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(Research Article)

Early Holocene presence of Norway spruce (*Picea abies*) on a high mountain nunatak in the Swedish Scandes: A further contribution to the biotic composition of the first deglaciated landscape and a link between past and present

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Abstract

A megafossil wood remnant of Norway spruce (*Picea abies* (L.) Karst.) was retrieved from a high-elevation nunatak in the southern Swedish Scandes. The site was nearly 600 m higher than the present-day treeline. These circumstances comply with analogous earlier recoveries, indicating presence of spruce at high elevations in the Scandes, several thousands of years prior to inferences made by pollen analysis. Radiocarbon-dating yielded a median age of 9300 cal a BP. This result adds firm detail and adheres to ongoing reappraisal of the structure and biodiversity of the late-glacial and early Holocene mountain landscape, in the light of growing megafossil and molecular genetic evidence.

Keywords: *Picea abies*; Megafossils; Holocene; Nunataks; Palaeoclimate; Radiocarbon-dating; Swedish Scandes

1. Introduction

By tradition, comprehension of palaeovegetation and biogeographic dynamics have almost exclusively relied on pollen analysis, an inferential method beset with shortcomings with respect to taxonomic detail and arboreal landscape structure (9, 4, 17, 19, 30). In particular, the early postglacial mountainscape and its plant cover have escaped true comprehension, due to the almost exclusive reliance on pollen analysis. This approach is particularly ill-suited to the high-alpine environment with poor pollen production, thin organic soils and lack of peat. One of the most blatant cases of failure of pollen analysis, concerns the early postglacial history of Norway spruce (*Picea abies* (L.) Karst.) in northern Scandinavia, and particularly in the high mountain regions of the Scandes. Another case, highlighting the discrepancy between megafossil and pollen stratigraphic data, is about the Holocene history of Siberian larch (*Larix sibirica*) in the Scandes (19).

Megafossils are pieces of ancient wood (trunks, roots or cones) preserved in peat, lake mud o beneath glacier ice, which have grown close to the site of finding.

For long, a generally maintained "truth" was that spruce stands out as one of the latest immigrated trees to Sweden, following the Weichselian glacial phase (5, 26, 4, 10, 7, 27). Accordingly, it was assumed to have spread gradually from east to west over northern Sweden during the past 4000 years, to reach the Scandes in the west only 2000-3000 years ago (6, 38).

Nevertheless, it has been evidenced by the megafossil approach that spruce grew on early deglaciated high-elevation nunataks already during the late-glacial and early Holocene epochs, about 13 000 and 11 200 years ago (14, 17, 18).

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This complies with newer data, indicating that the highest peaks were ice-free as early as about 20 000 years ago (3), in contrast to a more traditional view of early Holocene mountain deglaciation (40).

The early Holocene presence of spruce is firmly documented by megafossils at multiple sites in the subalpine/alpine and upper boreal landscapes along the entire Swedish Scandes. In some cases, the finding sites were located 500-700 m above modern treelines and ranging between 13 000 and 7000 years before the present (14, 23). Occasionally, macro- and megafossils tree remains have been released from the rim of melting glaciers and ice patches high above modern treelines, indicating glacier-free mountains and relatively warm conditions during the late-glacial and early Holocene epochs (21, 21, 22). Analogously, early presence of spruce is suggested also from macrofossil records in Norwegian high-mountain regions (35,34). Inferences based on ancient DNA, preserved in lake sediments, indicate late-glacial and early Holocene presence of spruce (31, 32, 28), and gain some support from the above-mentioned mega- and macrofossil records.

This paper reports and discusses a single megafossil spruce record from a remarkably exposed high-elevation site in the central Scandes of Sweden. It complements and adds detail to previously views of early postglacial species composition and structure of the earliest ice-freed alpine landscape in the Swedish Scandes.

1.1. Study area

The study comprises one of the highest mountains, surrounding the Handölan River in the southern Swedish Scandes with the highest peak, Mt. Storsnasen, reaching 1463 m a.s.l., which is about 800 m higher than the valley floor to the east. Hereabouts, subalpine birch forest (*Betula pubescens* ssp. *czerepanovii*) prevails, together with scattered outlier stands of Norway spruce (*Picea abies*) and Scots pine (*Pinus sylvestris*). The local present-day treeline of spruce is at 815 m a.s.l. (Fig. 3). A stand of closed spruce forest grows at the valley floor (625 m a.s.l.) about 4 km to the east of the study site (20). Spruce display old-established layering krummholz-individuals high above the treeline at the concerned site and on nearby high mountains (Fig. 4, 5).

The climate has a weakly oceanic character. Data from Storlien/Visjövalen meteorological station (642 m a.s.l.) display mean temperatures for the months of January, July and the year; -7.6, 10.7 and 1.1 °C, respectively, referring to the period 1961-1990. The bedrock at lower altitudes is composed of Seve amphibolite, covered with glacifluvial, lacustrine and peat deposits. Around the mountain peak, extensive boulder fields prevail, with scattered spots of alpine plant cover, mostly of snow bed character.

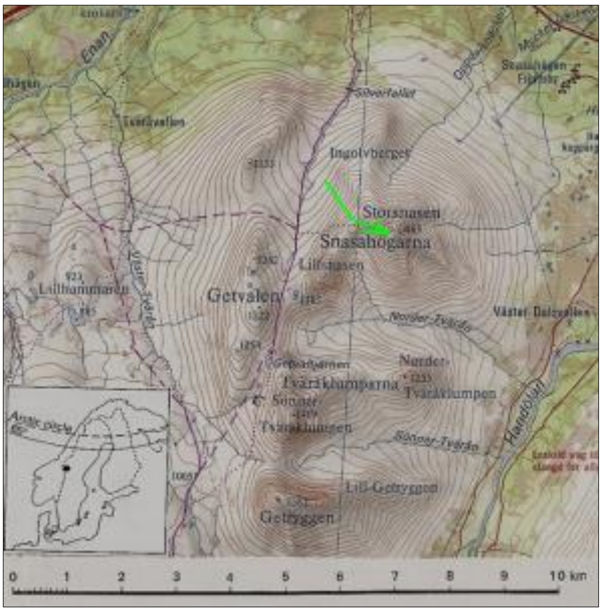

Figure 1 Location map showing the study site close to the peak of Mt. Storsnasen (arrow)

Figure 2 Mt. Storsnasen in the early summer, SE-aspect. The study site is indicated by an arrow. 2012-06-15

Figure 3 The present-day treeline of spruce, 815 m ö.h. This is an old-established layering individual, which quite recently attained tree-size Mt. Storsnasen. 2021-10-13

Figure 4 Vigorously growing krummholz spruce, perpetuated by layering, 275 m above the present-day treeline of spruce (Fig. 3). One living stem demonstrates that this specific individual prevailed here at least 643 years ago. Obviously, it survived the cold of the Little Ice Age, like many equals in this region (cf. Fig. 5). 1090 m a.s.l. Mt. Storsnasen. 2007-09-27

Figure 5 Krummholz spruce growing well above the treeline, in a slope c. 2 km to the south of the spruce depicted in Figure 4 and at the same elevation, 1090 m a.s.l. Radiocarbon dating of wood, preserved in the soil underneath the branches, yielded a minimum age of ca 1200 cal a BP (13). The spruce is well protected by snow during the winter. Intermittently it produces cones with viable seeds. Saplings recorded 2010 were still alive 2021. Mt. Norder-Tväråklumpen. 2021-08-28.

2. Methods

In July 2009, megafossil tree remains were systematically searched for within the summit area of Mt. Storsnasen, from the top and about 100 m downslope. Lack of peat and other preservation media, such as lake mud or perennial ice, yielded a poor return. However, some minor wood fragments were found, exposed close to the ground surface. These samples were re-considered in 2021 and one specimen was selected for radiocarbon-dating.

Radiocarbon-dating (AMS) was performed by Beta Analytic Inc. Miami. USA. Calibration to calendar years (95.4 % confidence interval) was conducted by use of INTCAl 09 database (37). Species identification was carried out by wood anatomy analysis (Erik Danielsson/Vedlab Inc.).

3. Results and discussion

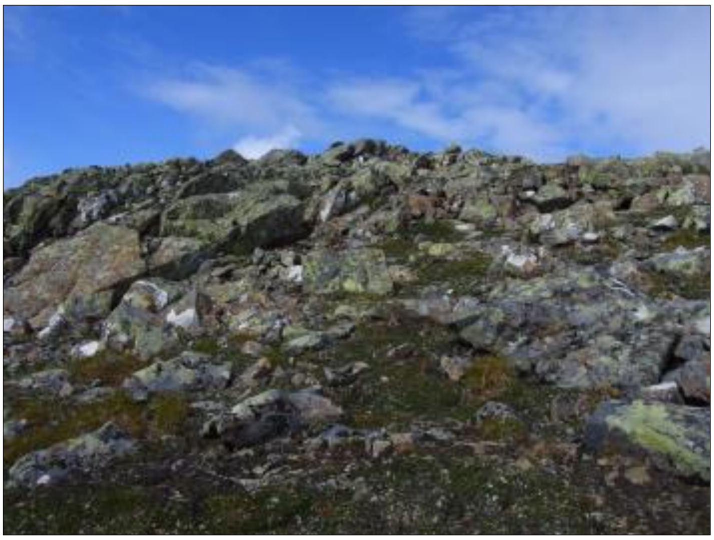

Figure 6 General overview of the fairly exposed finding site, 1405 m a.s.l, about 60 altitudinal meters below the mountain summit. 2009-07-15

One specimen was recovered to the south of this highest peak at an elevation of 1405 m a.s.l. (63° 14. 450´ N; 12° 21. 494´ E). The sampling site was a spot within an extensive boulder field (Fig, 6), with fine earth and a dense *Salix herbacea*-community, indicative of late-lying snow cover (Fig. 7).

Figure 7 At the soil surface, wood fragments were partly exposed in vegetation of predominant *Salix herbacea*. Visible parts were 14x4 cm, while hidden wood pieced were about 65 cm (not shown) and embraced some tiny twigs, with well-preserved bark and a diameter of 10-13 mm. The wood was radiocarbon-dated 9321 cal a BP (median). Presumably, this was a low-growing krummholz spruce or a tiny tree, resembling the ones displayed in Figure 4 and 5.

Table 1 Result of radiocarbon-dating of a megafossil spruce remnant

Laboratory ID	^{14}C a BP	Calibrated age (cal a BP)	Median
Beta-611313	8310±30	9438-9204	9321

This report is based on just one single sample, which precludes far-reaching conclusions. The result of radiocarbon dating is given by Table 1. With respect to the size of the dated wood sample, it is virtually impossible to judge whether it represents krummholz or a tiny tree. The elevation of the finding site, in relation to the modern treeline, is +590 m. The age span shows that the present dating aligns with and add detail to earlier results and inferences, obtained by megfossils from other parts of the Swedish Scandes. These prior records have highlighted a surge of tree establishment around 9600-9000 cal a BP in present-day alpine tundra and at sites of glacier cirques (1, 2, 21, 23).

The status of *Picea abies* as an early Holocene dweller in the Scandes is further enhanced by the present record is consistent with earlier evidence (cf. 14, 17, 18, 21, 35, 31, 34). Growth at this remarkable high elevation and at a particularly exposed site, close to a distinct high-mountain peak, argues for a climate strongly deviant from the present day. Accordingly, an increasing number of studies infer that the Holocene thermal maximum was around 10 000 cal a BP (e.g. 24, 43, 36, 25). Unfortunately, the unclear stature of the concerned specimen precludes any quantitative paleoclimatic inferences to be made.

Notably, the high relative position of the finding place may seem remarkable. However, it should be considered that, due to land uplift, this specific site was located 200-300 m closer to the sea level when the spruce grew here (33). As evident from Figure 4 and 5, spruce currently thrives, persists and even reproduces at corresponding elevations.

Specifically focusing on the history of *Picea abies*, the present result adheres to earlier studies, showing late-glacial and early Holocene presence of spruce on high early deglaciated nunataks, currently 600-700 m above present-day treelines (14, 18). This circumstance provides some support to the hypothesis that spruce could have survived the Weichselian glaciation or parts of it in the Scandes, or, more likely, at coastal sites at the western margin of the ice sheet (13, 18). This issue and postglacial migration routes over Scandinavia are currently debated on the basis of combined megafossil and molecular genetic evidence, although without definite conclusions (31, 42, 32, 28). Anyhow, the growth of spruce on late-glacial and early-Holocene ice-free nunataks maintains the hypothesis of ice-age survival near the western margin of the continental ice sheet (cf. 12, 11, 44). Only gathering of further megafossil data can bring the issue of progressive landscape differentiation closer to true comprehension.

The fact that spruce grew at this and other high and exposed sites, may imply that the high- alpine plant cover during this early warm time was particularly rich and luxuriant. This could be understood in terms of insolation-induced warming, high soil nutrient levels and low impact of competition (39, 8). Present-day alpine flora enrichment may constitute an analogy with postglacial conditions (16).

4. Conclusion

Wood remnants of Norway spruce (*Picea abies*) were unearthed on a high-alpine postglacial nunatak in the Swedish Scandes. Radiocarbon dating of this presumed krummholz individual yielded an age of 9300 cal a BP. The site is about 600 m higher than modern treeline and indicates an early Holocene thermal maximum. The object concerned in this study adds to a more details comprehension of the early deglaciated landscape. In particular, the traditional view of spruce as a late Holocene immigrant to the Scandes is once again falsified.

Compliance with ethical standards

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