MACROFOSSIL EVIDENCE DISPUTE UBQUITOUS BIRCH-PINE-SPRUCE SUCCESSION IN WESTERN FINNISH LAPLAND

by
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Reconstruction of the post-glacial migration of Norway spruce (Picea abies (L.) Karst.) into northern Fennoscandia is based on pollen records and radiocarbon (14C) ages from organic deposits. However, no macrofossil evidence indicates the distribution of spruce beyond its present timberline-treeline ecotone. We applied total sampling to study Holocene succession of tree species at two sites: Pousujärvi peat bog (68°51’N, 21°10’E), beyond the present tree limits of spruce and Scots pine (Pinus sylvestris L.) and at Lake Kompsiotievanlammit (68°30’N, 22°30’E) at the present pine treeline in western Finnish Lapland. Subfossil pine logs at the Pousujärvi site yielded 14C-ages from 5,000±40 to 5,110±60 yr BP (5,730 to 5,900 cal. BP). The pioneer species were found to be birch (Betula pubescens ssp.) yielding 14C-age of 7,980±60 yr BP (8,810 cal. yr BP). No spruce was present. All subfossil trunks sampled from Lake Kompsiotievanlammit were pines, and yielded ages less than 3500 yr BP. No spruce was present. Our results imply that Holocene tree species succession is incomplete in that spruce is absent in the chrono-stratigraphic sequences in regions where an edaphic dispersal barrier for spruce is comprised of tills derived from felsic rocks, particularly granulites.

Key words (GeoRef Thesaurus, AGI): paleobotany, Betula, Pinus, Picea, wood, mires, lakes, absolute age, C-14, Holocene, Lapland Province, Finland.

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INTRODUCTION

The static model of the (aspen-) birch-pine-spruce successional sequence advocates that forests repeat the same regeneration and succession stages after forest disturbances (Pastor et al. 1999) and within the Holocene migration of tree species. Conifer tree limits and timberlines, however, display evidence of diverse succession and migration patterns during the Holocene. East of Fennoscandia, spruce (Picea abies ssp. obovata) forms the present coniferous tree limit reaching 66°20'-69°25'N, whereas the tree limit of Scots pine (Pinus sylvestris L.) remains at latitudes 64°30'-66°N, respectively (Veijola 1998, MacDonald et al. 2000, Payette et al. 2002). In Fennoscandia, the northern limits of Norway spruce (Picea abies (L.) Karst.) and Scots pine both reach a latitude of 70°N, but the timberline of spruce is located at significantly lower latitudes than Scots pine (Kallio et al. 1971, Veijola 1998, MacDonald et al. 2000; Fig. 1). Even though spruce is a climax species in the successional sequence, it is absent over a large region in the northern boreal forests of Lapland (Fig. 1), where Scots pine is a dominant species and birch (Betula pendula Roth. and B. pubescens Ehrh.) is a secondary species.

Holocene migration of tree species, tree-line fluctuations and forest disturbances are associated with climate-driven factors (Moe 1970, Eronen & Hyvärinen 1987, Kremenetski et al. 1999, MacDonald et al. 2000, Kullman 2002, Payette et al. 2002). Evidenced by 14C-dated subfossil trunks, the expansion of spruce to sites north of the modern treeline in Eurasian Russia occurred 9,000-8,000 yr BP, and the retreat of spruce to its current treeline position occurred 4,000-3,000 yr BP (Kremenetski et al. 1998, MacDonald et al. 2000). Also, spruce macrofossils well above the present alpine tree limit in the Caledonian mountain range in central Sweden indicate that spruce was part of the forest migration during the early Holocene time period (8,000-11,000 yr BP; Kullman 2002). Hence, climate factors did not constrain the early migration of spruce in Fennoscandia. However, the conceptual pollen-derived migration model advocates that spruce reached its northernmost range limit as late as 3,500 yr BP in northern Fennoscandia (Moe 1970, Kremenetski et al. 1999). We argue that lithological provinces constitute edaphic dispersal barriers, such that spruce is absent on terrains with low soil water availability and nutrients and typified by acidic tills derived from felsic rocks, such as the granulite belt in northeast Fennoscandia (Sutinen et al. 2002, 2005). We attempted to see if spruce had been present, similar to the Russian (MacDonald et al. 2000) or Swedish (Kullman 2002) cases, in the early Holocene succession beyond its present tree limit/timberline.

Material and methods

STUDY SITES

The Pousujärvi (68°51’N, 21°10’E) site was selected because one of the present co-writers (M. Piekkari) discovered (within the geochemistry mapping of tills by the Geological Survey of Finland) that subfossil logs were present in peat layers. The Pousujärvi site is located beyond the present spruce and pine (Pinus silvestris L) tree limits (Fig. 1). The Lake Kompsiotievanlammit (68°30’N, 22°30’E; Fig. 1) site was selected on the basis of relative location to the present Scots pine treeline. Previous studies by Eronen et al. (2002) have indicated that subfossil pine logs are common in the lakes of Lapland, hence we located potential survey sites with airborne surveillance. A helicopter search revealed that logs were present on the bottom of Kompsiotievanlammit.
SAMPLING

Both selected sites were logistically accessible, hence we applied a total megafossil sampling to verify a tree species succession pattern in the outermost corner in northwest of Finnish Lapland. We used a 20 ton excavator at the Pousujärvi site to sample all subfossil trees 2.5 m in thickness from the peat bog. At the Kompsiotievanlammit site, we used haul-skidder with a 12-m-long loading crane and log grips (Fig. 2) to sample all subfossil trunks at the bottom of the lake. At both sites, disk samples were collected with a chain saw (Fig. 3). The peat profile was investigated and sampled for 14C-datings at the Geological Survey of Finland. Disks from the subfossil logs were analysed at the dendrological laboratory at the Finnish Forest Research Institute, Kolari station.

Fig. 2. Sampling with loading crane and log grips.

Fig. 3. Disk sampling for 14C-datings and tree-ring analyses.
RESULTS AND DISCUSSION

Birch megafossils
Near the bottom of the bog at the Pousujärvi site a birch (Betula pubensens ssp.) layer was detected. The most distinctive subfossil birch trunk, 20 cm in diameter and from 220 cm depth (Fig. 4) yielded a 14C-age of 7,980±60 (8,810 cal. BP), making this the oldest tree megafossil found in the Kilpisjärvi area, Finland. The supra-long Scots pine tree-ring record by Eronen et al. (2002) extends to 7,500 yr BP, but the oldest 14C-dated pine log in Lapland had yielded a date of 6,930 yr BP (7,680 cal. BP) (Eronen 1979). Wood material from the birch trunks was decomposed, but perfect in shape such that white bark and tree-rings were clearly visible (Fig. 4). Birch megafossils are not commonly found in Lapland, but one has been found beneath paleo-landslide materials in Kittilä (67°47’N, 25°28’E) yielding a 14C-age of 8,720 yr BP (9,730 cal. BP) (Sutinen 2005). Pollen statigraphy at the Toskaljavri site (69°11’N, 21°27’E at 704 m a.s.l.) (Seppä et al. 2002) also indicates that birch was the pioneer tree species after the deglaciation of the Kilpisjärvi area, but the time of early migration of 9,600 cal. yr BP is not concurrent with the megafossil data obtained here. Our observations are also supported by the findings of birch megafossils (9,709-8,954 cal. yr BP) found in peat layers in Siberia (between 70°59’N and 69°43’N) indicating that birch is a pioneer species (MacDonald et al. 2000). It should be noted, however, that the Yamal Peninsula and other regions eastward were not covered by the Fennoscandian Ice Sheet (FIS) during the Late Weichselian time period (Larsen et al. 2006). Thus, the timing of migration in the Kola Peninsula and Fennoscandia had been delayed by the retreating ice (MacDonald 2000).

Pine megafossils
The subfossil pine logs (21 in number) at the Pousujärvi site were found at depths of 1-2 m below the surface of the mire. The three dated logs yielded 14C-ages from 5,000±40 to 5,110±60 BP yr (5,730 to 5,900 cal. BP). On the basis of tree-ring analyses, the two oldest pine logs yielded a date of 6,006-6,054 cal. yr BP, and the three youngest 4,698, 4,385, and 4,369 cal. yr BP, respectively. Hence, pine had been present at Pousujärvi between 6,000-4,400. The Pousujärvi site is the very last site before Lake Kilpisjärvi on the Finnish-Norwegian border, where subfossil Scots pine logs were found. The altitude of 450 m (a.s.l.) is much lower than the nearest finding at Ailakkavaaran lompolo (68°57’N, 20°57’E at 515 m a.s.l.) by Eronen and Zetterberg (1996). Their time-envelop for the presence of pine ranges from 6,000 to 4,085 cal. yr BP, coinciding with our dates for the immigration time of pine. The stomata/pollen stratigraphy at the Toskaljavri site by Seppä et al. (2002), indicates pine immigration as early as 8,300 cal. yr BP, but this is not supported by pine megafossils.

The subfossil pine logs (37 in number) sampled from the bottom of Lake Kompsiotsjelamit yielded ages less than 3,500 yr BP as dated by the tree-ring Advance-10 master-series. Based on the radiocarbon (14C) dates of subfossil Scots pine logs, pine spread through northern Fennoscandia between 8,000-7,000 yr BP and reached its maximum distribution between 6,000-4,000 cal. yr BP, followed by a gradual retreat to its modern range limit (Eronen & Hyvärinen 1987, Eronen et al. 1999, 2002, Payette et al. 2002). After the retreat of pine to its present treeline, we suspect that the tree line had been stable for 3000 yr.

Peat profile
The existence of Equisetum and Menyanthes indicate that the type of Pousujärvi mire was a wet, oligotrophic fen. The huminosity of peat is H3-4. The top layer down to 60 cm is composed of Carex-Sphagnum peat with gyttja-horizons containing dystrophic algae. The second layer, from 60 to 190 cm, has an abundance of Equisetum indicating a wet environment. However, the top of this layer is typified by Bryales-Sphagnum peat also contains nanoligniquids suggesting temporary drier periods. The lower part of this second layer (130-190 cm), with Carex-Sphagnum peat, indicates a stable fen-stage. The lowermost peat layer (190-210 cm),
lying on gyttja deposits, is composed of eutrophic Bryales-Sphagnum (H3) peat with an abundance of Menyanthes. The 50 cm thick gyttja layer is lying on lacustrine silt.

The sampled peat profile yielded 14C-ages were consistent with the dates of pine and birch megafossils: 2,920±60 BP yr (3,060 cal. BP) at 30-cm-depth, 4,460±50 BP yr (5,050 cal. BP) at 70-cm-depth, 5,640±60 BP yr (6,410 cal. BP) at 150-cm-depth, 6,140±60 BP yr (7,000 cal. BP) at 200-cm-depth, and 7,830±80 yr BP (8,600 cal BP) at 240-cm-depth, respectively (Fig. 5). The results indicate that the maximum growth of peat was achieved between 5,050-7,000 cal. yr BP varying in rate from 0.6 mm/yr to 0.85 mm/yr. A clear climatic deterioration reduced the growth rate after 5,050 cal. yr BP, descending to 0.2 mm/yr and finally to 0.1 mm/yr. During the early Holocene, the rate was also rather low, 0.25 mm/yr. Similar to Pousujärvi pine megafossils, the timing of the maximum growth rate of the Pousujärvi peat are concurrent with the record of 14C-dated pine megafossils, indicating that pine was present between 6,000-4,000 cal. yr in outermost northwest Finnish Lapland (Eronen & Hyvärinen 1987, Eronen et al. 1999, 2002). However, the maximum peat growth between 6,000-7,000 cal. yr BP had no equivalent in the megafossils at the Pousujärvi study site.

Lack of spruce

We found no macrofossil evidence to indicate the presence of Norway spruce during the Holocene in northwest Finnish Lapland. Prior to our study, a number of subfossil logs were investigated in the area, but all have been identified as pines (Eronen & Hyvärinen 1987, Eronen et al. 1999, 2002). One may argue that spruce logs were decomposed or destroyed in the lakes by wave action. However, according to our visual observations birch megafossils are present at the bottom of the small ponds, such as in the Malla Strict Nature Reserve (69°03’N, 20°38’E at 500 m a.s.l.), and birch logs were preserved through the Holocene in the peat of the Pousujärvi site. Also, fragments of early Holocene birch wood (9,730 cal. BP) beneath 3.5 m thick landslide material have been preserved (Sutinen 2005). In addition, spruce stumps were preserved in the Siberian tundra and Caledonian mountain range in Sweden through the Holocene (MacDonald et al. 2000, Kullman 2002).

On the basis of 14C-dated megafossils, spruce (Picea abies ssp. obovata) migrated (app. 9,400 cal. yr BP) beyond its present tree limit much earlier compared to pine (app. 7,500 cal. yr BP) in Siberia (MacDonald et al. 2000). Also, spruce megafossils well above the present alpine tree limit in central Sweden indicate that spruce was part of the forest migration during the early Holocene (8,000-11,000 cal.1 yr BP; Kullman 2002). Thus, the conceptual migration model that advocated that spruce reached its northernmost range limit as late as 3,500 yr BP in northern Fennoscandia (Moe 1970, Kremenetski et al. 1999) appears controversial. Spruce is able to thrive at high altitudes and low temperature conditions similar to pine (Nikolov & Helmisaari 1992), hence the opposite spreading behaviour in northern Fennoscandia sounds irrational, that is spreading at the time of climatic deterioration and retreat of spruce in Siberia (MacDonald et al. 2000) and pine in Lapland (Eronen 1979, Eronen & Hyvärinen 1987), and as seen by the reduced growth of Pousujärvi peat. The Kompsoitevamurramit site lies on the present pine treeline, while the present spruce treeline is 60 km southeast of the site. If spruce arrived Lapland 3,500 cal. yr BP (Moe 1970, Kremenetski et al. 1999), why is there no evidence to indicate a spruce migration with a similar topoclimatic position as pine. Also, the presence of Nor-

![Fig. 5. The Pousujärvi peat profile. Given numbers refer to dates (cal. BP) obtained from peat samples.](image-url)
way spruce after 4,000 cal. yr BP in the Toskaljavri pollen stratigraphy (Seppä et al. 2002) appears vague. If spruce migrated to the Kilpisjärvi area, it should have left macro-signatures in the peat layers of Pousujärvi and other investigated peat sites in the region (Eronen & Zetterberg 1996).

With respect to the present spruce timberline in the transition between the mafic Tanaelv belt and felsic Lapland granulite belt in Finnish Lapland (Sutinen et al. 2005), we argue that in contrast to Siberian cases (MacDonald et al. 2000), spruce has not been a ubiquitous member of the Holocene tree succession sequence in northern Fennoscandia. Since spruce and pine have distinctly different site requirements with respect to soil water availability and nutrients (Sutinen et al. 2002), the reverse behaviour between the timberlines and migration patterns of Eurasian spruce and pine species may be associated with differences between the soils derived from the rocks of the Baltic Shield and those derived from Cambrian sedimentary rocks in subarctic Siberia.

REFERENCES


