The Holocene History of a Subalpine Birch Forest Enclave: Subfossil Evidence from Central Sweden
Histoire holocène d’une enclave forestière subalpine de bouleaux : données sur les fossiles subrécents du centre de la Suède

Leif Kullman

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Article abstract
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THE HOLOCENE HISTORY OF A SUBALPINE BIRCH FOREST ENCLAVE: SUBFOSSIL EVIDENCE FROM CENTRAL SWEDEN

Leif KULLMAN, Department of Physical Geography, Umeå University, S-901 87 Umeå, Sweden.

ABSTRACT Aspects of the Holocene history of the subalpine birch (Betula pubescens Ehrh. ssp. tortuosa (Ledeb.) Nyman) forest belt in the Scandes Mountains, Sweden, were analysed by radiocarbon dating of subfossil wood remnants forming an enclave high above the present-day birch limit. The birch population thrived continuously at the site throughout the period 8700-3400 years BP, suggesting the absence of major protracted coolings and mostly higher than present temperatures. Presumably, the disappearance of birch from the study site ca. 3400 BP, reflects substantial cooling, which is corroborated by independent proxy data. It is inferred that during the first few millennia of the Holocene, pine (Pinus sylvestris L.) formed the uppermost forest belt and pure birch stands were restricted to small enclaves with excessive and late-melting snow. Eventually, as climate cooled, these conditions became regionally ubiquitous and birch could spread from the pockets of favourable habitat to form the present-day subalpine birch forest belt above the coniferous forest. In the original pockets too much snow accumulated and there the birch perished.

RÉSUMÉ Histoire holocène d’une enclave forestière subalpine de bouleaux: données sur les fossiles subrécents du centre de la Suède. Certains aspects de l’histoire holocène de la zone forestière subalpine à bouleaux (Betula pubescens Ehrh. ssp. tortuosa (Ledeb.) Nyman) située dans la chaîne des Scandes, en Suède, ont pu être analysés grâce à la datation au radiocarbone de restes de bois fossiliés formant une enclave bien au-dessus de la limite actuelle des bouleaux. La population de bouleaux a constamment prosperé à ce site tout au long de la période de 8700 à 3400 BP, indiquant ainsi qu’il n’y eut pas de refroidissement prolongé, mais plutôt des températures généralement plus chaudes que celles d’aujourd’hui. On présume que la disparition du bouleau du site vers 3400 BP résulte d’un refroidissement important, ce que corroborent certaines données indirectes. On en conclut qu’au cours des premiers millénaires de l’Holocène, le pin (Pinus sylvestris L.) a formé la zone forestière la plus septentrionale et que les peuplements purs de bouleaux étaient limités à de petites enclaves très enneigées et à déneigement tardif. Avec le refroidissement climatique, ces conditions se sont généralisées à l’échelle régionale et le bouleau a pu se répandre à partir des enclaves pour former la zone forestière subalpine actuelle au-dessus de la forêt coniférienne. Dans les enclaves originales il y eut trop grande accumulation de neige, de sorte que le bouleau a disparu.


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INTRODUCTION

As a rule, the boreal region in the Scandes Mountains is fringed towards the barren alpine grounds by a discrete belt of broad-leaved deciduous mountain birch (Betula pubescens Ehrh. ssp. tortuosa (Ledeb.) Nyman). Its vertical extension ranges between 10 and 300 m and increases westwards parallel with climatic oceanicity and snow depth/duration (Kullman, 1981, 1993b; Haapasaaari, 1988). Below this birch belt, Norway spruce (Picea abies (L.) Karst.) and Scots pine (Pinus sylvestris L.) alternate as dominants.

The Holocene history of the birch belt is far from perfectly known or understood in terms of environmental change. Palynological data suggest that the abundance of birch above the coniferous forest has developed mainly during the latter half of the Holocene (Hafsten, 1965; Lundqvist, 1969; Moe, 1979; Nesje et al., 1991), although it is claimed by some researchers that in the west and north, the birch belt has an unbroken continuity extending back into the earliest Holocene (Sonesson, 1974; Hyvärinen, 1976; Aas and Faarlund, 1988). Evidence from subfossil wood, however, suggests that on the eastern flank of the Scandes Mountains (Sweden), a general birch belt above the coniferous forest emerged after ca. 7000 BP and particularly rapidly 6000-5000 BP, although single specimens or groups existed previously (Kullman, 1981, 1983). The present birch belt is lacking (cf. Kullman 1981, 1983). The nearest living solitary tree birches and small groves grow at 905 and 840 m a.s.l., respectively, on the SW-facing slope.

It has been hypothesized that the early Holocene absence and subsequent development of a subalpine birch belt reflects decreased climatic seasonality in response to orbital forcing (Kutzbach, 1987) resulting in declining June-August insolation and increased humidity and greater ecological importance of snow in a general landscape perspective. This should have favoured birch at the expense of pine, according to modern ecological traits (Kullman, 1981, 1993b; Treter, 1984). A model of this kind is also consistent with the existence of local tree-limit "pockets" of birch already in the earliest Holocene in habitats with topographic preconditions for excessive snow accumulation / preservation, exactly as the situation is today in some eastern mountains where a general birch belt is lacking (cf. Kullman 1981, 1983). The present paper, which draws on subfossil wood, accounts for a demised local birch grove of the kind postulated above, its Holocene history and geocological setting.

STUDY SITE

The study was carried out on the WSW-facing flank of Mount Getryggen in the Swedish Scandes Mountains (63°11'N; 12°18'E) (Fig. 1). This is a relatively steep slope whose highest peak is 1382 m a.s.l. Towards the west it planes out at ca. 950 m a.s.l. The site is open and exposed towards the predominant westerlies in this area. The climate, as recorded by the nearest meteorological station (Storlien/Visjövalen, 642 m a.s.l. and ca. 14 km to the northwest), is weakly maritime. The mean annual temperature (1961-90) is +1.1°C and the mean temperatures for January and July are -7.6°C and +10.7°C, respectively. Mean annual precipitation is 857 mm, of which ca. 45% falls as snow (data from the Swedish Meteorological and Hydrological Institute).

The bedrock, which comprises amphibolite and sedimentary gneiss, is covered with shallow till and peat deposits. Predominant vegetation is a mosaic of moss-rich heath and peat mounds, with dwarf-shrubs such as Empetrum hermaphroditum Hagerup, Vaccinium myrtillus L., Betula nana L. and Juniperus communis L. The peat mounds, 0.2-1 m high, are extensively developed up to an altitude of ca. 1070 m a.s.l. (Fig. 2). Water erosion has dissected these deposits and exposed a multitude of subfossil birch logs (Fig. 3), on which this study focuses. This is a snow accumulation area up to the elevation of the study site (Fig. 4), indicated for example by fronds of the chionophilous Athyrium distentifolium Tausch ex Opiz, where subfossil wood is extracted from the ground (Fig. 5). As a rule, snow remains until July and thus precludes the growth of birch here at the present. Above ca. 1015 m a.s.l., no large snow-fields remains into the summer. The nearest living solitary tree birches and small groves grow at 905 and 840 m a.s.l., respectively, on the SW-facing slope.

This site was found after several years of search for deposits containing birch subfossils well above the present-day tree-limit. Obviously, birch stands at this relatively high elevation were never widespread previously during the Holocene.

METHODS

Within the study site, peat deposits were systematically sampled between 1000 and 1015 m a.s.l., along a stretch of ca. 500 m. Subfossil wood was collected at all stratigraphical levels. Only a few of the subfossils were radiocarbon dated, all with a diameter larger than 6 cm. Radiocarbon dating was carried out at the Radiocarbon Dating Laboratory, Stockholm...
RESULTS AND DISCUSSION

FOREST HISTORY

Thirteen radiocarbon dates of tree-sized birch are presented for the elevational band 1000-1015 m a.s.l. and ranging, evenly dispersed, between 8680 ± 100 and 3415 ± 70 yr BP (Table I, Fig. 6). This implies that peat started to form and birch colonised the site rapidly after the regional deglaciation, which took place ca. 9100 yr BP (Lundqvist, 1986). Birch was the only subfossil tree species found at this site. The subfossils were well preserved and represented tree-sized individuals (i.e. >2 m tall), with ages up to ca. 100 yr. The uppermost pine occurred at 895 m a.s.l., on the SW-facing slope and dated 5735 ± 80 yr BP (ST-12758).

Subfossil birch was intensively searched for, but not found higher than 1015 m a.s.l., which is ca. 50 m below the limit for deposits, apparently suited for preservation of wood. In this interval, large quantities of stems and twigs of Salix spp. were present in the peat. One nearly tree-sized Salix yielded a radiocarbon age of 6025 ± 80 yr BP (ST-12753). Considering the steep topography, however, it is possible that birch growing at altitudes higher than 1015 m a.s.l. have been moved downslope by water or snow. However, the lack of late-melting snow at higher elevations makes this less likely and rather explains why these deposits have been preserved to the present. The fact that the birch has endured on the study site for more than 5000 yr, despite continuous glacio-isostatic land uplift amounting to ca. 100 m (Grönli, 1981) and resulting climatic stress, indicates that this site was always below its altitudinal thermal limit. Possibly, the soils were too dry for birch at higher elevations due to sparsity of snow.

The study site, with its large amounts of subfossil birch in a localized enclave, is exceptional with respect to the high 14C-age of the oldest specimen and the elevated position relative to the equivalent present-day range-limits, i.e. "forest-limit" (sensu Kullman, 1979) of pine and birch.
Radiocarbon dates of subfossil birch

<table>
<thead>
<tr>
<th>Laboratory no.</th>
<th>Altitude (m a.s.l.)</th>
<th>(^{14}\text{C date}^*) (BP)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ST-12749</td>
<td>1000</td>
<td>6165 ± 85</td>
</tr>
<tr>
<td>ST-12750</td>
<td>1010</td>
<td>6470 ± 85</td>
</tr>
<tr>
<td>ST-12751</td>
<td>1010</td>
<td>4715 ± 80</td>
</tr>
<tr>
<td>ST-12752</td>
<td>1010</td>
<td>5355 ± 80</td>
</tr>
<tr>
<td>ST-12754</td>
<td>1010</td>
<td>9415 ± 70</td>
</tr>
<tr>
<td>ST-12755</td>
<td>1015</td>
<td>6405 ± 225</td>
</tr>
<tr>
<td>ST-12680</td>
<td>1000</td>
<td>8680 ± 100</td>
</tr>
<tr>
<td>ST-12982</td>
<td>1000</td>
<td>6200 ± 70</td>
</tr>
<tr>
<td>ST-12983</td>
<td>1000</td>
<td>5895 ± 105</td>
</tr>
<tr>
<td>ST-12984</td>
<td>1000</td>
<td>5980 ± 85</td>
</tr>
<tr>
<td>ST-12985</td>
<td>1015</td>
<td>7320 ± 70</td>
</tr>
<tr>
<td>Beta-57615</td>
<td>1000</td>
<td>5460 ± 70</td>
</tr>
<tr>
<td>Beta-57616</td>
<td>1000</td>
<td>6030 ± 80</td>
</tr>
</tbody>
</table>

* All dates are given with ± 1 \(\delta\)

FIGURE 6. Radiocarbon dates of subfossil birches. 

Datations au radiocarbone des fossiles subrécents de bouleaux.

CLIMATIC IMPLICATIONS

The results suggest the unbroken existence of a birch population on this high-elevation site for the period 8700 to 3400 yr BP. The temporal separation of the datings is of a magnitude which justifies the assumption of population continuity, although climatically induced shifts in physiognomy between stunted krummholz and more erect tree forms have
possibly occurred (cf. Kullman, 1993c). For example an optimum period emerges around or shortly prior to 6000 yr BP, which is corroborated by regional palynological data (Lundqvist, 1969). On the whole, the results are indicative of the absence of substantial coolings to present-day conditions or cooler during the above interval. This view is corroborated by glaciological evidence from this part of the Scandes (Mottershead et al., 1974; Mottershead and Collin, 1976; Shakesby et al., 1990; Matthews, 1991; Karlén and Matthews, 1992).

The subfossil birch record was discontinued at a time, i.e. ca. 3400 yr BP, when the same occurred for subfossil pine in various parts of northwestern Europe (Karlén, 1976; Dubois and Ferguson, 1985, Kullman, 1988, 1989, 1992; Aas and Faafunf, 1988; Lowe, 1991), apparently concurrent with major cooling (Karlén, 1991; Nesje, 1992; Matthews and Karlén, 1992). The results are entirely in accord with pollen analytical inferences from southern Norway, indicating a drastic and lasting lowering of the birch tree-limit 3600-3300 yr BP (Caseldine and Matthews, 1985, 1987). The virtual disappearance of subfossil wood at this time may give an exaggerated impression of the duration and magnitude of the cooling due to upfreezing of subfossil wood during cold periods (cf. Kullman, in press). It is fully possible that peat accumulation, i.e. the basic precondition for preservation, had declined substantially in response to modest cooling, as evidenced, e.g. in northern Canada (Gorham, 1990).

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