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Early Holocene presence of beaver (Castor fiber L.) in the Scandes sustains warmer-than-present conditions and a patchily treed and rich mountainscape.

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Abstract: *Post-Little Ice Age climate recovery of the past 100 years or so has evoked significant changes of the high-mountain landscape. For example, alpine treelines have advanced and glaciers/ice patches have shrinked. By the last-mentioned process, megafossil tree remains of different boreal species have been exposed for the first time since their burial by growing snow and ice millennia ago. Obviously, the concerned remains represent tree exclaves in ice-empty glacier cirques. In these settings, finds of megafossil of Pinus sylvestris, with signs of beeing gnawed by beaver (Castor fiber L.) are reported from diffferent sites in northern Sweden. They age 9500-9300 cal. yr BP and are located 500-400 m atop of present-day treelines. The detailed character of these "forest" outposts have been largely unknown, althogh macrofossils indicate a forest floor of present-day boreal affinity. Presence of beaver, an obligate forest-dweller, further enhances the inference of a genuine forest character with a high biodiversity of these tree ouliers. Early Holocene presence of beaver in the Scandes raises questions about postglacial immigration routes.*

Keywords: *Megafossil trees, beaver, early Holocene, wood outposts, palaeoclimate biodiversity, Swedish Scandes*

1. INTRODUCTION

Post-Little Ice Age climate warming and associated glacier and ice patch shrinkage have opened a new window to past high-mountain vegetational and faunal composition as well as human utilization of the ancient mountainscape (Schlüchter & Jörin 2004; Benedict et al. 2008; Nesje et al. 2011; Reckin 2013; Koch et al. 2014; Kullman & Öberg, 2020a). In the Swedish Scandes, summers (J.J.A.) have warmed by 1.7 °C during the period 1901-2020 (Kullman & Öberg 2020b). This course of change has caused glaciers and perennial ice patches to disintegrate (Lundqvist 1969; Holmlund et al.1996; Lindgren & Strömgren 2001), which has released ancient woody material, so-called megafossils. These remnants represent former tree stands, later on extirpated and entombed by snow and ice for many millennia. By the current warming phase of the past 100 years or so, megafossil tree remnants (logs, brances, roots and cones) are being exposed by the late summer at the forefields of many Swedish glaciers and perennial ice patches, as reported and discussed previously (Öberg & Kullman 2011; Kullman & Öberg 2013, 2015). From these studies it appears that current sites of glaciers and ice patches, 400-700 elvational meters atop of current treelines, harboured early Holocene stands of many of today´s boreal tree- and ground-cover species prevailing in northern Scandinvia. In addition, one regionally extirpated species, viz. *Larix sibirica*, was found under these circumstances. Moreover, the last-mentioned studies evidenced early Holocene presence of *Picea abies* (Kullman 2018), previously for long considered as a more recent immigrant from the east.

Here, distinct morphs of megafossil tree remains are reported and discussed. Focus is specifically of ancient logs with characteristic signs of being gnawed by beaver (*Castor fiber* L.). These records add to articulate the climatic and vegetational implications of the existing megafossil narrative from the same sites as focused in previous studies of postglacial tree histories and climate change (Öberg & Kullman 2011; Kullman & Öberg 2013, 2015; 2020a,b; Kullman 2017).

2. STUDY AREAS

This study concerns two areas in the Scandes of northern Sweden (Fig.1). No. 1 is the glacier *Kårsaglaciären* in northern Lapland and No. 2 comprises the glaciers *Tärnaglaciären* and

Murtserglaciären in southern Lapland. Detailed accounts of their settings and postglacial and modern arboreal histories are provided by last-mentioned six references.

No. 1. *Kårsaglaciären* (68° 18´N; 18° 20´E) is located in the east-facing slope of Mt. Kårsatjåkka (Fig. 2A). During the past 100 years, the lower front has moved upslope from 810 to 965 m a.s.l., and a forefield about 1 km in length has become freed of ice. By the late summer, this area is ”strewn” with megafossils of different species, recently exposed by the retreating ice margin. These remains of former tree growth, high above current treelines, date between 11760 and 5900 cal. yr BP, which roughly bracket postglacial absence or much reduced size of the glacier until the late-Holocene Neoglacial inception of the glacier. The nearest present-day treeline of pine is 520 m a.s.l. (Kullman 2015)

No. 2. *Tärnaglaciären* (65° 51´N; 15° 36´E) is situated in an cirque with a south-eastern aspect of Mt, Murtsertjåkke (Fig. 2B). Withdrawal of the lower front ranges 1070 to 1240 m a.s.l., i.e. a total 170 m in elevation during the past 100 years. Below the front, an extensive and semi-permanent snow/ice patch extends to a proglacial meltwater pond 1070 m a.s.l. Megafossils of different species have been recovered at the forefields and range between 11 200 and 4480 cal. yr BP

No. 3. *Murtserglaciären* (65° 49´N; 15°14´E) is a former small glacier in the east-facing slope of Mt. Murtsertjåkke, ca 2 km to the south of Tärnaglaciären (Fig. 2C). Its lower margin is about1390 m a.s.l. Today, after a century of substantial thinning and insignificant frontal retreat, it has changed character to an ice patch. Megafossils of pine and birch are dated 9195- 5900 cal yr BP.

Figure1. Location of study areas in northern Sweden (Lapland). **1**. *Kårsaglaciären*. **2**. *Tärna.*

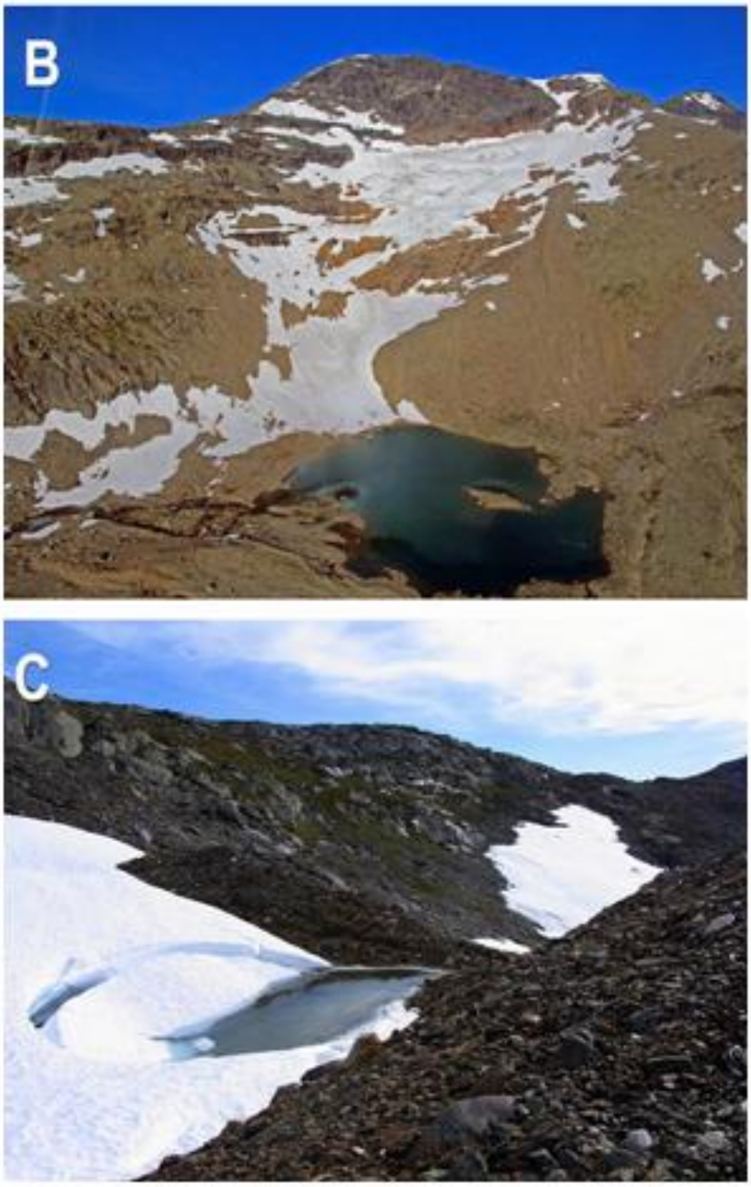

Figure 2. Overviews of the studied glacier habitats, including adjacent meltwater ponds. Megafossil tree remains are found at these levels and even higher upslope. **A.** *Kårsaglaciären*. Photo: 2013-09-12. **B**. *Tärnaglaciären*. Photo: 2012-08-28. **C**. *Murtserglaciären* Photo: 2012-08-28. All sites display meltwater ponds in close association with the lower forefields, recently released from the ice.

3. RESULTS

Altogether three megafossil tree remains (*Pinus sylvestris* L.) with characteristic signs of being gnawed by beaver, *Castor fiber* L. (general appearance and teeth furrows), have been recovered on the forefields of receding glaciers/ice patches in Swedish Lapland (Table 1, Fig. 3). They all date to the early Holocene, 9530-9190 cal yr BP, at sites 380-520 m higher than the present-day treelines of the respective species, and in near association with meltwater ponds in the lower forefields. All recovered specimens represent medium-sized trees. It is unlikely that they are preserved *in situ*, but more likely that they have been dislocated from higher primary growth positions by meltwater streams or snow avalanches.

Table1. *Radiocarbon dates of subfossil pine remains with signs of beeing gnawed by beaver (Castor fiber L). Sources: Öberg & Kullman 2011; Kullman & Öberg 2013, 2015).*

Site no.	^{14}C yr BP	Intercept cal.yr BP	Elevation m a.s.l.	Rel. elevation m	Lab. code
1	8270±60	9280	940	420	Beta- 250914
2	8520±70	9530	1070	380	Beta-264394
3	8220±40	9190	1210	520	Beta-332277

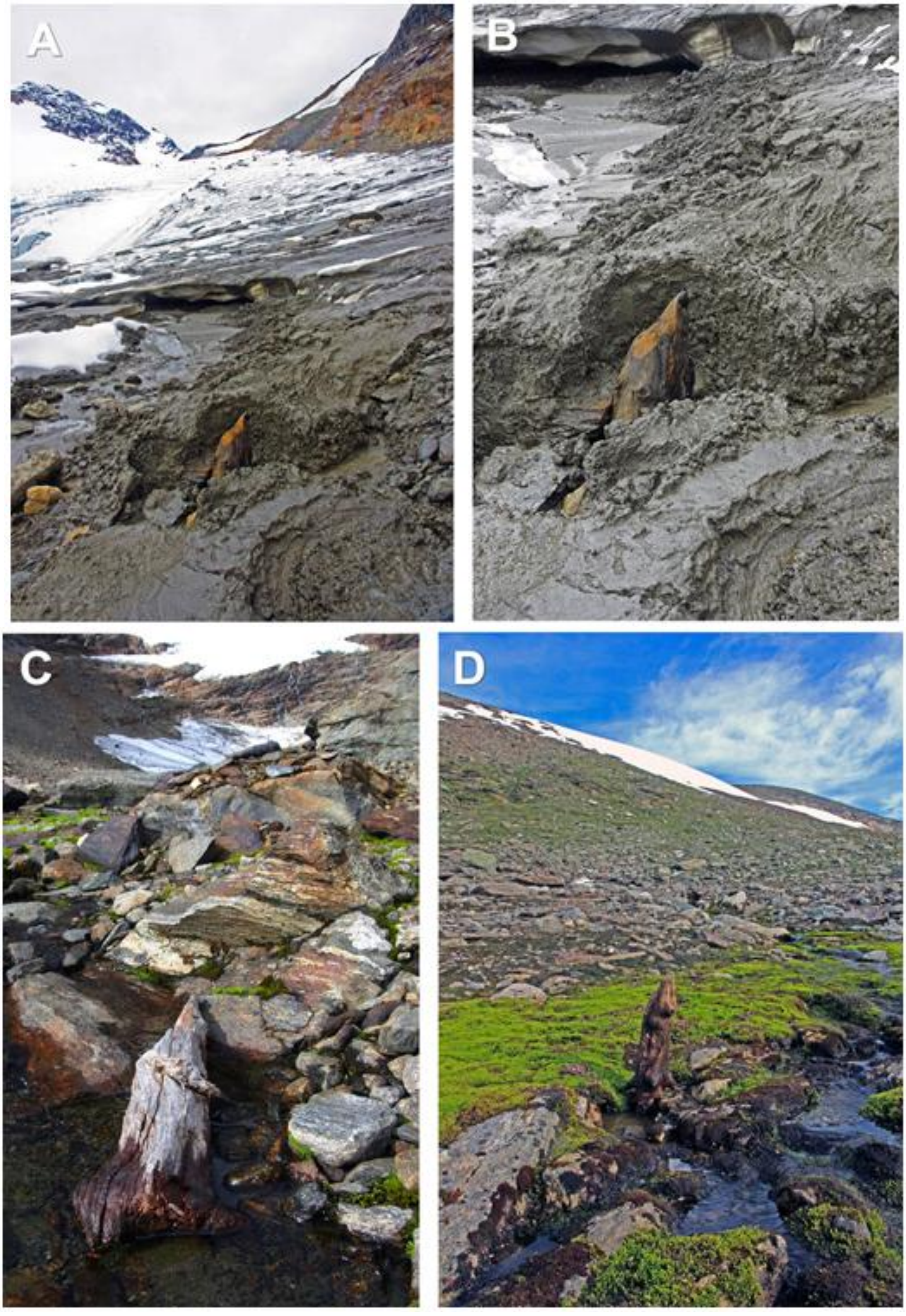

Figure 3. Megafossil tree remains (*Pinus sylvestris*) with signs of being felled by beaver (*Castor fiber*). Radiocarbon dates are given here in intercept form. **A & B**. Site 1. 9280 cal yr. BP, 420 m higher than the local pine treeline. **C.** Site 2. 9435 cal. yr BP, 380 m higher than the local pine treeline. **D**. Site 3. 9190 cal. yr BP, 520 m higher than the local pine treeline. The dated log is upraised from its original position, partly beneath an eroding moss cover.

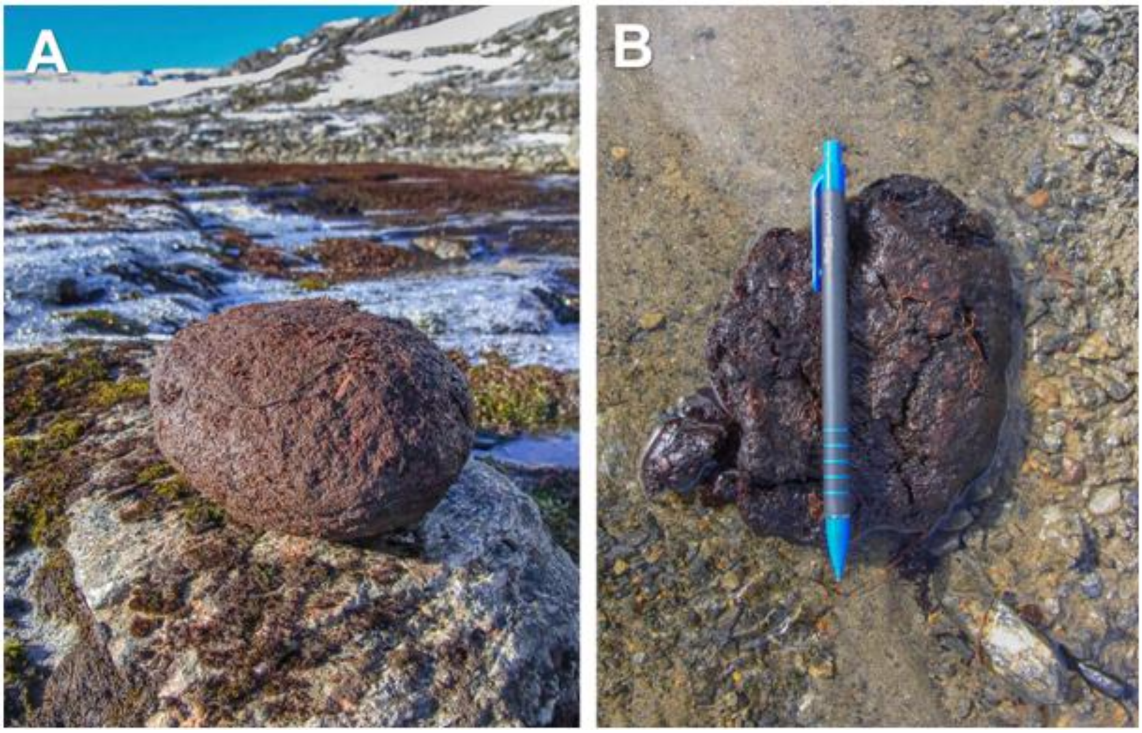

Figure 4. **A**.”Peat ball”, outwashed from beneath the glacier cover and with a multitude of plant macro remains (vascular plants and bryophytes), representative of present-day northern boreal ground cover flora. A bulk sample of the peat and its content returned an age 5175 cal. yr, indicative of a glacier smaller-than-present at that time and a species-rich forest floor. Ice patch near *Tärnaglaciären*, 1115 m a.s.l. *Photo:* 2012-09-22. **B.** Peat cake dated 3890 cal. yr BP, without tree remains and reasonably shortly predating glacier inception. *Tärnaglaciären*, 1075 m a.s.l. Photo: 2010-08-20. Source: Kullman & Öberg 2013, 2015.

4. DISCUSSION

The concerned megafossil pine remains comply with a general view of early Holocene tree growth of different tree species at much higher elevations than today and consequently in a substantially warmer climate. Obviously, ice-free glacier cirques offered congenial growth conditions to boreal trees and other plants, with respect to insolation, moisture, wind shelter and propagule accumulation (Kullman & Öberg 2020a,b). At all the investigated sites, megafossils of different tree species have been recovered at higher positions and earlier than displayed by the beaver-gnawed stems presented in this study. This implies that early Holocene summer temperature may have been at least 3 °C warmer than the early 21st century (Kullman & Öberg 2013).

Pine is not the most preferred species by beaver for building or forageing. Thus, the confinement of utilization of this species may be a sign of its preponderance in the treeline ecotone (Kullman 2013), or just a consequence of a small and unrepresentative sample. Indeed, megafossils of more palatable trees and shrubs are recorded in these habitats, e.g. *Sorbus aucuparia, Alnus incana, Populus tremula, Salix* spp. (Kullman & Öberg 2013).

Aside of *Pinus*, early Holocene tree assemblages in these exclaves, 400-700 m atop of current treelines, contained macrofossils of *Betula pubescens* ssp. *czerepanovii*, *Picea abies*, *Larix sibirica*, *Sorbus aucuparia*, *Alnus incana*, *Populus tremula*. Of these, *Larix* and *Picea* have by traditional pollen analysis been considered as non-existent at the late glacial and early Holocene treeline ecotone in the Scandes (e.g. Huntley & Birks 1983), although invalidated by Kullman (2008, 2018; Paus et al. 2011).

Analyses of plant macrofossils contained in outwashed ”peat balls” from beneath the ice blanket at the concerned ”beaver sites” (Fig. 4) have revealed that a forest floor of present-day mountain taiga affinities prevailed in association with the early Holocene trees. Hereabouts glacier ice and perennial snow/ice patches came into existence during the Neoglacial, shortly after about 4000 cal. yr BP and thereby sealed this plant cover repository for millennia to come (Fig. 5).

Characteristic ground cover species in these early tree exclaves were, *Vaccinium myrtillus*, *Vaccinium vitis-idaea*, *Empetrum hermaphroditum*, *Betula nana*, *Calluna vulgaris*, *Arctous alpina*, *Salix herbacea*, *Salix* spp., *Juniperus communis*, *Ledum palustre* (Kullman & Öberg 2013). The presence of beaver, an obligate forest-dweller has historically been restricted to areas with trees and abundant shrubs and with lightly frozen water bodies during the winter (Tape et al. 2018). Thus, the current findings of beaver action further sustain the inference of discrete and scattered high-productive species-rich forest communities in ice-empty glacier cirques, high above present day treeline positions (Kullman & Öberg 2020a, b). These habitats are assumed to have offered particularly congenial growth conditions for a diverse tree- and ground cover flora, different from surrounding more poor and trivial alpine tundra, prevailing over most of the high-mountain landscape during the early Holocene. For more detailed inferences in these respects, see Öberg & Kullman (2011). All this happened during the warmest phase of the early Holocene, 9000-9500 years before the present, a period of extensive tree spreading at high elevations (Kullman 2013: Kullman & Öberg 2020).

Possibly, these early and species rich high elevation forest exclaves may have functioned as dispersal nodes in the context of downslope spread of trees and other plant species by the early Holocene (Kullman 2001, 2008; Väliranta et al. 2011).

Analogously, data from NW Alaska, have dated beaver presence in current tundra areas, about 8000 cal. yr BP. This was also in a warmer-than-present climate with more advanced treelines (McCulloch & Hopkins 1966).

The surprisingly early presence of beaver is of particular interest in terms of immigration and spread of biota following the general deglaciation of northern Scandinavia. During the early Holocene with a higher Bothnian sea level in the east, incised bays penetrated more deeply westwards into the Scandinavian penisula. This might have promoted water spread of some plants and animals towards the west (cf. Kolstrup 2007; Kolstrup & Olsen 2012; Kullman in press). On the other hand, faunal spread of vertebrates from the west is a possibility, judging from palaeorecords of e.g. Red Squirrel (*Sciurus vulgaris*) at the Nowegian coast, dated 11 500-10 400 ^{14}C years before present (Larsen et al. 1987).

5. Conclusion

• Climate warming during the past 100 years has evoked substantial glacier/ice patch recession in the Swedish Scandes.

• Megafossils of different tree species are exposed at the forefields of of receding glaciers and snow patches.

• They range in age between c. 11 700 and 4000 cal, yr BP, when temperatures were as most 3 °C higher than present and treelines 500-700 m above current levels.

• As particularly focused in this study, some megafossils showed sign of being gnawed by beaver (*Castor fiber* L.), an obligate forest dweller. The concerned specimens range in age between 9530 and 9190 cal. yr BP.

• These findings, in addition to recovered contemporary macrofossils specimens of common ground cover plants, enhance the forest structure of the early tree enclaves, inferred by the tree megafossils.

• These”beaver datings” are the earliest in the Swedish Scandes and raises questions about postglacial immigration routes. This aspect is tentatively discussed.

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