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Vegetation history and *Picea abies* (L.) Karst. establishment in the Härjedalen province (central Sweden)

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ABSTRACT

The traditional theory about *Picea abies* (L.) Karst. arrival and establishment in Sweden is being revised. Until *Picea abies* megafossils were radiocarbon dated between the late-Glacial and the mid-Holocene (Kullman, 2000), it was widely accepted that *Picea abies* established at the Swedish East coast approximately 3500 B.P., then spreading to the South and West. Early- to mid-Holocene occurrence of *Picea abies* in previous pollen diagrams, such as Lundqvist (1969), that were considered as long distance pollen transport, could now be interpreted as early outposts of *Picea abies*. The overall aim of this project is to reconstruct the past vegetation in central Sweden. The specific question is whether pollen records can verify the early-Holocene *Picea abies* establishment in Sweden as is suggested by Lundqvist (1969). A pollen analysis study was performed in Stenhammaren, in the Härjedalen province (central Sweden), a few kilometres from the site with high early pollen proportion of *Picea abies*. The results permit the reconstruction of the past vegetation in the site, however no early *Picea abies* pollen has been found. Nevertheless, the presence of *Picea abies* trees near the study site in the early-Holocene should not be discarded, and further research is needed.

Keywords: *Picea abies*, early-Holocene, central Sweden, pollen analysis.

RESUMEN

La teoría tradicional acerca de la llegada y establecimiento de *Picea abies* (L.) Karst. en Suecia está siendo revisada. Hasta que megafósiles de *Picea abies* fueron datados por radiocarbono entre el fin de la glaciación y el Holoceno Medio (Kullman, 2000), era ampliamente aceptado que *Picea abies* se estableció en la costa este de Suecia aproximadamente 3500 A.P., propagándose más tarde hacia el sur y oeste. La aparición en el temprano y medio Holoceno de *Picea abies* en diagramas de polen previos, tales como Lundqvist (1969), eran considerados polen transportado desde larga distancia, ahora podrían ser interpretados como posiciones tempranas de *Picea abies*. El objetivo general de este proyecto es reconstruir el pasado de la vegetación en el centro de Suecia. La cuestión específica es si registros de polen pueden verificar el establecimiento de *Picea abies* en Suecia al comienzo del Holoceno, como sugiere Lundqvist (1969). Se ha llevado a cabo un estudio de análisis de polen en Stenhammaren, en la provincia de Härjedalen (centro de Suecia), a pocos kilómetros del lugar con alta proporción de polen de *Picea abies* temprano. Los resultados permiten la reconstrucción del pasado de la vegetación en el lugar, sin embargo no se ha encontrado polen temprano de *Picea abies*. A pesar de todo, la presencia de árboles de *Picea abies* cerca del lugar de estudio al comienzo del Holoceno no debe ser descartada, y más investigaciones son necesarias.

Keywords: *Picea abies*, Holoceno temprano, centro de Suecia, análisis de polen.

INTRODUCTION

Approximately 3500 B.P. *Picea abies* (L.) Karst. arrived to the Swedish Bothnian Coast from Finland and became competitive and dominant there, then spreading to the West and South (Huntley & Birks, 1983). That has been the traditional theory of Norway spruce arrival and establishment in Sweden (based on pollen analysis) until Norway spruce megafossils, dating back to early-Holocene, were found by Kullman (1995, 1996, 2000, 2002). Altogether, 76 subfossils were recovered and radiocarbon dated between the late-Glacial and the mid-Holocene. These finds conflict with the initial and generally accepted model for the Norway spruce migration to Sweden. Moreover, the new discoveries demonstrate that Norway spruce has been present in Scandinavia since about 11000 B.P. (Kullman, 2000). Before these finds, early- to mid-Holocene occurrence of *Picea abies* pollen in previous pollen diagrams were considered to be a result of a long distance transport from distant Norway spruce forests. One such site with high pollen proportion during early- to mid-Holocene is Tönningfloarna, in central Sweden (Lundqvist, 1969). In the light of Kullmans finds, these early occurrences of pollen in Tönningfloarna may rather be interpreted as early outposts of *Picea abies* (Giesecke & Bennett, 2004). But the early occurrence of *Picea abies* pollen in pollen diagrams is not commonly interpreted as early local stands. However in except for a study carried out by Segerström & von Stedingk (2003) a *Picea abies* pollen were already recorded 9000 years ago in the area where *Picea abies* macrofossils had been found by Kullman (2000), showing that low pollen proportions may be interpreted as local presence under certain circumstances.

The overall aim of this project was to reconstruct the Holocene vegetation development in central Sweden. The goal can be reached by doing a pollen analysis. It is the most widely adopted and versatile technique employed in the reconstruction of Quaternary environments (Lowe & Walker, 1997) since Lennart von Post presented the first modern percentage pollen diagram in 1916 marking the foundation of what it is now known as palynology (Manten, 1967).

The specific aim was to examine the early-Holocene *Picea abies* pollen proportions recorded by Lundqvist (1969) and to discuss *Picea abies* establishment in central Sweden. A study was performed in Stenhammaren, a mire situated few kilometres from Tönningfloarna, the site studied by Lundqvist (1969) with high pollen proportion of *Picea abies* already at 7000 B.P. The study site is located in the Härjedalen province (central Sweden). A peat core was taken from the mire, analyzed for pollen and radiocarbon dated.

MATERIAL AND METHODS

Study site

The study site, Stenhammaren, is a small mire (5000 m^2) at 600 m above sea level. It is located ca 10 km from Tönningfloarna and 25 km north of Sveg (62º14´N, 14º16´E), in the Härjedalen province, central Sweden (Figure 1).

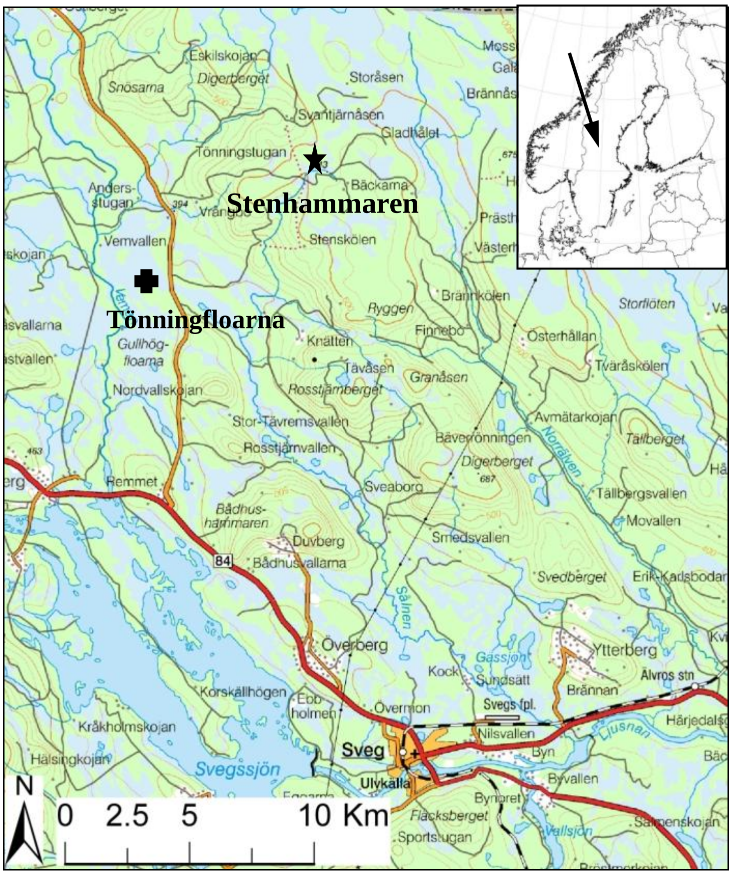

Figure 1. Map showing the location of Stenhammaren (marked with a star) and the nearby Tönningfloarna (marked with a cross) in the Härjedalen province (Sweden). Insert map shows the geographical location of the study area in Fennoscandia. Mires are colored in light blue.

The bedrock is predominantly granite and other acidic rocks, although basic volcanic rock and calcareous schists occur increasingly towards the northwest (Bruun *et al*, 2003). The zone shows maritime-continental climate conditions, with a January mean temperature between -12 and -9 ºC, a July mean of 11–13 ºC, and a mean annual precipitation of 500–600 mm in the lowlands and 700–1200 mm in the mountains (Bruun *et al*, 2003). Deglaciation of the area took part 9300-9000 ^{14}C years B.P. (Lundqvist, 1973).

The study site is a sloping mire rich in herbs and shrubs. Some of them are *Menyanthes trifoliata,* various species of Cyperaceae and Rosaceae*, Drosera rotundifolia, Vaccinium oxycoccus, Rumex acetosa, Rubus chamaemorus, Salix sp.* and *Equisetum sp*. There are also some scattered stands of *Pinus sylvestris* and *Betula pubescens* on the hummocks, where the major species are *Empetrum nigrum, Betula nana, Sphagnum* and *Andromeda polifolia.* The surrounding area is formed by a closed forest of *Picea abies* and *Betula pubescens*. Overall, the understorey vegetation is composed by *Vaccinium vitis-ideae, Vaccinium myrtillus, Empetrum nigrum, Sorbus aucuparia, Juniperus communis* and *Epilobium angustifolium* (Figure 2).

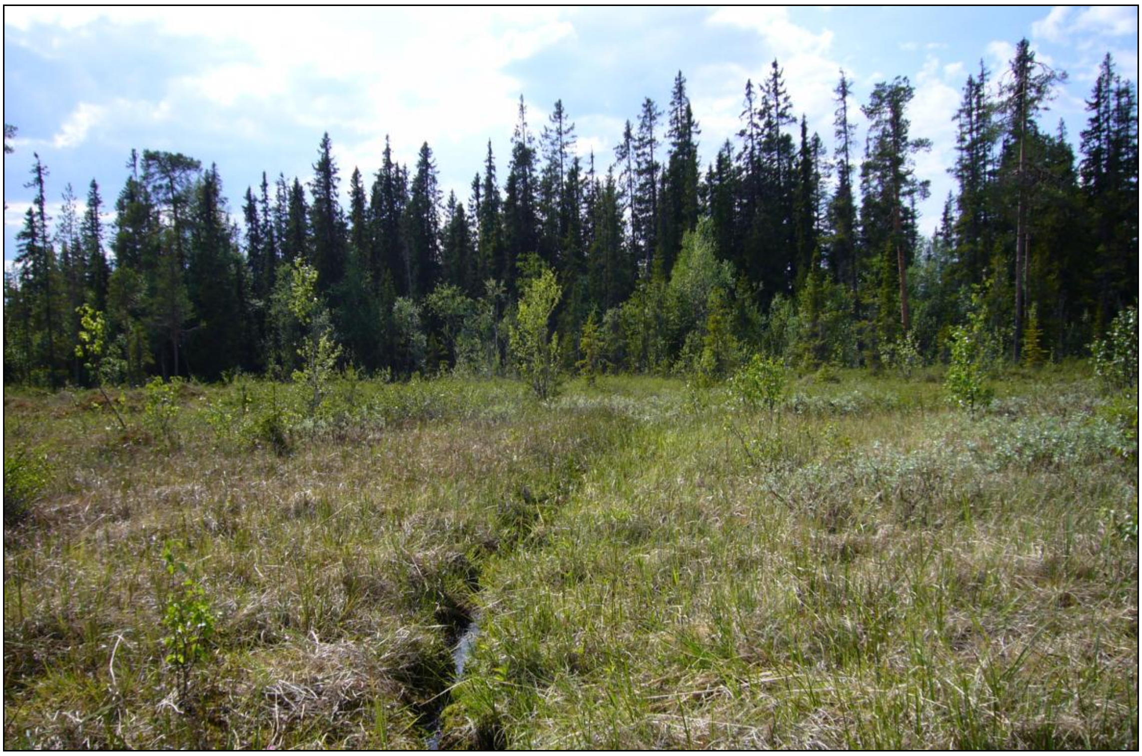

Figure 2. Stenhammaren, the sampling site in the Härjedalen province.

For pollen analysis a 195 cm long peat core was taken from the mire using a "Russian" peat corer (cf. Jowsey, 1966).

Radiocarbon dating

To create a chronology along the core depth, two bulk-peat samples, at 60 cm and 166 cm depth were taken for radiocarbon dated. The ^{14}C analyses were performed at the Ångström laboratory at Uppsala University (Sweden). The radiocarbon dates were made by ^{14}C AMS (accelerator mass spectroscopy).

Pollen analysis

Firstly, 30 peat samples (each representing one cm), were cut out from the peat core. From the bottom to 90 cm depth, there were five cm between every sample, and above 90 cm, there were 10 cm between each sample. All of them were digested in 5% potassium hydroxide over night. This digestion breaks up the matrix and dissolves humic materials. The dark brown solution was sieved (using a one mm net size mesh) to eliminate the solid phase. The remaining material was treated with acetolysis according to standard methods (cf. Moore et al, 1991). Since the deepest samples contained high amounts of mineral material, hydrofluoric acid treatment was required (cf. Moore et al, 1991).

Then, in order to make a rough estimate of the appearance of Norway spruce in the peat core, and decide what levels in the peat core should be analysed, a number of peat samples were taken, diluted with water and mounted on microscope slides to identify the level where Norway spruce pollen become common. Then, 14 levels in the peat core were selected for proper pollen counting between 185 cm and 30 cm.

After preparation, the selected samples were stained (using a mix consisting of safranine and glycerine) and mounted on microscope slides. The slides were analysed for pollen grains and spores and about 500 pollen grains were counted in each sample. Pollen identification was carried out using the keys in Moore et al (1991) and Beug (2004), and also a reference pollen collection was available.

The percentage frequencies were calculated based on a total terrestrial pollen sum. The pollen diagram was constructed using the programs TILIA and TGview by Grimm (1991, 2004). The pollen diagram (Figure 3) includes the percentage of apophytes, which are any native plants growing on disturbed land and generally associated with human activities, here refers to Asteraceae, Poaceae, *Epilobium* type, *Cannabis* type, *Rumex acetosa, Rumex acetosella* and *Galium* type. But the principal indicator of human activities is the percentage of anthropochores, which is also included in the diagram because it refers to pollen grains from cultivated species (Cerealia type). The term QM ("*Quercetum mixtum*" or mixed-oak woods) includes a mix of a thermophilous trees, which are *Quercus, Tilia, Ulmus, Fraxinus, Carpinus, Juglans* and *Fagus*.

RESULTS

Peat stratigraphy and chronology

The first peat analysis by eye is performed to observe if wood remains are included in the sample that could indicate that trees have grown on the site. Three big portions of wood are found at the depths of 129 cm, 143 cm and 163 cm in the peat core. While the most superficial part of the peat core (until a depth of 15 cm) shows the lowest humification, the degree of humification is higher through the rest of the peat core. At the depth of 185 cm starts the mineral soil. The age of the bulk-peat sample at 60 cm depth is shown in table 1. The bulk-peat sample at 166 cm depth did not show enough organic material for the radiocarbon dating.

Table 1. Radiocarbon date from Stenhammaren.

Laboratory code	Depth (cm)	^{14}C age B.P.	Calibrated age ranges (cal. B.P.) at 2 σ
Ua-35991	60-61	2280±30	2150-2360

The chronology along the peat core has been estimated comparing with the migration pattern and establishment of *Picea abies* in other pollen diagrams in the nearby area, such Tönningfloarna (Lundqvist, 1969) and Styggtjärnen (Giesecke, 2005). The estimated relation between peat core depth (cm) and age (years before present) is shown in table 2.

Table 2. Estimated age in relation to the peat core depth.

Depth (cm)	Estimated age (yr B.P.)
0-80	Present-3000
80-165	3000-7000
165-185	7000-8000

Vegetation history at Stenhammaren, Härjedalen (central Sweden)

Based on the tree development that the percentage pollen diagram from Härjedalen shows (Figure 3), three main zones could be distinguished, in the following referred to as zones A, B and C.

- **Zone A: the *Alnus-Betula-Pinus-Populus-Corylus/Myrica* period, 185 cm – 165 cm, 8000 yr B.P.- 7000 yr B.P. (estimated dates).**

The most frequent tree pollen are from *Pinus* and *Betula* (which increase from 20% to 50%). There are also smaller proportions of *Alnus*, *Populus* and *Corylus/Myrica* pollen (the data do not allow for distinction between *Corylus* and *Myrica*), but they are decreasing at that moment. *Sorbus* has some relevance in terms of share of pollen in this period. *Ulmus* and *Quercus* pollen are also recorded. Pollen from the dwarf shrubs Ericaceae and *Calluna* are recorded of ca 1% each, but decrease at the end of the period. The most common herb pollen are from Poaceae, Cyperaceae, *Filipendula and Melampyrum.* Polypodiaceae spores are highly abundant. Spores from *Lycopodium* and *Equisetum* are also recorded.

- **Zone B: the *Alnus-Betula-Pinus* period, 165 cm – 80 cm, 7000 yr B.P.- 3000 yr B.P. (estimated dates).**

This is a period with high predominance of trees (about 90% of the terrestrial pollen during the period). *Pinus* is the main pollen recorded during the period, and shows an increasing trend, while in general the trend of *Betula* pollen is descendent. *Alnus* has still some relevance but the pollen signal is weaker than during the previous period. *Populus* and *Corylus/Myrica* pollen are also recorded but in a low share, although *Corylus/Myrica* pollen displays a peak at 115 cm depth. *Salix* and *Ulmus* pollen are regularly recorded and peak at 130 cm depth and 115 cm depth respectively (the latter coincides with a peak in QM percentage pollen). *Quercus, Tilia* and *Sorbus* pollen appear as scattered occurrences.

Stenhammaren

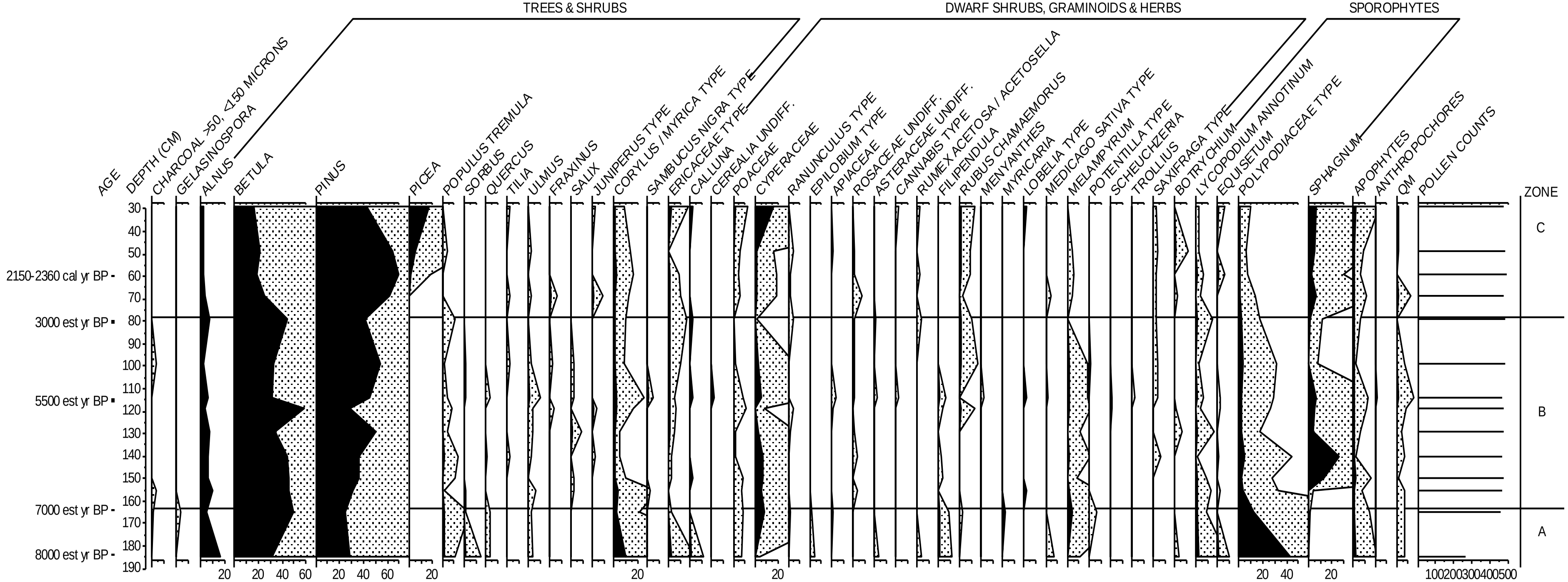

Figure 3. Percentage pollen diagram from Stenhammaren. From the left: age (both calibrated ^{14}C date with ranges at 2σ and estimated dates); depth scale in cm; percentage of individual pollen taxa and spore types; percentage sums of apophytes pollen, anthropochores pollen and QM pollen; sum of pollen count. The horizontal lines divide the pollen diagram into three main zones. The black fields represent the percentage of each pollen type, and the grey fields represent a X10 exaggeration of the percentage values. Only the pollen types important for the discussion are shown, while other pollen types occurring in low frequencies have been omitted from the diagram.

The most common dwarf shrub pollen is still from Ericaceae with increasing shares. At 115 cm depth various herb pollen appear as scattered occurrences: *Lobelia* type, *Medicago sativa* type, *Trollius*, *Menyanthes,* Cerealia, Apiaceae, Asteraceae and *Cannabis* type (some of them only on this level). Some of the species that appear at this level are associated with humans like Cerealia type and the shrub *Sambucus nigra* (see discussion); which imply a peak in the percentage of apophytes and anthropochores. Also at this level *Filipendula* appearance stops while *Rubus chamaemorus* pollen starts to appear. There are some charcoal particles recorded at 100 cm depth.

There are charcoal particles and *Gelasinospora* spores at 155 cm depth. Further, Polypodiaceae spores decrease and S*phagnum* spores are recorded with high shares at the beginning of this period.

- **Zone C: the *Betula-Pinus-Picea* period, 80 cm – 30 cm, 3000 yr B.P.-present (estimated dates).**

The beginning of this period is marked by the gradual decrease of the share of *Betula* pollen to about 15%. First, *Pinus* pollen becomes more important, increasing from 40% to 70%, but from 55 cm depth *Pinus* pollen decrease. The first *Picea abies* pollen first appears at c. 2250 ± 100 cal yr B.P. (about 60 cm depth) and it gradually becomes more important. *Alnus* pollen is also recorded but in a low share and *Populus* pollen is recorded only sporadic.

Although *Melampyrum* pollen is regularly recorded through most of the study period, there is a marked decrease in its pollen proportion at the beginning of this period. Cyperaceae pollen shows a peak at the end of the period.

DISCUSSION

Vegetation history at Stenhammaren, Härjedalen (central Sweden)

Mire development

The first stage of the peat land development showed fen conditions, as indicated the predominance of Polypodiacea, and then transformed to *Sphagnum* mire conditions 7000 years ago (estimated date). Lundqvist (1969) suggested that the paludification in the area is relatively old, dating from the deglaciation to about 5000 B.C. The decrease in Polypodiaceae, while Ericaceae dwarf shrubs became more important on the mire, also indicates a decrease in humidity. Finally, at 115 cm depth *Rubus chamaemorus* appeared which indicates late succession stage on the mire.

Forest development

In general, the study site showed a forested landscape with a very low representation of herb or shrub pollen after 8000 yr B.P. (estimated date).This is supported by the finds of macroscopic wood remains at 129 cm, 143 cm and

163 cm. depth that also indicate a forest cover on the mire. The forest surrounding the mire consisted principally of *Alnus, Betula* and *Pinus* from 8000 yr B.P. (estimated date) until the first appearance of *Picea abies* in the zone c. 2250 ± 100 cal yr B.P. (about 60 cm depth). After that, *Picea abies* gradually became more important while *Pinus* and *Betula* became less frequent. *Alnus* pollen was regularly recorded from the first sample onwards with a gradually decreasing share. *Alnus* grew along the wet areas around the mire and the small streams. Furthermore, *Corylus/Myrica* pollen shows the same trend as *Alnus* in the pollen graph. Such a trend in *Alnus* pollen record, as well as in *Corylus* pollen record, is also found in the nearby Tönningfloarna (Lundqvist, 1969) and Styggtjärnen (Giesecke, 2005), located ca 38 km north-west of Tönningfloarna, suggesting that *Alnus* and *Corylus* populations were present in the area throughout the whole period represented by the diagram. Moreover, Giesecke (2005) pointed out an early-Holocene maximum extension of *Corylus avellana* and *Alnus glutinosa* distribution in central Sweden, and a later decline. The presence of *Alnus* may indicate prevailing wet conditions, and a decrease in humidity with the decline in *Alnus* pollen (Bergman, 2005).

The absence of *Populus* in the Tönningfloarna pollen graph (Lundqvist, 1969), and the smaller *Populus* percentage in Styggtjärnen (Giesecke, 2005) compared with Stenhammaren pollen graph, could be interpreted as a small local stand or scattered trees surrounding the mire. The maximum of *Populus* was achieved between 8000 and 7000 years ago (estimated dates), when also charred particles suggested there was possibly local fires. Coinciding with the appearance of *Picea abies* the growth of *Populus* in the site stopped.

Since *Quercus* pollen production is relatively high and well dispersed (Sugita et al, 1999), the scattered pollen occurrences in the graph might be interpreted as long distant transport pollen; this is also discussed by Giesecke (2005) who found the same pattern in Styggtjärnen. The pollen signal from *Fraxinus* and *Tilia* are also interpreted as long distance transport pollen because the records are very week, similar to the results by Lundqvist (1969) and Giesecke (2005). *Tilia* shows a low pollen production (Sugita et al, 1999), thus, Giesecke (2005) suggested that *Tilia* was probably not a common tree in the region.

Lundqvist (1969) referred to a climatic amelioration at 6000-5000 B.C. that caused an increase of the thermophilous trees with more *Betula* and some invasion of *Corylus* and *Ulmus*. This warmer period is also reflected in the older half of the diagram, where *Quercus*, *Ulmus* and *Corylus/Myrica* are regularly recorded. *Ulmus* shows also a weak pollen signal between 7000 and 3000 yr B.P. (estimated ages), but it is interpreted as scattered trees in the surrounding area because the signal is continuous and because the warmer climate conditions after 7000 yr B.P. (estimated date) could allow the establishment of *Ulmus* (Andersson, 2008). The importance of thermophilous trees during the early-Holocene is mentioned by Giesecke (2005). This is also reflected in Stenhammaren with a peak in QM percentage pollen at 115 cm depth (ca 5500 years ago estimated date), it implies an increase in thermophilous trees or a thinning of the tree canopy due to a disturbance that allowed for more QM pollen to be visible in the percentage diagram. The decrease of *Ulmus* reflected the end of the warm period about 3000 yr B.P. (estimated age).

The general low proportions of herbs are mostly interpreted as natural openings caused by wind, grazing animals and wetlands. However, coinciding with this warming of the climate during the Holocene, which maximum is reached between 7000 and 5000 years ago (Cox & Moore, 2000); lots of new herbs appeared at 115 cm depth (ca 5500 years ago estimated date), some of them only appearing in the diagram during this period of time.

At 155 cm depth charred particles and *Gelasinospora* indicate that there was a fire. Other charred particles are recorded at 100 cm depth. These two levels with charcoal particles suggested that the area experienced forest fire from time to time, and one such fire could have been responsible of changes in vegetation, such as the appearance of lots of new herbs (see above) ca 5500 yr B.P. (estimated date)

Human impact?

The warmer climate conditions could, besides stimulating changes in the vegetation, also have promoted the appearance of humans in the region. From archaeological studies it is known that humans have been present in the region since bronze-age (Engelmark, 1978). They were hunters and gatherers that colonized the land in pace with the melting ice after the last glacial time. In the present study, pollen from plants associated with humans like *Sambucus nigra* and Cerealia (increasing the signal of apophytes and anthropochores in the graph) were recorded at 115 cm depth (ca 5500 years ago estimated date). Evidence of cereal cultivation has appeared already ca 2700 B.C. in Rudetjärn, at the cost of central Sweden (Engelmark, 1978). Engelmark (1978) concluded that the evidence for Neolithic agriculture was too imperfect to say how the land was used. Hence, here the interpretation of the early appearance of humans was rejected since the find is only a single cereal pollen grain and no other studies could support the hypothesis. The changes in the Stenhammaren pollen diagram at this time were interpreted as an effect of natural disturbance rather than human activity.

The *Picea abies* dilemma

One of the questions was whether *Picea abies* has been growing at Stenhammaren as early as suggested by Lundqvist (1969). This was not elucidated in the present study because no early signal of *Picea abies* pollen has been found and the first spruce pollen occurrence happen c. 2250 ± 100 cal yr B.P. Nevertheless, since Stenhammaren mire is smaller than Tönningfloarna which is a vast mire (Lundqvist, 1969), it is more likely that this study reflects a local pollen production and cannot show the regional pollen signal. The early scattered occurrences of *Picea abies* pollen in Tönningfloarna (Lundqvist, 1969) could be interpreted as local stands only since no *Picea abies* pollen were recorded in Stenhammaren. Furthermore, *Picea abies* pollen dispersal is smaller than pollen dispersal from other trees and shrubs in the boreal region (Hicks, 2001; Broström, 2002; Segerström & von Stedingk, 2003).

Hicks (2006) discusss in her study: "When no pollen does not mean no trees", that the situation mentioned in her title is possible where only a few and widely scattered trees are present in the landscape. Scattered single trees and small stands of *Picea abies* are precisely the types of landscapes proposed by Kullman (2000) throughout the early- and mid-Holocene in Sweden.

Although pollen analysis is a good tool for reconstructing the past vegetation and vegetation changes at a site, there are some improvements in my study which could help to find the possible early *Picea abies* pollen appearance. For instance, a counting strategy with denser sample interval could have enhanced the chance to identify temporal occurrences of low shares of *Picea abies*.

CONCLUSIONS

- No early *Picea abies* pollen has been found, but it does not necessarily mean that there were not *Picea abies* trees near the site in the early-Holocene. The different pattern in *Picea abies* pollen curve between Stenhammaren and Tönningfloarna (Lundqvist, 1969) could indicate local *Picea abies* populations at Tönningfloarna.

- Weak evidence of anthropogenic pollen can previously be interpreted as possible human impact, but further evidence is needed. To elucidate the Human past activities into an area is required a multi-proxy investigation, it includes other disciplines of science different from Palaeoecology, such as History and Archaeology.

FUTURE STUDIES

- For a better understanding of species establishment, several peat cores in the same area in similar sites should be taken and analysed for pollen, then compared and discussed. Also, comparison between already published pollen graphs from nearby zones is helpful.

- *Picea abies* is able to regenerate by layering, which could imply a less pollen production and a weak pollen signal in peat cores. It could be interesting to carry out a study with pollen traps in an area where *Picea abies* mainly regenerates by layering. Then compare that pollen production with the production in an area where Norway spruce mainly regenerates by sexual reproduction. This could be even more interesting since Leif Kullman have found the oldest tree in the world in Sweden. This *Picea abies* individual has a root system which has been growing for 9,550 years due to its ability of reproducing by layering and therefore form clones (Owen, 2008).

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APPENDIX:

"HISTORIA DE LA VEGETACIÓN Y ESTABLECIMIENTO DE *Picea abies* (L.) Karst. EN LA PROVINCIA DE HÄRJEDALEN (CENTRO DE SUECIA)"

1. INTRODUCCIÓN

Hace aproximadamente 3500 años, *Picea abies* (L.) Karst. llegó a la costa Botnia de Suecia desde Finlandia, haciéndose competitivo y dominante allí, para después propagarse hacia oeste y sur (Huntley & Birks, 1983). Esta ha sido la teoría tradicional de la llegada y establecimiento de *Picea abies* en Suecia (basada en análisis de polen) hasta que fueron encontrados por Kullman (1995, 1996, 2000, 2002) megafósiles de *Picea abies* datados en el Holoceno temprano. En conjunto, 76 subfósiles fueron recuperados y datados por radiocarbono entre el final de la última glaciación y el medio Holoceno. Estos hallazgos entran en conflicto con el inicial y generalizado modelo de migración de *Picea abies* en Suecia. Además, los nuevos descubrimientos demuestran que *Picea abies* ha estado presente en Suecia desde hace alrededor de 11000 años (Kullman, 2000). Antes de estos hallazgos, los registros polínicos de *Picea abies* en el medio y temprano Holoceno, en diagramas de polen previos, fueron consideradas como el resultado de transporte de larga distancia desde bosques lejanos. Un lugar con alta proporción de polen en el Holoceno temprano y medio es Tönningfloarna, en el centro de Suecia (Lundqvist, 1969). En vista de los descubrimientos de Kullman, estos registros tempranos de polen en Tönningfloarna pueden ser ahora interpretados como posiciones tempranas de *Picea abies* (Giesecke & Bennett, 2004). Pero estos registros polínicos no son normalmente interpretados como presencia local excepto por el estudio llevado a cabo por Segerström y von Stedingk (2003). Polen de *Picea abies* fue registrado y datado 9000 años atrás en el área donde habían sido encontrados macrofósiles de *Picea abies* por Kullman (2000), mostrando que proporciones bajas de polen pueden ser interpretadas como presencia local bajo ciertas circunstancias.

2. OBJETIVOS

El objetivo general de este proyecto es reconstruir el desarrollo de la vegetación durante el Holoceno en el centro de Suecia. El objetivo puede ser alcanzado mediante un estudio polínico. Es la técnica más ampliamente empleada en la reconstrucción de entornos Cuaternarios (Lowe & Walker, 1997) desde que Lennart von Post presentara en 1916 el primer diagrama moderno de porcentajes de polen, marcando la fundación de lo que actualmente es conocido como Palinología (Manten, 1967).

El objetivo específico es examinar los registros tempranos de polen de *Picea abies* hallados por Lundqvist (1969). Para ello el estudio se ha llevado a cabo en Stenhammaren, una turbera situada a pocos kilómetros de Tönningfloarna, el lugar estudiado por Lundqvist (1969) con alta proporción de polen de *Picea abies* ya 7000 años atrás.

3. MATERIAL Y MÉTODOS

Lugar de estudio

El lugar de estudio, Stenhammaren, es una pequeña turbera (5000 m^2) a 600 m sobre el nivel del mar. Se sitúa a aproximadamente a 10 km de Tönningfloarna y 25 km al norte de Sveg (62º14´N, 14º16´E), en la provincia de Härjedalen, centro de Suecia (“Figure 1” y “Figure 2” en el texto). Allí se toma la muestra de turba de 195 cm de longitud para análisis de polen.

Datación por radiocarbono

Para crear la cronología a lo largo de la muestra de turba tomada, se cortan dos volúmenes de turba a 60 cm y 166 cm de profundidad para se datadas por el método de ^{14}C. El análisis de radiocarbono se lleva a cabo en el laboratorio Ångström de la Universidad de Uppsala (Suecia).

Análisis de polen

Se cortan 30 submuestras de 1 cm de la muestra inicial de turba tomada en Stenhammaren, y se digieren en hidróxido de potasio al 5% durante una noche. La solución obtenida se cuela y el remanente se trata mediante acetolisis de acuerdo con métodos estándar (Moore et al, 1991). En la parte más profunda de la muestra de turba también se requiere el tratamiento con ácido hidrofluorídrico según Moore et al (1991) ya que contiene cantidades elevadas de material mineral.

De las submuestras tratadas se seleccionan 14 entre los niveles de 30 cm y 185 cm, se tiñen con una mezcla de safranina y glicerina y se montan en placas de vidrio para el análisis de granos de polen y esporas. Alrededor de 500 granos de polen se cuentan en cada nivel seleccionado. La identificación de los granos de polen se lleva a cabo usando las guías Moore et al (1991) y Beug (2004), también se dispone de una colección de polen de referencia. Las frecuencias de los porcentajes se calculan en base a la suma total de polen terrestre y el diagrama de polen se construye usando los programas TILIA TGview de Grimm (1991, 2004).

4. RESULTADOS

Estratigrafía de la muestra de turba y cronología

Mediante el análisis visual de la muestra inicial de turba, se encuentran tres porciones de madera a las profundidades: 129 cm, 143 cm y 163 cm lo que podría indicar que han estado creciendo árboles sobre la turbera. La parte más superficial de la muestra (hasta los 15 cm) manifiesta la menor humificación mientras que el grado de humificación se incrementa con la profundidad. A la profundidad de 185 cm comienza el suelo mineral.

La edad del trozo de turba tomado a los 60 cm y datada por el método de ^{14}C se muestra en la tabla 3. El pedazo de turba tomado a los 166 cm no mostraba suficiente material orgánico para la datación por radiocarbono.

Tabla 3. Fecha datada por radiocarbono en Stenhammaren.

Código del laboratorio	Profundidad (cm)	Edad ^{14}C A.P.	Rangos de edad calibrada (cal. A.P.) a 2 σ
Ua-35991	60-61	2280±30	2150-2360

La cronología a lo largo de la muestra de turba inicial se ha estimado comparando con el patrón de migración y establecimiento de *Picea abies* en otros diagramas de polen de zonas cercanas, tales como Tönningfloarna (Lundqvist, 1969) y Styggtjärnen (Giesecke, 2005). La relación estimada entre la profundidad (cm) de la muestra de turba inicial y la edad (años antes del presente) se observa en la tabla 4.

Tabla 4. Edad estimada en relación a la profundidad de la muestra de turba.

Profundidad (cm)	Edad estimada (años A.P.)
0-80	Presente-3000
80-165	3000-7000
165-185	7000-8000

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El diagrama de porcentaje de polen de Stenhammaren se muestra en la “Figure 3“ del texto. En el eje vertical de izquierda a derecha se pueden leer: edad (tanto la fecha datada por ^{14}C y calibrada con rangos del 2σ como las fechas estimadas); la profundidad en cm; los porcentajes individuales en la tasa de polen y en los tipos de esporas; la suma de los porcentajes de apofitas, polen de antropocores y polen de QM. Apofitas son cualquier planta creciendo en áreas perturbadas y generalmente asociadas con actividades humanas. Pero el principal indicador de actividades humanas es el porcentaje de antropocores, ya que se refiere a granos de polen de especies cultivadas. El término QM (“*Quercetum mixtum*”) incluye la suma de los porcentajes d epolen de un mix de árboles termófilos, que son *Quercus, Tilia, Ulmus, Fraxinus, Carpinus,* *Juglans* y *Fagus*. Los campos en negro representan el porcentaje de cada tipo de polen, mientras que los campos en gris representan la exageración x10 de esos valores. Sólo se muestran los tipos de polen y esporas importantes para la discusión, mientras que otros con bajas frecuencias se han omitido en el diagrama.

Las líneas horizontales dividen el diagrama de polen en tres zonas principales. Esta división se ha basado en el desarrollo del polen de los árboles que el diagrama de Stenhammaren muestra. Éstas son:

- Zona A: El período de *Alnus-Betula-Pinus-Populus-Corylus/Myrica*, 185 cm – 165 cm, 8000 años A.P. - 7000 años A.P. (fechas estimadas).
- Zona B: El período de *Alnus-Betula-Pinus*, 165 cm – 80 cm, 7000 años A.P. - 3000 años A.P. (fechas estimadas).
- Zona C: El período de *Betula-Pinus-Picea*, 80 cm – 30 cm, 3000 años A.P.- presente (fechas estimadas).

5. DISCUSIÓN

Historia de la vegetación en Stenhammaren, Härjedalen (centro de Suecia)

En general la zona de estudio muestra en paisaje arbolado con una baja representación de hierbas y arbustos después de los 8000 años A.P. (fecha estimada). Esta hipótesis es apoyada por los restos de madera hallados a los 129 cm, 143 cm y 163 cm de profundidad. El bosque que rodea la turbera consta principalmente de *Alnus, Betula* y *Pinus* a partir de los 8000 años A.P. (fecha estimada) hasta la primera aparición de *Picea abies* en la zona, 2250 ± 100 años cal A.P. (alrededor de los 60 cm de profundidad). Después *Picea abies* se vuelve más importante gradualmente mientras que *Pinus* y *Betula* se vuelven menos frecuentes. El polen de *Alnus* es regularmente registrado desde la primera muestra con una tasa gradualmente descendente. Además el polen de *Corylus/Myrica* (los datos no permiten la distinción entre *Corylus* y *Myrica*) muestra la misma tendencia que *Alnus* en el diagrama de polen. Tal tendencia en el registro polínico de *Alnus*, además de en el de *Corylus*, también se encuentra en la cercana Tönningfloarna (Lundqvist, 1969) y Styggtjärnen (Giesecke, 2005), localizada a aproximadamente 38 km nor-oeste de Tönningfloarna, sugieren que las poblaciones de *Alnus* y *Corylus* estuvieron presentes en la zona a lo largo de todo el periodo representado en el diagrama. Además, Giesecke (2005) señala la extensión máxima de *Corylus avellana* y *Alnus glutinosa* en el Holoceno temprano para declinar después. La presencia de *Alnus* podría indicar la prevalencia de condiciones húmedas y un descenso de humedad con el descenso del polen de *Alnus* (Bergman, 2005).

La ausencia de *Populus* en el diagrama de Tönningfloarna (Lundqvist, 1969), y el pequeño porcentaje en Styggtjärnen (Giesecke, 2005) comparado con Stenhammaren, podría ser interpretado como pequeñas poblaciones locales o árboles aislados en el área circundante a la turbera. Coincidiendo con la aparición de *Picea abies,* cesa el crecimiento de *Populus* en la zona.

Puesto que la producción de polen por parte de *Quercus* pollen es relativamente alta y bien dispersa (Sugita et al, 1999), los registros aislados en el diagrama se interpretan como polen transportado desde larga distancia; esto es también discutido por Giesecke (2005), quien encontró el mismo patrón en Styggtjärnen. La señal polínica de *Fraxinus* y *Tilia* es también interpretada como polen transportado desde larga distancia ya que los registros son muy débiles, lo cual es similar a los resultados encontrados por Lundqvist (1969) y Giesecke (2005). *Tilia* muestra una baja producción de polen (Sugita et al, 1999) por lo que Giesecke (2005) sugirió que *Tilia* no era probablemente un árbol común en la región.

Lundqvist (1969) hace referencia a una mejora en el clima 6000-5000 años A.C. que causó un incremento en las poblaciones de árboles termófilos, con más *Betula* y algo de invasión de *Corylus* y *Ulmus*. Este periodo más cálido se refleja también el la parte inferior del diagrama, donde *Quercus*, *Ulmus* y *Corylus/Myrica* son registrados regularmente. *Ulmus* muestra una señal polínica débil pero continua entre 7000 y 3000 años A.P. (fechas estimadas), por lo que es interpretado como árboles aislados creciendo en zonas circundantes ya que la señal es continua y las condiciones climáticas más cálidas hace 7000 años (fecha estimada) pudieron permitir el establecimiento de *Ulmus* (Andersson, 2008). La importancia de los árboles termófilos durante el Holoceno temprano es mencionada también por Giesecke (2005). En el diagrama de Stenhammaren se refleja con un pico en el porcentaje de pollen de QM a 115 cm de profundidad (ha ce aproximadamente 5500 años, fecha estimada), lo que implica un incremento en la población de árboles termófilos o un clareo en la cubierta vegetal debido a alguna alteración que permitiese al polen de QM ser más visible en el diagrama de polen. El descenso en *Ulmus* refleja el final del periodo templado hace aproximadamente 3000 años (fecha estimada).

Las generalmente bajas proporciones de especies herbáceas son interpretadas mayormente como aperturas naturales. Sin embargo, coincidiendo con el calentamiento durante el Holoceno, cuyo máximo es alcanzado hace entre 7000 y 5000 años Cox & Moore, 2000); muchas nuevas especies herbáceas aparecen a 115 cm de profundidad (aprox. 5500 años B.P., fecha estimada), algunas de ellas sólo durante este periodo de tiempo.

A 155 cm de profundidad, las partículas quemadas y *Gelasinospora* indican que en el lugar hubo un fuego. Otras partículas quemadas son registradas a 100 cm de profundidad. Estos hallazgos sugieren que el área experimentó fuego de tiempo en tiempo, y uno de ellos pudo haber sido el responsable de cambios en la vegetación, tal como la aparición de muchas nuevas especies herbáceas aproximadamente 5500 (fecha estimada).

¿Impacto humano?

Las condiciones climáticas más cálidas, además de estimular cambios en la vegetación, pudieron promover la aparición de humanos en la región. Gracias a estudios arcaeoecológicos se sabe que hubo humanos en la zona desde la edad de bronce (Engelmark, 1978). En el presente estudio se ha encontrado polen procedente de especies asociadas a humanos como *Sambucus nigra* y Cerealia a 115 cm de profundidad (5500 años A.P., edad estimada). Han aparecido evidencias de cultivos de cereal ya alrededor de 2700 A.C. en Rudetjärn, en la costa del centro de Suecia (Engelmark, 1978). Engelmark (1978) concluyó que la evidencia de cultivo en el Neolítico era muy imperfecta para decir cómo se usó la tierra. Por lo tanto, la interpretación aquí acerca de la aparición temprana de humanos en la zona es finalmente rechazada, ya que sólo se ha registrado un único polen de cereal y no hay otros estudios que apoyen la hipótesis. Los cambios en el diagrama de polen de Stenhammaren en este tiempo son interpretados como alteración natural más que actividad humana.

El dilema de *Picea abies*

Una de las preguntas era si *Picea abies* ha estado creciendo en Stenhammaren tan temprano como sugiere Lundqvist (1969). La pregunta no es solucionada ya que no se registra ninguna señal temprana de polen de *Picea abies*, el primer registro aparece 2250 ± 100 años cal A.P. Sin embargo, Stenhammaren es una turbera más pequeña que Tönningfloarna, la cual es muy amplia (Lundqvist, 1969), por lo tanto el presente estudio refleja producción local de polen y no puede mostrar el registro regional. Los registros dispersos que el polen de *Picea abies* muestra en Tönningfloarna (Lundqvist, 1969) podrían ser interpretados como poblaciones locales. Además, la dispersión del polen de *Picea abies* es menor que en otras hierbas y árboles en las regiones boreales (Hicks, 2001; Broström, 2002; Segerström & von Stedingk, 2003).

Hicks (2006) demuestra en su estudio: "When no pollen does not mean no trees", que esta situación es posible cuando encontramos pocos árboles y muy dispersos en el paisaje. Individuos esparcidos y pequeñas poblaciones de *Picea abies* son precisamente los paisajes propuestos por Kullman (2000) para *Picea abies* durante todo el Holoceno temprano y medio en Suecia.

6. CONCLUSIONES

- No se ha encontrado polen de *Picea abies* temprano, pero eso no significa necesariamente que no hubiese árboles de *Picea abies* cerca del lugar de estudio en el Holoceno temprano. El patrón diferente en el registro de polen de *Picea abies* entre Stenhammaren y Tönningfloarna (Lundqvist, 1969), podría indicar poblaciones locales de *Picea abies* en Tönningfloarna.

- Evidencias débiles de polen antropogénico podría ser interpretado previamente como un posible impacto humano, pero son necesarias más evidencias. Para elucidar el pasado de las actividades de los Humanos en una zona, se requiere una investigación que incluya otras disciplinas de la ciencia además de la Palaeoecología, como la Historia y la Arqueología.

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