

**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**

**Holozän-Geschichte einer subalpinen Birkenwald-Enklave:
Subfossile Belege von Zentralschweden.**

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Article 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.

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

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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 fossilisés formant une enclave bien au-dessus de la limite actuelle des bouleaux. La population de bouleaux a constamment prospéré 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 originelles il y a eu trop grande accumulation de neige, de sorte que le bouleau a disparu.

ZUSAMMENFASSUNG Holozän-Geschichte einer subalpinen Birkenwald-Enklave: subfossile Belege von Zentralschweden. Aspekte der Holozängeschichte des subalpinen Birkenwaldgürtels (*Betula pubescens* Ehrh. ssp. *tortuosa* (Ledeb.) Nyman) in den Scandes-Bergen, Schweden, wurden analysiert mittels Radiokarbondatierungen auf subfossilen Holzresten, die eine Enklave hoch über der heutigen Birkengrenze bilden. Die Birken-Population gedieh an diesem Platz während der Periode von 8700 bis 3400 Jahren v.u.Z., und weist so auf das Fehlen von grösseren langanhaltenden Abkühlungen und auf meist höhere Temperaturen als die gegenwärtigen. Vermutlich spiegelt das Verschwinden von Birke am untersuchten Platz um etwa 3400 v.u.Z. eine wesentliche Abkühlung welche durch unabhängige indirekte Daten bestätigt wird. Man folgert, dass während der ersten paar Jahrtausende des Holozän Kiefern (*Pinus sylvestris* L.) den nördlichsten Waldgürtel bildeten und dass reine Birken-Populationen auf schmale Enklaven beschränkt waren, mit übermässigem und spät schmelzendem Schnee. Schliesslich, mit der Abkühlung des Klimas, verallgemeinerten sich diese Bedingungen regional und Birken konnten sich von den Enklaven geeigneter Ansiedlung ausbreiten und so den gegenwärtigen subalpinen Birkenwaldgürtel oberhalb des Nadelwaldes bilden. In den ursprünglichen Enklaven sammelte sich zu viel Schnee an und die Birken gingen ein.

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; Haapasaari, 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, 1992, 1993a).

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

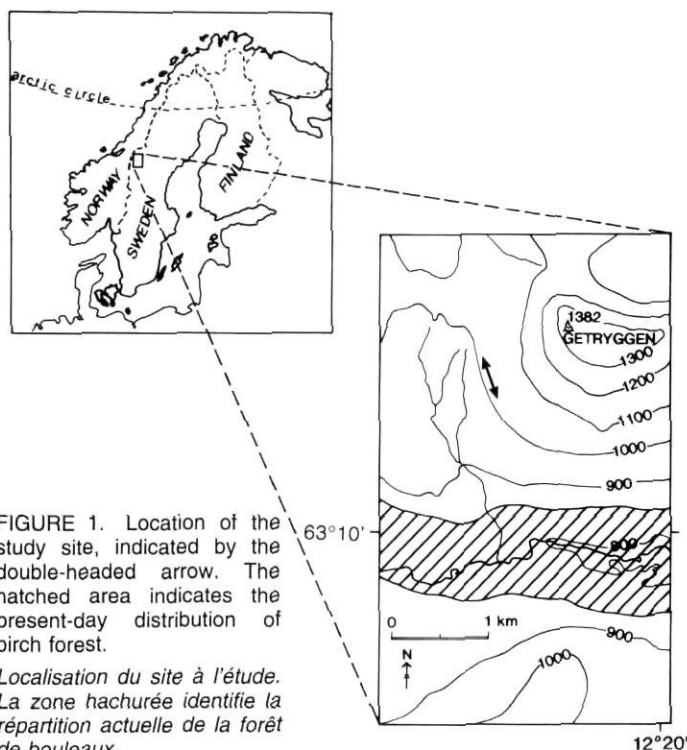


FIGURE 1. Location of the study site, indicated by the double-headed arrow. The hatched area indicates the present-day distribution of birch forest.

Localisation du site à l'étude. La zone hachurée identifie la répartition actuelle de la forêt de bouleaux.



FIGURE 4. View of the study site (1005 m a.s.l.) in early June, showing its character as snow accumulation area.

Vue du site (1005 m d'altitude) début juin, illustrant son caractère de zone d'accumulation de neige.

and Beta Analytic Inc., Miami, Florida. The half-life used was 5568 ± 30 yr, with one standard deviation. All dates are presented as radiocarbon yr BP (A.D. 1950).

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



FIGURE 2. Small erosion scar in peat deposit, 1010 m a.s.l.
Dépôt de tourbe à 1010 m d'altitude.

FIGURE 3. Subfossil birch stem excavated from highly humified peat, 1010 m a.s.l. Radiocarbon age is 6470 ± 85 (ST-12750).
Branche de bouleau fossile dégagée d'une tourbe humifère, à 1010 m d'altitude, datée à 6470 ± 85 (ST-12750).

BP (Table 1, 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 (Grønlie, 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 ^{14}C -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,



FIGURE 5. Subfossil birch is often found in depressions with excessive snow accumulation, indicated by fronds of *Athyrium distentifolium*. This is the site for the oldest birch (8680 ± 100 yr BP, ST-12980).

*On trouve souvent des fossiles subrécents de bouleaux dans des dépressions où il y a accumulation excessive de neige, qu'indique la présence d'*Athyrium distentifolium*. Ce site a abrité le plus vieux bouleau (8680 ± 100 yr BP, ST-12980).*

310 and 180 m, respectively. Previously published datings of birch subfossils mainly originated from just a few tens of metres above the present-day tree-limit, or lower (Kullman, 1988, 1989, 1992). Extensive field surveys in a regional perspective suggest that the latter is the normal situation (*cf.* Selsing, 1979). From central southern Norway, however, single specimens derive from similar relative elevations as in the present study, although the positions are not so accurately defined (Aas and Faarlund, 1988; Nesje *et al.*, 1991). This is also hinted from older narrative geobotanical reports (Birger, 1908; Fries, 1913; Smith 1920), further indicating that the enclave studied here is a rare but not an entirely unique feature.

It is a reasonable inference from the above circumstances that birch formed the upper tree-limit in this, and presumably other, spatially restricted areas from the very beginning of the Holocene. Apparently this site, with its birch enclave, was an azonal feature during the initial phase of its existence. In a broader geographical context pine constituted the uppermost

TABLE I
Radiocarbon dates of subfossil birch

Laboratory no.	Altitude (m a.s.l.)	^{14}C date* (BP)
ST-12749	1000	6165 ± 85
ST-12750	1010	6470 ± 85
ST-12751	1010	4715 ± 80
ST-12752	1010	5355 ± 80
ST-12754	1010	3415 ± 70
ST-12755	1015	6405 ± 225
ST-12980	1000	8680 ± 100
ST-12982	1000	6200 ± 70
ST-12983	1000	5895 ± 105
ST-12984	1000	5980 ± 85
ST-12985	1015	7320 ± 70
Beta-57615	1000	5460 ± 70
Beta-57616	1000	6030 ± 80

* All dates are given with $\pm 1 \delta$

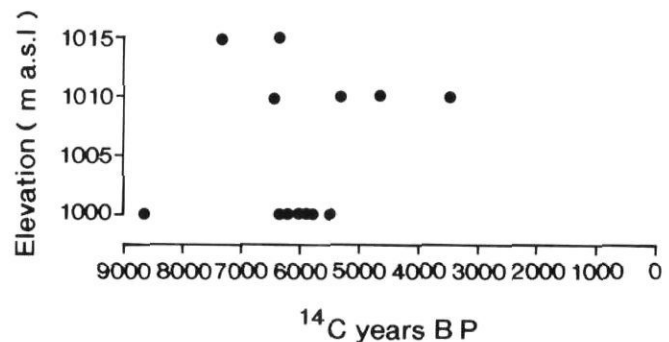


FIGURE 6. Radiocarbon dates of subfossil birches.

Datations au radiocarbone des fossiles subrécents de bouleaux.

forest, at least until *ca.* 7000 BP (Kullman, 1988, 1989, 1992). Prior to that, a general birch belt could have been absent due to a strongly seasonal climate with too little snow and summer drought. Only in habitats characterized by great snow accumulation and sufficient soil moisture was birch able to grow up to high above its present limit and relatively close to its contemporary thermal limit. Eventually, as climate became less seasonal, snow became more persistent and the summers cooler. This favoured birch at the expense of pine and enabled it to spread "infectiously" from the pockets, where it subsequently demised due to excessive snow cover. This course of climatic development is consistent with the theory of orbital forcing (Milankovitch hypothesis) (*cf.* Kullman, 1993a).

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 Faarlund, 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 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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