pine (*Pinus sylvestris* L.), sometimes at accelerating rates, is noted at three studied Lithuanian peat bogs, namely Kerėplis, Rėkyva and Aukštumala, all representing different degrees of tree coverage and geographic settings. Present establishment rates seem to depend on tree density on the bog surface and are most significant at sparsely covered sites where about three-fourth of the trees have established since the mid-1990s, whereas the initial establishment in general was during the early to mid-19th century. Three methods were used to detect, compare and describe tree establishment: (1) tree counts in small plots, (2) dendrochronological dating of bog pine trees, and (3) interpretation of aerial photographs and historical maps of the study areas. In combination, the different approaches provide complimentary information but also weigh up each other's drawbacks. Tree counts in plots provided a reasonable overview of age class distributions and enabled capturing of the most recently established trees with ages less than 50 years. The dendrochronological analysis yielded accurate tree ages and a good temporal resolution of long-term changes. Tree establishment and spread interpreted from aerial photographs and historical maps provided a good overview of tree spread and total affected area. It also helped to verify the results obtained with the other methods and an upscaling of findings to the entire peat bogs. The ongoing spread of trees in predominantly undisturbed peat bogs is related to warmer and/or drier climatic conditions, and to a minor degree to land-use changes. Our results therefore provide valuable insights into vegetation changes in peat bogs, also with respect to bog response to ongoing and future climatic changes.

1. Introduction

Vegetation shifts within particular regions and habitats may point to changes in prevailing environmental conditions. Peatlands are globally important landscape components covering approximately 4 million km^2 across the northern hemisphere and are sensitive to environmental changes (MacDonald et al., 2006). Understanding of peatland response to climate change is urgent as peatlands are crucial for the global carbon budget. If conditions are to be changed, terrestrial stored carbon in peatlands can be made available for exchange with the atmosphere (Korhola, 1994; MacDonald et al., 2006; Yu et al., 2010; Limpens et al., 2011; Gažovič et al., 2013). The moisture balance in peatlands may be observed as wetness changes in the acrotelm, the unsaturated zone near the bog surface, and depends on both precipitation and temperature controlled evapotranspiration (Charman et al., 2009). In general, relatively warm and dry periods generate drier conditions in the acrotelm and lowered bog-water tables, which could result in decreased peat growth and carbon net uptake (Gorham, 1991; Lafleur et al., 2003; Gažovič et al., 2013). Increased understanding of past and ongoing

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peatland vegetation changes due to environmental controlled moisture variations in the acrotelm is therefore of crucial importance for the prediction of peatland development and carbon budget, even more so under changing climatic conditions.

During the Holocene, climate driven variations affecting the moisture balance of the acrotelm has simultaneously changed the decomposition of the peat (Aaby, 1976), the bog vegetation and species composition (Barber, 1981; Barber et al., 1994), as well as the degree of peatland tree coverage (Leuschner et al., 2002, 2007; Eckstein et al., 2009, 2010, 2011). More recently, Edvardsson et al. (2012a, 2012b, 2014) have shown that widespread bog-tree establishment phases have occurred during relatively warm and dry periods of the Holocene. It is therefore likely that ongoing environmental changes affecting bog-surface conditions in peatlands will affect species composition and thus result in simultaneous tree establishment or degeneration phases. Such phases of increased bog-tree establishment have been discussed in studies from raised bogs in southern Sweden (Linderholm and Leine, 2004; Edvardsson, 2013). However, the extent, rate, and reasons behind ongoing tree establishment have not been addressed in these studies, nor has the scale of occurrence (local or regional phenomena) been specified.

About 10% of Lithuania is covered by peatlands, of which 44% have been colonized by woody vegetation (Povilaitis et al., 2011). Pukienė (2001) has shown that over the past two millennia several phases of bog-tree establishment have occurred in Lithuania, likely in the absence of human interference. One might thus assume that tree-population dynamics in Lithuanian peatlands reflect natural ecosystem responses to changing environmental conditions. However, many of the tree establishments observed in peatlands during the last century may have been caused by anthropogenic impacts such as groundwater lowering, mire drainage or peat mining activities. In addition, effective precipitation has decreased in the region, resulting in a hydrological regime less favorable for open raised bog habitats (Taminskas et al., 2007; Šimanauskienė et al., 2008), even inside pristine mires. The interaction and connections between peatland development, anthropogenic activity and climatic changes therefore is under heavy debate in Lithuania (Šimanauskienė et al., 2008; Linkevičienė et al., 2008; Taminskas et al., 2012). Despite this ongoing debate and the need for more regional assessments, research on Lithuanian peatlands has remained somewhat scarce (Stravinskienė, 1981; Balevičius, 1984) and was mainly focused on localized phenomena (Pakalnis, 1972, 1987; Bumblauskis, 1983; Pukienė, 1997).

The aims of this study therefore are to (1) test the hypothesis of increased tree establishment in peatlands; (2) compare different approaches to detect tree establishment and spread in selected bogs; and to (3) compare the establishment and spread of trees in peatlands with different initial tree coverage density and geographic settings. Changes in tree coverage, tree age and tree spread were studied in three Lithuanian peatlands using (1) systematic, field-based tree counts in small plots where we defined different age classes, (2) dendrochronological analysis of trees, and (3) remotely sensed interpretation of tree establishment using aerial photography and historical maps.

2. Material and methods

2.1. Study sites

The Lithuanian peatlands selected for this study are Kerėplis, Rėkyva, and Aukštumala (Fig. 1). They represent raised bog environments with varying degrees of tree coverage (Fig. 2) as well as distinct geographic contexts and different distances from the Baltic Sea. The bogs are vegetated by Scots pine (*Pinus sylvestris* L.), but tree density, spread and age distribution were considered to differ significantly between the sites. The Kerėplis peat bog is located in southeastern Lithuania (54°27′ N, 24°32′ E, c. 140 m a.s.l., 269 km from the Baltic Sea) and is part of a peatland complex covering approximately 144 ha. The study site within the Kerėplis bog is characterized by relatively dense and homogenous tree coverage (Fig. 2a). The second study area is the Rėkyva peatland complex, located in northern Lithuania (55°51′ N, 23°15′ E, 130 m a.s.l., 138 km from the Baltic Sea). The peatland complex is 2608 ha in size and contains six bogs of which the Aukštelkė bog is the last remaining natural area and under a strict reserve status. We therefore chose this area as our study site. The bog surface is sparsely covered with pine trees and different generations of trees can be distinguished in the field (Fig. 2b). The third peatland complex is Aukštumala, which is located in southwestern Lithuania (55°23′ N, 21°22′ E, c. 1 m a.s.l., 19 km from the Baltic Sea). It is 3018 ha in size, and the bog area is sparsely covered by scattered groups of trees, often separated by hundreds of meters of open bog surfaces (Fig. 2c).

2.2. Data collection and development

Three different methods were used to study tree age, tree establishment and tree spread across the peat bogs. At first the composition of trees belonging to different age classes was studied by tree counts in 400 m^2 squares (20 × 20 m) representative for the vegetation of the bog. We allocated trees within these plots to five age classes, 0–20, 21–50, 51–80, 81–110, and >111 years. About one-fifth of the trees counted per plot were sampled with an increment borer. Thereafter the total number of annual growth rings in each extracted tree core were counted under a microscope to verify or improve height–diameter–age relations and to reallocate trees to a different age class where needed.

In a second step, 169 pine trees were sampled at the peat bogs using an increment borer. Depending on stand density, the trees were sometimes spread over relatively large areas, at the most separated by 3 km. A total of 62 bog pines were sampled at Kerėplis, 56 at Aukštumala and 51 at Rėkyva. Drill height above bog surface and GPS positions were recorded for all trees sampled. To ensure that as many annual growth rings as possible were to be measured from each sample, the trees were cored close to the ground level at an average height of 0.4 m. After the mounting of cores on woody supports, drying and sanding, tree-ring chronologies were established based on measurements of annual rings using a LINTAB measurement device and the WinTSAP software (Rinn, 2003). The conventional cross-dating techniques (Fritts, 1976; Cook and Kairiukstis, 1990) were used to date individual trees and for the development of tree-ring chronologies. The quality of the cross-dating, measurements and the tree-ring chronologies were evaluated using the COFECHA software (Holmes, 1983). Thereafter, tree germination dates were approached by adding the estimated number of annual growth rings missing due to sampling height above the bog surface. To enable this estimation, five small trees from each site, 0.5 to 1 m in height, were sawed down at root level and their annual height increase assessed by determining their ring age at different heights. The trees from Aukštumala showed an average height growth rate of 2.32 cm yr^{-1}, whereas 2.99 and 3.57 cm yr^{-1} were recorded for the trees growing at Rėkyva and Kerėplis, respectively. Based on these data the year of germination could be approximated for each individual tree. In case that the cores did not contain the pith the estimated number of missing rings was added as well using transparent concentric circles (Bollschweiler et al., 2008).

In a third step, we analyzed tree cover changes and calculated the total size of the tree covered areas using aerial photographs and historical maps in an ArcGis ArcMap 10.2 environment (Johnston et al., 2001). These documents were used to provide further evidence on periods during which trees established, the spatial spread of woody plants across the peat bogs, but also to inform whether the changes observed in approaches 1 and 2 were indeed representative of the entire bogs. Historical maps were obtained from the archives of Nature Research Centre, Institute of Geology and Geography; aerial photographs – covering the years 1945–1955 and 1966–1981 were obtained from the State Land Fund (Archives of the Institute of Land Management, Lithuania) and the