

A palaeoecological study of the establishment of beech forest in Söderåsen National Park, southern Sweden

Maja Damber

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Cover Picture: Lake Odensjön. Photograph by: Maja Damber

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MAJA DAMBER

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Abstract: This study focuses on a sediment sequence retrieved from Lake Odensjön, positioned within Söderåsen National Park in Scania, southern Sweden. The investigated sequence, covering the uppermost 86 cm of sediments, is unique due to its very distinct annual varves, which have allowed for precise dating (Hertzman in prep.). In addition, the large amount of well-preserved *Fagus sylvatica* leaves visible in the sediments younger than ca. 1930 CE suggesting that a major vegetational change occurred in the lake surroundings around this time. With an already constrained chronology, the sediment sequence was investigated based on its palaeoecological record (pollen and plant macrofossils). The aim was to decipher how the forest composition and openness have changed in the lake surroundings from 1500 CE, with a focus on the development from 1930 CE., and investigate how such changes may be connected to shifts in land usage, as well as other landscape changing factors, in the surrounding area. A dendrochronological study was also carried out to further determine the establishment of the local *Fagus* population present around Lake Odensjön. Map material and photographs were used in combination with the palaeobotanical methods to help facilitate the interpretation of the forest composition and openness. The collected data suggests that an initial decline of *Fagus* forests occurred in the mid-16th century, due to a combination of factors such as over-exploitation, over-grazing, and implementation of land reforms. The studied area is believed to have reached its most open stage during the mid-18th to mid-19th century, indicated by sparse macrofossil and pollen records of tree taxa along with high pollen percentages of *Juniperus* and herbs and graminids. During the second half of the 19th century, the forest is believed to have grown denser, indicated by an increase in tree taxa in the macrofossil and pollen records, in particularly *Fagus*, and a decrease in shrubs, herbs and graminids. The shift towards a denser forest is believed to be due to a change in human activity, in particular decreased grazing. The dendrochronological data suggests that the local *Fagus* population growing around Lake Odensjön today was established after 1860 CE. The palaeobotanical data suggests that the culmination of the shift from a more open landscape, to a denser forest, did not necessarily date back to exactly 1930 CE, as indicated by the abrupt increase in leaves visible in the core, but rather occurred in the beginning of the 20th century, whereafter the forest continued to expand until the mid-20th century.

Keywords: Odensjön, southern Sweden, palaeoecology, pollen, macrofossils, lake sediments, *Fagus sylvatica*

Supervisor(s): Mats Rundgren, Dan Hammarlund

Subject: Quaternary Geology

Maja Damber, Department of Geology, Lund University, Sölvegatan 12, SE-223 62 Lund, Sweden. E-mail: majadamber@hotmail.com

En paleoekologisk studie över etableringen av bokskog i Söderåsens nationalpark, södra Sverige

MAJA DAMBER

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Sammanfattning: Denna studie fokuserar på en sedimentsekvens som hämtats från Odensjön, i Söderåsens nationalpark i Skåne, södra Sverige. Den undersökta sekvensen, som täcker de översta 86 cm av sedimenten, är unik på grund av dess väldigt tydliga årsvarv, som har möjliggjort en precis datering (Hertzman in prep.). Tilläggsvis, den stora mängden välbevarade *Fagus sylvatica*-blad synliga i sedimenten yngre än cirka 1930 v.t., tyder på att en stor vegetationsförändring inträffade i sjöns omgivning omkring denna tid. Med en redan definierad kronologi undersöktes sedimentsekvensen utifrån dess paleoekologiska arkiv (pollen och plantmakrofossil). Målet var att uttyda hur skogssammansättningen och öppenheten har förändrats i sjöns omgivning från 1500 v.t., med fokus på utvecklingen från 1930 v.t., och undersöka hur sådana förändringar kan vara kopplade till förändringar i markanvändning, liksom andra faktorer som förändrat landskapet, i det omgivande området. En dendrokronologisk studie utfördes även för att ytterligare fastställa etableringen av den lokala *Fagus*-populationen som finns runt Odensjön. Kartmaterial och fotografier användes i kombination med de paleobotaniska metoderna för att underlätta tolkningen av skogens sammansättning och öppenhet. De insamlade data antyder att en initial nedgång av bokskog inträffade i mitten av 1500-talet på grund av en kombination av faktorer som överexploatering, överbetning samt genomförande av markreformer. Det studerade området tros nå sitt mest öppna stadium under mitten av 1700- till mitten av 1800-talet, vilket indikeras av låga värden på träd taxa i pollen- och makrofossilarkiven, tillsammans med höga pollenprocentandelar av *Juniperus*, örter och graminider. Under andra hälften av 1800-talet antas skogen växa tätare, vilket indikeras av en ökning av träd taxa-värden i pollen- och makrofossilarkiven, i synnerhet *Fagus*, och en minskning av *Juniperus*, örter och graminider. Övergången till en tätare skog antas bero på en förändring i mänsklig aktivitet, särskilt minskat bete. De dendrokronologiska uppgifterna tyder på att den lokala *Fagus*-populationen som växer runt Odensjön idag etablerade sig efter 1860 v.t. De paleobotaniska data antyder att kulmen av övergången från ett mer öppet landskap till en tätare skog inte nödvändigtvis går tillbaka till exakt 1930 v.t., utan inträffade i början av 1900-talet följt av en fortsatt expansion av skogen till mitten av 1900-talet.

Nyckelord: Odensjön, södra Sverige, paleoekologi, pollen, makrofossil, sjösediment, *Fagus sylvatica*

Handledare: Mats Rundgren, Dan Hammarlund

Ämnesinriktning: Kwartärgeologi

Maja Damber, Geologiska institutionen, Lunds Universitet, Sölvegatan 12, 223 62 Lund, Sverige. E-post: majadamber@hotmail.com

1 Introduction

The study of past ecological and environmental changes is central for understanding the dynamics of contemporary ecological systems. Not only do records of past environmental changes enable an understanding of how ecosystems have been changing, but also how past anthropogenic disturbances have been influencing these changes (Willis & Birks 2006). Sediments found in lake basins constitute one of the most prominent records for studying past environmental changes during the Quaternary (Sadori et al. 2016). Lake sediments originate from the organic production occurring within the lake ecosystem, along with inwash of material from the lake catchment area, being of both organic and inorganic origin (Cohen 2003). Pollen grains, spores, and macrofossils provide some of the most important biological evidence preserved in the sedimentary record of lake basins. This fossil flora and fauna can provide indications on both the local and the regional ecological changes of the area surrounding the studied lake, including changes in vegetation composition, reflecting both natural and anthropogenic processes (Bradshaw 2008).

The present study explores the palaeobotanical record of the uppermost sediment preserved in Lake Odensjön, positioned within Söderåsen National Park in Scania, southern Sweden. The Söderåsen horst ridge is famous for its deciduous forests, including beech, oak, ash, as well as its exciting geology. Lake Odensjön has a diameter of 150 m and a maximum depth of 19.9 m, and the lake is surrounded by steep talus slopes reaching up to 100 m asl. The formation history of lake Odensjön has been thoroughly debated, but as of date, the theory of Berglund & Rapp (1988) stating that the lake originate as an over deepened cirque basin, is considered the most credible. From previous studies, map material and literature (e.g. Persson 1971; Brunet 1995; Wallerman 1995), we know that the landscape in Scania would see a lot of drastic changes following the 16th century. The ownership of forests consisting of beech and oak would change from being in the hands of the state to being in the hands of the individual farmers. Landscape reforms would take place, dividing villages as well as changing the configuration of what the fields, meadows and forests would look like. The lack of forest regulations along with extensive grazing, increased trade and industry, as well as a growing population, would altogether play a part of impoverishing the forests growing in the area. A new chapter would open up with a regrowth of the forest in the light of agricultural innovations, including soil improving agents followed by the introduction of commercial fertilizer, and forest regulations being established.

A 91 cm long sediment sequence was extracted with a freeze corer from Lake Odensjön in January 2016. Sediments from one side of the freeze corer were later studied by Hertzman (in prep.) with a focus on the distinct varves, the chronology of the sequence and the geochemistry. The chronology was constructed based on lamina counting in combination with ²¹⁰Pb and ¹⁴C dating. The uppermost 33 cm of the core were dated with ²¹⁰Pb, and macrofossils from the depths of 687, 760 and 885 mm respectively, were used for ¹⁴C dating. According to Hertzman (in prep.), the 91 cm

long sequence covers the period from the 16th century onwards. With an already constrained chronology, sediments from another side of the freeze corer were used for the present study. The sediments from Lake Odensjön have not yet been described in detail based on their pollen and macrofossil content, and not many other extensive palaeoecological studies focusing on the period from the 16th century onwards have been carried out in the close vicinity. Some previous palaeoecological studies include Berglund & Rapp (1988), who conducted a pollen study of Lake Odensjön with cores extracted in 1984, but their work is focused solely on the Late Weichselian development. Göransson (2000) conducted a pollen study on sediments from the ponds Härsnärsdammarna (ca. 2.3 km NW of Lake Odensjön), and Bergman (2000) conducted a pollen study at the peat sites of Höja (ca. 3.1 km NW of Lake Odensjön) and Skärålid (ca. 3.7 km NW of Lake Odensjön). Although these studies provide an interesting insight into the vegetational development of the area close to Lake Odensjön, the timespan they cover is far longer and in turn the resolution is lower, which means that they provide limited information of what was really happening in the landscape during the recent centuries. Hopefully, by conducting a high-resolution palaeoecological study on the already available recent sediment from Lake Odensjön, new light will be shed on the ecological evolution, in particular with regard to the change in forest cover in these parts of Scania, as well as how these changes were impacted by the anthropogenic activities occurring during this time.

1.1 Aim of study

As described by Hertzman (in prep.), the uppermost sediments of the freeze core from Lake Odensjön deposited since around 1930 CE contains a very large amount of well-preserved *Fagus sylvatica* leaves. This suggests that a major vegetational change occurred in the lake surroundings as recently as a century ago, that should be possible to detect and explore in great detail with palaeobotanical methods. Accordingly, this study aims to establish how the forest composition and openness have changed in the proximity of Lake Odensjön from 1500 CE, with a focus on the development around 1930 CE, and investigate how such changes may be connected to the shift in land usage, as well as other landscape changing factors, in the surrounding area.

By developing a pollen stratigraphy in combination with a plant macrofossil stratigraphy for the already dated sediment sequence from Lake Odensjön, the project aims to assess which tree species were present in the lake surrounding, and how open/dense their forest cover was, back to 1500 CE. These two palaeoecological analyses are accompanied by a dendrochronological study, which aims to further determine the establishment of the local beech population present around Lake Odensjön today.

Research questions addressed in this study are:

- Are there any indications of significant changes in the tree species assemblage around 1930 CE, and how are these expressed in the pollen and

macrofossil data?

- Did the density of the forest change around 1930 CE?
- At what time did the forest reach its maximum openness, and how is that expressed in the pollen and macrofossil data?
- Are there any indications of changes in species composition of the forest as well as forest openness from 1930 CE to present?
- Is it possible to attribute changes in the forest assemblage around 1930 CE to human activity in the area during the preceding decades to centuries, specifically changes in land usage?

2 Background

2.1 Forest history in southern Sweden during the last millennia with a focus on *Fagus* forest development

From the period since the last glacial ended ca. 11700 cal BP, *Fagus* migration would initially be restricted to Italy and the Balkans (Huntley et al. 1989) (Fig. 1). Migration would later occur from these areas in a northwards and north-westwards direction at varying rates. Huntley et al. (1989) propose that the primary factor behind the Holocene migration of *Fagus sylvatica* is climatic change. The early-Holocene climates were strongly seasonal, compared to present climate (Bartlein et al. 1986). This would have favoured taxa such as *Quercus*, *Tilia* and *Pinus* (Huntley et al. 1989). As the strong seasonality decreased during the later Holocene, taxa such as *Fagus sylvatica* are likely to have been favoured (Huntley et al. 1989).

Fagus reaches relatively high pollen percentages in regional pollen diagrams in Scania around 3500 ¹⁴C years BP (Björkman 1997). However, *Fagus* most probably only constituted a minor forest component during this time. *Fagus sylvatica* was one of the latest tree species invading the Nordic countries during the postglacial (Diekmann et al. 1999), although pollen from *Fagus* have been found in southernmost Sweden from way before 4000 ¹⁴C years BP, but it is difficult to assess if *Fagus* were actually growing in southern Sweden, or if these pollen represent long-distance transport from the south of the Baltic where *Fagus* were widespread at the time (Björkman 1999). In the period 6000-3000 cal BP, the vegetation in Scania prior to the expansion of *Fagus* was dominated by a mixed deciduous forest including *Alnus*, *Quercus* and *Tilia* (Berglund et al. 2007). *Corylus* was probably widespread in semi-open forests and the herb layer would be scarce (Björkman & Bradshaw 1996a). *Acer* was now frequent in the forests for the first time, and *Carpinus* probably immigrated to Scania at the same time as *Fagus* and expanded around 3000 cal BP (Berglund et al. 2007). At the same time, a dramatic change towards a more open landscape is recorded. This change was especially prominent on the large plains in southern Sweden and in Denmark (Bradshaw & Holmqvist 1999). *Poaceae*, *Filipendula*, *Rumex ace-*

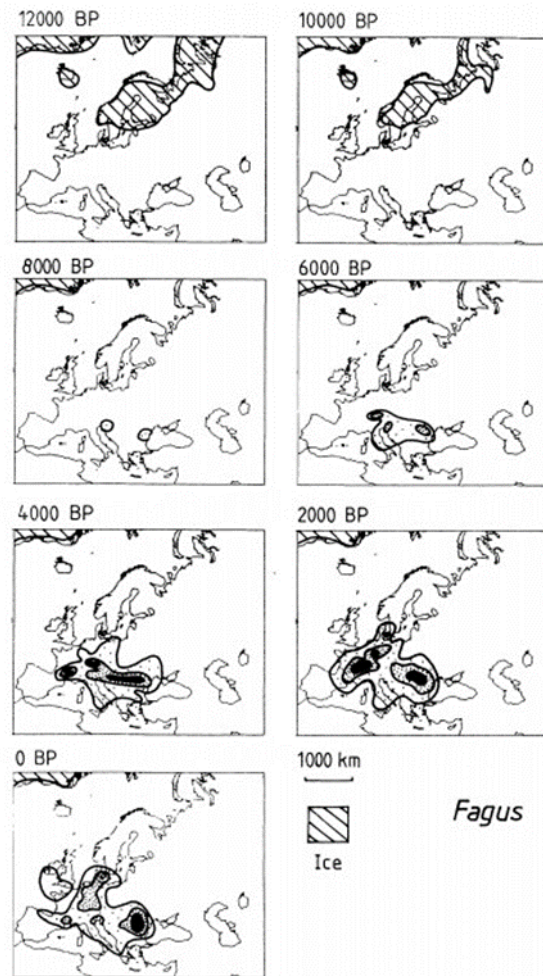


Fig. 1. Modified isopoll maps constructed by Huntley et al. (1989), reflecting the Holocene changes in the distribution and establishment of *Fagus* in Europe. Ages for timeslices are in uncalibrated ¹⁴C ages. (Isopolls drawn at 2, 10, 20%.)

tosa/acetosella, *Artemisia*, *Chenopodiaceae*, *Plantago* and *Cerealia* all show increasing pollen percentages. Pollen diagrams from this period reflect the expansion of agricultural land (Berglund et al. 2007). The composition of the forests changed, with *Ulmus*, *Tilia*, *Fraxinus* and *Corylus* decreasing markedly in percentages, while *Betula* is expanding (Berglund et al. 2007).

Around 2200 – 1500 ¹⁴C years BP *Fagus* expanded substantially in Southern Scandinavia (Björkman 1997), and this initial phase of *Fagus* population increase is recorded from regional pollen diagrams at different locations and times, ranging from 2800 ¹⁴C years BP in Holmegaard and Fugslø in Denmark (Aaby 1986), 1500-1200 ¹⁴C years BP in northernmost Scania, Blekinge and Halland (Björkman 1997), and 1000 ¹⁴C years BP at Trummen in Småland (Digerfeldt 1972). Björkman & Bradshaw (1996a) performed a study which indicates that the spread of *Fagus* on a local scale in southern Sweden was highly influenced by disturbances in the forest regime. Around 950 ¹⁴C years BP, a ground fire disturbance is recorded in Siggaboda, Småland, which was followed by significant changes in the vegetation (Björkman & Bradshaw 1996a). Both *Carpinus betulus* and *Fagus*

sylvatica simultaneously increase in percentages in the pollen record from Siggaboda (Björkman & Bradshaw 1996a). A second fire is recorded at Siggaboda around 330 ¹⁴C years BP, which resulted in further expansion of *Fagus* (Björkman & Bradshaw 1996a).

The distribution of *Fagus* is at present limited by numerous climatic factors (Björkman 1997). In addition, *Fagus* expansion is partly limited due to the fact that it primarily thrives on well-drained soils, particularly soils that are easily penetrable and nutrient-rich (Rackham 1980), accompanied by the fact that it has great difficulty to immigrate into mature stands of other tree species that have an unbroken forest continuity (Björkman & Bradshaw 1996a). The controlling factors for the local establishment of *Fagus sylvatica* in southern Sweden seems to primarily be disturbances such as ground fire, creating suitable seed bed conditions and opening of the landscape (Björkman & Bradshaw 1996b), as well as former land-use (Björse et al. 1998). Semi-open cultural landscapes seem to be most favourable for the establishment of *Fagus*, as shown by Björkman (1996) based on a study of peat profiles in southern Sweden. Björkman (1999) concluded that the immigration of *Fagus* into southern Sweden occurred with a discontinuous front and outlying populations. Chance along with site-specific factors also played a large role in the timing of stand-scale establishment of *Fagus* (Björkman 1999).

2.2 Forest and land-use history in southern Sweden during the last centuries

This section shortly describes, century by century, how forest development and land-use changes impacted the landscape in southern Sweden during the recent centuries.

2.2.1 16th century

In 1558 CE, *Fagus* and *Quercus* was declared to be a property of the state. Farmers were not allowed to damage or cut these trees down, as their nuts were deemed important for pannage, and therefore an important source of income for the state (Eliasson 2002). Probably more importantly, *Quercus* was used as timber for the warships. Throughout the 16th and the beginning of the 17th century, *Quercus* was probably one of the more important trees for the Swedish state. For the farmers, *Quercus* growing on their meadows and fields could induce problems. The large trees would cast shadows on their crops and the leaves were resistant to decomposition and would thus dry up, destroying cereals and grass beneath them (Eliasson 2002). On the other hand, the acorns supplied by *Quercus* would be readily used for feeding the pigs (Diekmann 1999). Eliasson (2002) describes how this conflict between the state and the farmers would inevitably lead to a dramatic decline of *Quercus* during these centuries.

2.2.2 17th century

The oldest map existing over Scania was constructed by Buhrman in 1684 CE. The map gives an overview of the landscape in Scania, and despite the lack of de-

tail in the map, it clearly shows how the area around Lake Odensjön was dominated by *Fagus sylvatica* forest, with occasional open fields in the plains surrounding Söderåsen. In an interpretation of the map by Troedsson (1966), he explains that the map is heavily generalized, which means that the area of *Fagus* forests would have been somewhat smaller in reality than shown on the map. Forest management with sowing and planting was barely occurring in the 17th century, and the *Fagus* forests existing in Scania during this time can be considered self-sown (Brunet 1995). This does not mean that the forests were virgin forests, considering that they still had been cultivated by humans for a long time.

During the 17th century, *Fagus* trees were often used for firewood and timber, and cattle, horses and pigs were often grazing the forests. A lot of these forests were used for pannage, with pigs rooting the soil looking for fallen nuts to feed on and in turn loosening and turning over the soil, releasing nutrients for plants (Sjöbeck 1927). This process could possibly have a positive effect on the rejuvenation of the *Fagus* forest, as nuts get buried in the soil, giving them a better chance to develop into new plants compared with nuts lying on top of the soil. However, animals such as cattle and horses grazing on younger tree plants would have had a very negative input on the rejuvenation of the forest, despite the fact that *Fagus* is considered one of the least sensitive deciduous trees towards grazing (Rackham 1980). During the 17th century, it was not certain that farmers owning a piece of forest could use it however they wanted, considering that the state owned the right of forests consisting of *Fagus* and *Quercus* (Gillberg 1765). The farmers were left to freely use trees of a lower quality, like *Alnus*, *Betula*, *Salix* and *Corylus*. It was not until 1793 CE that the farmers got the right to freely dispose of *Fagus* forests, and 1830 CE respectively for *Quercus* (Bergman 1965).

2.2.3 18th century

The forest areas had started to decrease in Scania during the 18th century, and in the mid-19th century they reached their smallest size (Brunet 1995). This decrease can broadly be ascribed to woodcutting exceeding the regrowth of trees in combination with grazing becoming all the more excessive, impeding the regrowth of trees (Brunet 1995). Industry, trade and population was also rapidly increasing, further impoverishing the forest resources (Wallerman 1995). Following the decline of the forests, people started to realize that the development with deforestation was not sustainable, and a governmental regulation was made which stated that when using the forest, regrowth should be assured (Persson 1971). From the mid-18th century to the 19th century, pastures that were used for replanting of forest are described in the literature to be present in Scania (Persson 1971). Nevertheless, these replanting pastures were far too few and small to make up for the decreasing tree cover, and the forests continued to steady decline. In a study by Björkman (2001) on the horst ridge Kullaberg (ca. 36 km NW of Lake Odensjön), an open period is evident from 1650 CE to 1800 CE, characterised by high pollen percentages of *Juniperus*, *Calluna* and *Poaceae*.

2.2.4 19th-20th century

Many large changes occurred in the landscape during the mid-19th century, with reforms taking place. From 1830-1850 CE the *Laga skifte* land reform was being implemented all over Scania, pushing for a change in the landscape. The *Laga skifte* entailed that the pieces of land a farmer owned was scored based on the quality of the soil. If the soil was of poor quality, the farmer would get a larger area of land compared to a farmer with high-quality soil. Forest and grazing fields that were once shared, were now becoming private property (Persson 1971). As people were forced to move out from the villages, parts of the forest and grazing fields would be used as agricultural fields. The 19th century was a period of heavy cultivation of land in Scania, and the field area would increase by four times between 1805 CE and 1914 CE (Wallerman 1995). Large areas of wetland would be drained in Scania, and tree-rich meadows would disappear. Hemberg (1918) explains how the cultivation and water regulations happening in the 19th century would result in the soil getting dryer in places. This shift in soil moisture could on the contrary promote the spread of *Fagus* in wetter *Quercus* forests, as *Fagus* had the opportunity to immigrate and could easily outcompete *Quercus* with its shading leaf cover. The land reforms had large impact on the vegetation, although other factors also affected the landscape during this period. As described above, *Fagus* and *Quercus* forest that had previously been in the hands of the state, become free for use by the farmers once again in 1792 and 1830 CE respectively.

In the second half of the 19th century the landscape would withstand further changes. Wallerman (1995) describes that Scania would transform from a hay and grazing landscape to an agricultural and forest landscape. This shift would take place primarily because of the new innovations seen in the agriculture. Farmers were cultivating nitrogen fixing pea plants, and streams were dammed up for the watering of fodder meadows, which acted as an indirect agent for increasing harvest. This method allowed for water to spread out over the meadow and wet the soil, and in turn this also released nutrients with the water (Länsstyrelsen Skåne 2020). In the mid-19th century different kinds of soil improving agents were emerging, with marl being the dominant one. Commercial fertilizers would be introduced in the beginning of the 20th century, but would not be widely used until after 1950 CE.

Since the mid-19th century the forest area has successively been increasing in Scania, and towards the end of the century reforestation gained strong momentum along with a radical decrease in forest grazing (Wallerman 1995). The *Fagus* forest had managed to recover at a surprising speed, and with a good rejuvenation even on poor soils, which probably is attributed to pigs grazing the woods (Persson 1971). As a result of the innovations seen in the agriculture, large pastures that previously were used for giving manure could instead be used for planting trees, as manure was no longer necessary in as big quantities for keeping the agricultural fields sustained. *Fagus*, mainly imported from central Europe or Denmark, was being planted (Wallerman 1995). Around 1875 CE, the first planting of *Picea* occurred in Scania, and in the beginning of

the 20th century *Picea* had become one of the more common trees to plant (Persson 1971). The planting would primarily take place in pastures previously dominated by *Juniperus*, and to a lesser degree on former *Fagus* and *Quercus* land, as well as on the less successful arable lands (Brunet 2007). After some time, *Picea* was planted at the expense of deciduous forests, replacing them in places. As of 2005 CE, 40 % of the forest area in Scania consisted of planted *Picea* (Brunet 2005). In 1974 CE, *Fagus* forests would become protected by law from being altered into coniferous forests (Brunet 1995). *Fagus* forests had become an important part of the landscape image of Scania, and natural reserves were starting to emerge.

2.3 Palaeoecological methods used in the study of forest history

Pollen, plant and animal macrofossils are some of the most helpful tools for reconstructing past changes in climatic and environmental conditions, including changes in ecosystem composition and forest development. To understand how these techniques are useful, it is important to understand their history, as well as how they are used. Below follows a short introductory description of both pollen analysis and macrofossil analysis.

2.3.1 Pollen analysis

Pollen grains are the reproductive propagules formed by the male seed-producing plants (Bennett & Willis 2002). The grains contain the male gamete, and aim to reach the pistil in flowering plants, or female cone in coniferous plants, for germination. Spores are frequently included in pollen diagrams as well, and represent the spore-producing sporophyte plants such as ferns (Pteridophyta) and mosses (Bryophyta) (Bennett & Willis 2002). Pollen and spores are mainly dispersed by wind (anemophilous) or by insects (entomophilous). Anemophilous pollen grains are lightweight and generated in very high quantities, in order to maximize a successful pollination. Due to the high production quantity, many pollen grains will accumulate on land and in water bodies, where some subsequently will be incorporated in the sediment (Bennett & Willis 2002).

Pollen grains typically feature three elements. The central part, which is the living part of the pollen grain and consists of generative cells and a vegetative cell, is covered by the intine, which forms the inner pollen wall containing cellulose (Bennett & Willis 2002). The outer wall of the pollen grain is called the exine. The reason as to why pollen grains are preserved so readily in anaerobic environments is due to a complex substance called sporopollenin, which makes up the exine of the pollen grain together with cellulose (Bennett & Willis 2002). The sporopollenin is the only surviving element found in fossil pollen. Sporopollenin is there to protect the gametophyte when it is moving its way towards a pistil (for flowering plants) or a female cone (for coniferous plants). Due to its protective nature, sporopollenin is extremely resistant to chemical and physical degradation, which not only allows it to be preserved in anaerobic sediment, but also allows us to use chemicals to remove the material

that the pollen is imbedded in, enabling us to study them (Bennett & Willis 2002). Depending on the taxon, the outer wall of a pollen grain will have very distinct and/or varying features. The distribution and number of germinal apertures, overall size and shape, and the morphological and structural features are the fundamental characteristics pollen identification is based on (Bennett & Willis 2002).

Pollen analysis, or palynology, can be considered one of the most widely employed palaeobiological methods for reconstructing Quaternary environments (Seppä & Bennett 2003). Pollen analysis has its roots in the Swedish naturalist and geologist Lennart von Post, who published the first modern pollen diagram in 1916. With time, it has become a highly versatile instrument for not only tracking vegetational changes at a local, regional, and continental scale during the late Quaternary, but also for assessing anthropogenic impacts on the vegetation and landscape (Mackay et al. 2003) as well as being used as a tool for developing conservation policies (Froyd & Willis 2008).

With the help of pollen analysis, scientists have managed to trace back old migration patterns of tree species (Seppä & Bennett 2003) (Fig. 1). The primary response plants see to long-term climate changes is considered to be migration. Scientists have noted that the distribution changes of plants match well with climate model simulations, which suggest that each plant species since the last glacial maximum have migrated as a response to climate change (Seppä & Bennett 2003). Birks & Birks (2000) points out that pollen-based reconstructions of past tree lines should preferentially be done together with macrofossil analysis. Pollen analysis alone will give weak results, considering that pollen are easily transported above and beyond the tree line limit, but together with macrofossil analysis from which the timing of local arriving tree species can be deduced, a more adequate tree line can be constructed. Seppä & Bennett (2003) note that another aspect highlighted by pollen analysis is the establishment of invading species. Studies have given new insight into the stand-scale processes of the Holocene invasion of major tree species into landscapes that already had a sufficient forest cover. One of the more important topics today in conservation research concerns biodiversity (Seppä & Bennett 2003). The fundamental factors affecting the development of biodiversity relates to historical changes. Although it is not simple, pollen analysis is a potential method for reconstructing vegetation diversity. At the largest spatial scale, pollen records have also managed to track changes in past biomes (Seppä & Bennett 2003).

Although pollen analysis is considered a very versatile instrument for reconstructing past vegetation, theoretical and practical problems arise with the method, and caution should be taken when interpreting the data (Godwin 1934). One source of error concerns the pollen preservation, which will vary considerably both depending on taxa and site (Godwin 1934). Preservation of pollen material will primarily occur in waterlogged and anaerobic deposits, whereas the preservation potential will be poor in deposits with coarser material. Taxa such as *Juniperus*, *Populus* and members of Rosaceae have a low preservation potential,

which in turn can distort the pollen signal at the expense of these taxa. Some taxa also might be favored in the analysis based on their much more recognizable features, such as *Alnus*, whereas other taxa, like *Quercus*, will be harder to identify. Another source of error lies within how the results are presented (Godwin 1934). The amount of pollen will generally be expressed in percentages of the total terrestrial pollen. This will entail that the percentages of a single genus will always affect the percentage values for all the other groups included in the analysis. Other sources of error include the variable production and transportability of pollen between species, their differing time of flowering, as well as pollen downwash through the soil by descending water in rapidly forming peats (Godwin 1934).

2.3.2 Macrofossil analysis

Macrofossils are animal and plant remains that can be observed and identified with the naked eye. Macrofossils range in size from small fragments of plants or seeds, to pieces of wood and even whole trees (Birks 2002; Birks 2007). Macrofossils include visible remains of plants, including fruits and seeds, buds and bud scales, as well as leaves and stems of bryophytes. The preservation potential of fossil plant remains will vary considerably depending on the material and site. The best-preserved macrofossils are often found in acidic peat deposits, as they have been protected from oxidation (Birks 2007). Additionally, macrofossil remains are also commonly found in lacustrine and fluvial sediments (Birks 2007). Quaternary macrofossil analysis will in most cases mainly focus on the study of the material mentioned above, and to a lesser degree of identifiable leaves and conifer needles (Birks 2007). Deciduous tree leaves are often very delicate, and will therefore in most cases only be preserved in very small fragments. However, in annually laminated fine-grained sediments they are sometimes found in pristine condition (Staff et al. 2011).

Macrofossil analysis has been around since the 19th century and used to be the only technique available for studying Quaternary vegetation history before pollen analysis was developed (Birks 2002). With the help of macrofossils, many parts of the Quaternary climate and vegetation history have managed to be established, including the interglacials, full-glacial and the late-glacial (Birks & Birks 2000). After pollen analysis was developed in the 1920s, macrofossil analysis saw a heavy decline as it was seen as an inferior way of studying vegetation and climatic history. It was not until the 1960s before scientists started to realize that the limitations entailed in pollen analysis could be helpfully complemented by macrofossil analysis (Birks 2002). The most prominent limitations of pollen analysis would be that many pollen cannot be identified to species level but often just to the genus or family level, and that determining the source area of pollen can be extremely complex (Birks & Birks 2000). Plant macrofossils have the advantage of being dispersed within a considerably closer distance from their source compared to pollen, and it is often easier to identify macrofossils with a greater taxonomic precision (Birks & Birks 2000). In fact, macrofossils tend to almost exclusively be deposited locally, with the exception of

a few remains that have a very good wind-dispersal, such as the fruits of *Betula* (Lowe & Walker 2014). If a macrofossil of a species is found together with abundant pollen of the same species, it may be concluded that said species was actually present at the site, and that the pollen recorded are not only of long-distance origin (Birks 2014). For taxa that produce very limited amounts of pollen, or no pollen at all, macrofossils might be frequent and document local plant presence. On the other hand, the abundance of macrofossils cannot really compare to the abundance of pollen, and much more sediment is required for the study of macrofossils (Birks & Birks 2000). Overall, plant macrofossil analysis is nowadays seen as a very good complement to pollen analysis, as well as being used independently, not in the least for obtaining suitable material for AMS radiocarbon dating.

Despite the advantages mentioned with macrofossil analysis, there are sources of error both concerning the handling of the data as well as in the interpretation of the data. One source of error arises due to the great variability of the quantity of plant material preserved depending on site, as well as where the plant material is extracted on the site. Macrofossils seldom reach the center of large, deep lakes, and therefore coring should preferably be executed in the littoral zone on these sites (Birks 2002). Waterlogging is often the most important factor for the preservation of macrofossils in peats, river silts and lake sediments (Hall & Huntley 2007). At some depositional sites, such as river silts, material might be reworked and thus result in incorporation of macrofossils that do not

represent the contemporary vegetation (Hall & Huntley 2007). Another problem arises due to the nature of macrofossil stratigraphical data. The representation of macrofossil stratigraphical data will usually be mixed data, with binary (presence/absence), ordinal values (categorical with an unknown distance between the categories, e.g. small presence/high presence/abundant presence), and quantitative count data (Birks 2014). As problem easily can arise with a mixed dataset, they require extra care in their handling and interpretation (Birks 2014). Another source of error is the interpretation of zero values. For macrofossils, non-zero values almost certainly reflect presence of the taxon at the site, whereas zero values can reflect the taxon in question just not being found in the sediment sequence examined despite local presence at the site, or an actual absence of the taxon near the examined site, and it is therefore important to take extra care when interpreting macrofossil data (Birks 2014).

3 Site description

3.1 General description

Lake Odensjön (56.00457°N 13.27552°E, 60 m asl.) is positioned close to Röstånga within Söderåsen National Park in Scania, southern Sweden (Fig. 2). The lake is known for its beautiful location in the deepened fracture valley of Nackarpsdalen which attracts both tourists and locals for swimming and grilling, as well as to attend the occasional concerts that are held at the locality during the summertime. Lake Odensjön has a diameter of 150 m and a maximum depth of around

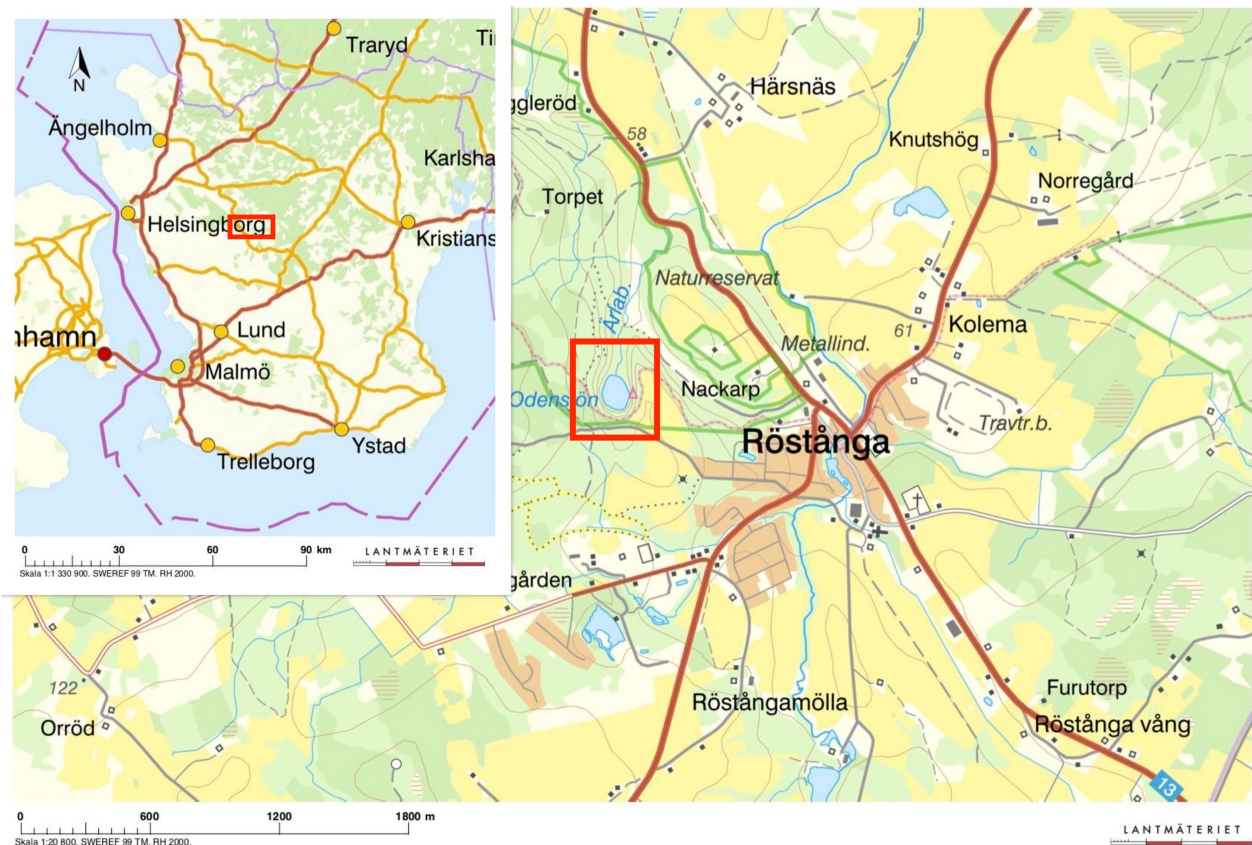


Fig. 2. Maps illustrating the position of Lake Odensjön in Scania, southern Sweden. Modified from Lantmäteriet (2020a).

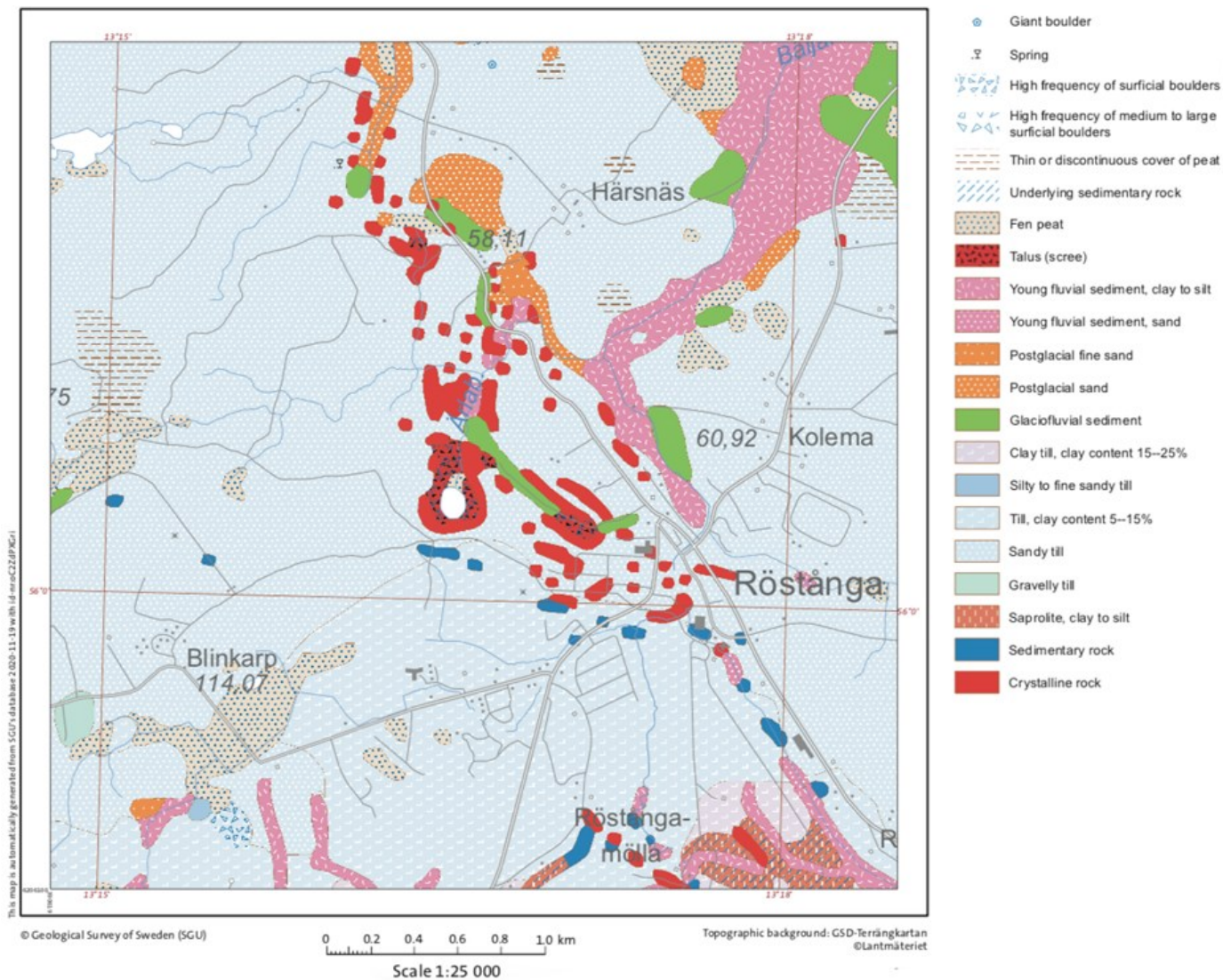


Fig. 3. Map illustrating the Quaternary deposits surrounding Lake Odensjön. Modified from SGU (2020).

19 m (Svalövs Kommun 2020). Due to the lakes peculiarly round shape in combination with the steep mountain walls draped with talus, reaching up to around 100 m asl., the formation history of the lake has long been debated as well as mythicized. It was believed that the lake was bottomless, as well as having a connection to Lund Cathedral. The name Odensjön is thought to be derived from the one-eyed Norse god Odin, by cause of the round shape of the lake resembling his sole eye (Svalövs kommun 2012). Early on, it was thought that the lake perhaps was the remnant crater from an exploding volcano, or that it had been eroded by a waterfall as a result of the melting ice during the last ice age (Svalövs kommun 2013). But today, one theory regarding the creation of Lake Odensjön that is widely accepted, was proposed by Rapp et al. (1986). The theory suggests that Lake Odensjön is an over-deepened cirque basin, which originated due to local glaciation. The cirque is believed to mainly have been excavated during long periods of tundra before the Alleröd period, and particularly before the expansion of the Weichselian inland ice before 21 000 cal BP (Rapp et al. 1986). During the tundra periods, masses of drifting snow would be captured in the valleys of Söderåsen, setting the groundworks for nivation hollows and cirques to be created.

The cirque would be persevered when the inland ice covered the area, and would rejuvenate again during the following tundra periods, e.g. the Younger Dryas (Rapp et al. 1986). At the site, semi-circular hollows are shaped into the bedrock, which is partially covered by till from the Weichselian ice. These hollows are interpreted by Rapp et al. (1986) as to be derived from the nivation processes that were active during the tundra-climate periods before the advance of the Weichselian ice.

The bedrock underlying Lake Odensjön consists of Precambrian granitic gneiss, which primarily makes up the bedrock surface north of the locality (Wikman et al. 1993). Cambrian sandstone occurs towards the south of Lake Odensjön, which is bordered to the south with schists that began being deposited during the Cambrian and continued deposition until the early Ordovician. Ordovician and Silurian schists are dominating the area south of the Cambrian-Silurian schists, and they are believed to reach a thickness of at least 1000 m. Permian-Carboniferous diabase dikes occur throughout the area in NW-SE direction (Wikman et al. 1993). Angular talus material makes up the Quaternary deposits on the slope leading down to Lake Odensjön, with bedrock protruding on the plateau above the talus and along the valley of Nack-

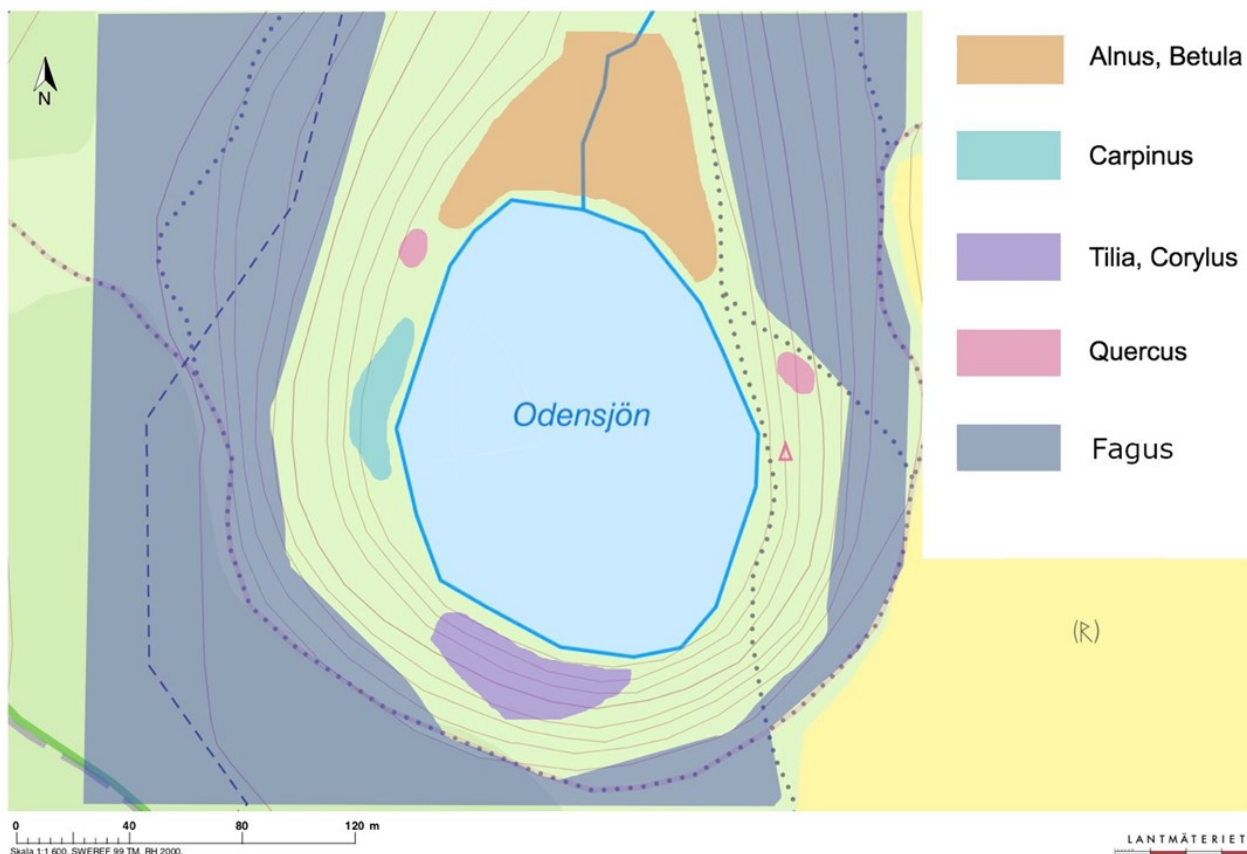


Fig. 4. Rough sketch of the current tree cover around Lake Odensjön in present time based on mapping carried out within this study. Modified from Lantmäteriet (2020a).

arpsdalen (Ringberg 1984) (Fig. 3). Sandy till is deposited on the plateau in the surrounding area and clayey till is dominating south of Lake Odensjön. Lake Odensjön drains through a small stream, Ärlabäcken, towards N/NE, and fen peat is found surrounding this stream just north of the lake. Glacifluvial sediments are dominating further north along Ärlabäcken, as well as along the valley of Nackarpsdalen, reaching a thickness of around 4-5 m (Ringberg 1984).

3.2 Current vegetation

Lake Odensjön is located in the nemoral vegetation zone, which is defined by temperate climate and frost resistant deciduous forests. The area surrounding the lake was mapped with regard to the tree cover, on 21 February 2020 (Fig. 4). In the upper parts of the slope around Lake Odensjön and on the plateau above the slope, *Fagus sylvatica* forest is dominating. Walking around the lake beneath the steep talus, you can find stands of *Tilia cordata*, *Corylus avellana* and *Carpinus betulus*. *Alnus glutinosa*, *Betula pendula* and *Betula pubescens* are also found growing in the fen towards the north, where the lake drains through Ärlabäcken in the direction towards Nackarpsdalen. Due to the steep slope and the angular talus blocks, a special vegetation type with lichens and mosses has evolved here, with rock- and landslide vegetation that shifts depending on bedrock, how far the weathering has gone as well as which latitude the slope faces (Svalövs kommun 2019). Above the talus slope, a couple of 100

m towards the west, there is also an area with planted *Picea abies*. The mean annual temperature as measured from the closest weather station in Svalöv (55° 54'29.2"N 13°07'02.6"E, ca. 16 km from Odensjön) is at 7.7 °C (SMHI 2020a), and the mean annual precipitation is 687.1 mm as measured from the same station (both are normal values from the period 1961-1990) (SHMI 2020b).

3.3 Vegetation and land-use history

This section presents a short description of how the vegetation has changed in the close vicinity to Lake Odensjön during the recent centuries. The information is primarily based on map material retrieved from the Swedish National Land Survey (Lantmäteriet 2020b).

In the beginning of the 18th century, Söderåsen mainly consisted of *utmark* (out-land), as the villages with their fields and meadows were located on the plains around the ridge of Söderåsen (Persson 1971). *Utmark* refers to the pastures and forests which secured a place for animals to graze, beyond the fields located next to the village with arable lands and meadows, which are referred to as the *inåga* (in-field). A soil protocol from Klåveröd (ca. 7.4 km NW of Lake Odensjön) in 1670 CE can give insight on what the forest cover could look like on Söderåsen during the beginning of the 18th century. The forest is here described as being prosperous, mainly consisting of *Fagus* trees, but also with elements of *Quercus* (Håkansson 1948). This depiction of the forest also

corresponds with what is seen in a map from Toarp in Billinge parish (ca. 4 km NNE of Lake Odensjön) in 1692 CE (Lantmäteriet 2020c).

During the 18th century, the forests in Scania started to decrease in size (Brunet 1995). Persson (1971) describes how the areas surrounding Söderåsen would have had a shortage in forests during this time. This shortage resulted in an increased pressure on the forests on Söderåsen, exceeding that of what the forests could withstand. Håkansson (1948) describes the landscape in Konga parish (ca. 5 km SW of Odensjön) during the 17th – 18th century as a transition zone between *risbygd* and forests. The term *risbygd* refers to the mosaic type of landscape characterising the transition zone between hayfield-dominated land and forest-dominated land. The *risbygd* is characterised by deciduous forests and soil dominated by sand or till. Agriculture occurred on a very small scale on these lands. The *risbygd* would push away the forest towards the north, and at the end of the 18th century the *risbygd* is described to have expanded all the way up to the foot

of Söderåsen, at the expense of the forest. A map over Gillastig (ca. 1.5 km W of Lake Odensjön) (Fig. 5) from 1790 CE illustrates how far the impoverishment of the *Fagus* forest could go (Lantmäteriet 2020d). In this area, *Fagus* forests had become extremely sparse, and *Juniperus* was dominating the shrub layer in places (Håkansson 1948). This depiction of a sparse *Fagus* forest cover and/or a dominant *Juniperus* cover is supported by maps of Duveskog (ca. 1.4 km south of Lake Odensjön) in 1782 CE (Lantmäteriet 2020e) and Toarp, Billinge parish in 1743 CE (Appendix 1) (ca. 4 km NNE of Lake Odensjön) (Lantmäteriet 2020f).

The 19th century was a period with a lot of changes happening in the landscape. Map material suggest that the Laga skifte land reform was implemented in the close vicinity to Lake Odensjön both in 1830 CE and 1833 CE (Lantmäteriet 2020g; Lantmäteriet 2020h). Many parcels of land in the direct vicinity of Lake Odensjön is described in text from map material as being predominantly lacking in forests during 1804 CE (Lantmäteriet 2020i). The very



Fig 5. Map of Gillastig (ca. 1.5 km W of Lake Odensjön) from 1790 CE. The map illustrates a relatively sparse *Fagus* forest cover (depicted as brown, larger trees) and a dominating *Juniperus* cover (depicted as green, smaller shrubs). Modified from Lantmäteriet (2020d).



Fig. 6. Map from 1810 CE depicting the area around Lake Odensjön. Rings drawn together represents *Fagus* forests and lines represents altitude differences. The tree cover is here seen as sparse surrounding Lake Odensjön. Modified from Länsstyrelsen (2020).



Fig. 7. Map from 1865 CE depicting the area around Lake Odensjön. The blue oval represents the position of Lake Odensjön. Rings drawn together represents *Fagus* forests and lines represents altitude differences. The tree cover is here seen as relatively sparse surrounding Lake Odensjön, although somewhat more dense compared to in 1810 CE (fig. 6). Modified from Lantmäteriet (2020j).



Fig. 8a. Map illustrating the area around Lake Odensjön from 1910-1915 CE. *Fagus* is illustrated as circles drawn together and *Picea* is illustrated as asterisks. *Fagus* appears to have established surrounding Lake Odensjön and *Picea* is present NW of the Lake on the plateau. Modified from Lantmäteriet (2020k). Fig. 8b. Map illustrating the area around Lake Odensjön from 1905 CE. The legend states from top to bottom: Forest, plot, arable land, meadow, peat-bog. The map suggests that *Fagus* appears to have established surround Lake Odensjön at this time. Modified from Lantmäteriet (2020l).

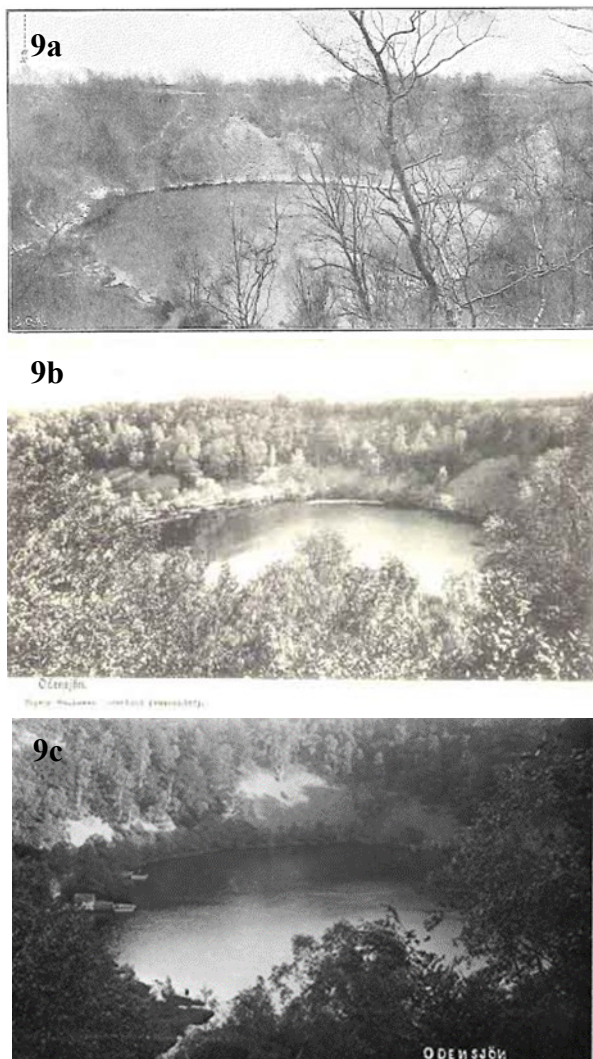


Fig. 9a. Photograph of Lake Odensjön taken by Hennig (1902) in 1902 CE. 9b. Photograph of Lake Odensjön in 1906 CE (Röstångabygdens kulturförening 2020). 9c. Photograph of Lake Odensjön presumed to have been taken in 1927 CE (Sveriges hembygdsförbund 2020).

steep slopes close to the lake are described as “incompetent land” (Lantmäteriet 2020i), indicating that this area would probably not have been of interest for the farmers. Maps depicting the whole area of Scania were conducted in 1810 CE (Fig. 6) (Länsstyrelsen 2020) and 1865 CE (Fig. 7) (Lantmäteriet 2020j). The close vicinity to Lake Odensjön is depicted as being relatively open on both of these maps, although somewhat more in the map from 1810 CE.

In the beginning of the 20th century, the forests are described to grow denser once again in Scania. Maps of the Lake Odensjön area from 1905-1915 CE (Fig. 8a and 8b) illustrate how the area was now for the most part covered by deciduous forests (Lantmäteriet 2020k; Lantmäteriet 2020l). In Fig. 8a and 8b it is visible that *Picea* had already begun to be planted NW of Lake Odensjön in 1910-1915 CE. Pictures taken of Lake Odensjön around 1902 CE (Hennig 1902) (Fig. 9a), 1906 CE (Röstångabygdens kulturförening 2020) (Fig. 9b) and presumably 1927 CE (Sveriges hembygdsförbund 2020) (Fig. 9c), shows how the vegetation on the upper part of the ta-

lus slope as well as on the plateau around Lake Odensjön consisted of a dense forest cover during this time. Pannage was still heavily used in Scania during the first half of the 20th century, facilitating the rejuvenation of the forests. According to Persson (1971), it is not that certain for how long pannage was used in the *Fagus* forests of Söderåsen. In the Skärålid area (about 4.3 km north of Lake Odensjön) pannage seems to have been occurring until 1930 CE (Persson 1971).

During the 20th century, *Picea* became a common tree to plant in Scania. In a map depicting Billinge (ca. 5.8 km SE of Lake Odensjön) in 1910-1915 CE, *Picea* appears to be relatively common in the area, growing amongst the partially dense *Fagus* forest (Lantmäteriet 2020m). As mentioned in section 2.2.4, the government would take into action for the protection of other tree species that were declining as a result of *Picea* being planted, and in 1974 CE *Fagus* forests were protected from being altered into coniferous forests (Brunet 1995). By comparing aerial photos from 1960 CE and present time (Fig. 10), the *Picea* forest growing west of Lake Odensjön has visibly decreased in size and been replaced by *Fagus* forest, presumably by planting. The *Picea* forest growing west of Lake Odensjön in 1960 CE had expanded considerably compared to what is shown on the map from 1910-1915 CE (Fig. 8a). An oblique aerial photo, although with an unknown date, shows a clearer view of the *Picea* forests close to Lake Odensjön at the time when it had an extent similar to that shown on the aerial photo from 1960 CE (Fig. 11). In the late 20th century, many areas now included in the Söderåsen National Park would become protected, but it would take until year 2000 for Odensjön and Nackarpsdalen to be included.

4 Methods

4.1 Core preparation

As described above, the investigated sediment sequence was extracted with a freeze corer at 19.9 m depth in January 2016 and thereafter wrapped in plastic and kept frozen at -18 °C (Hertzman in prep.). Two equally sized and parallel sediment sequences previously attached to opposite sides of the freeze corer were cut using a band saw. The two sections were correlated and marked for every 10 cm, down to a depth of 86 cm, and thereafter scraped clean at freezing temperature. A 2 cm wide rod of frozen sediment to be used for pollen analysis was cut out from one of the sections with the band saw. The uppermost 2 cm of the rod experienced some chipping followed by melting, which resulted in significant loss of material for this section of the rod. The pollen rod was later cut out into 43 samples (2 cm x 2 cm) with the help of a handsaw. As there was a clearly visible boundary between abundance and absence of *Fagus sylvatica* leaves at the depth of 26 cm, it was decided to make two separate samples (14a and 14b) with a 1 cm width at this depth, to possibly capture the anticipated abrupt change in the vegetation. The total number of pollen samples was 44, but only 28 of the samples were used for the pollen analysis. Macrofossil samples were cut applying the

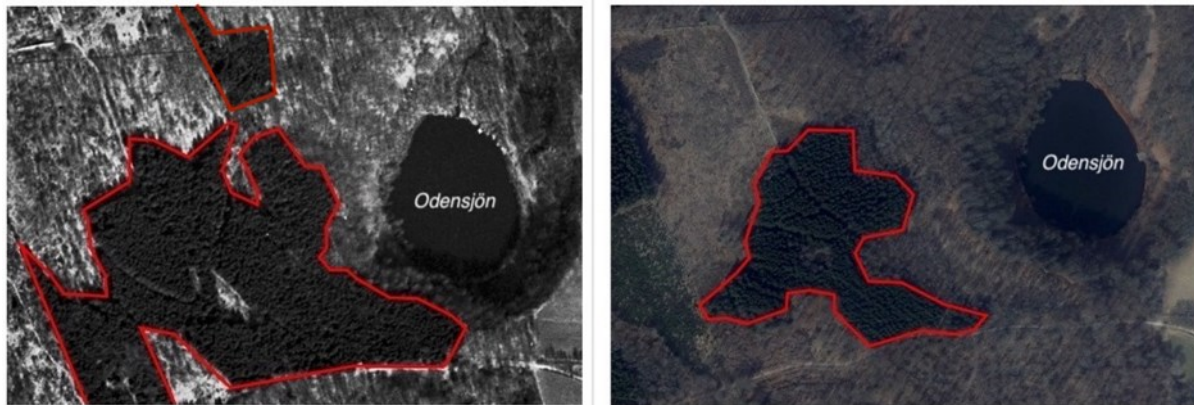


Fig. 10. Aerial photos from 1960 CE (to the left) and present time (to the right). Red markings indicate the distribution of *Picea* growing west of Lake Odensjön, which has decreased since 1960 CE. Modified from Lantmäteriet (2020a).



Fig. 11. Oblique aerial photo with an unknown date. The *Picea* forests appears to be at the same extent as in 1610 (Fig. 10).

same method using the remaining material of the two parallel sequences, resulting in a total of 44 samples representing a 2 cm depth interval. All samples were used for the macrofossil analysis.

4.2 Pollen preparation and analysis

The pollen samples were taken out from the freeze room to thaw. As the samples were thawing, the innermost section of each sample was removed with a small spatula. The visible varves in the sediment had clearly been distorted in these inner parts as a result of the freeze corer intruding into the sediment during coring, and could in turn distort the pollen signal. The remaining material of each sample was mixed in order to blend together the pollen signal and retrieve an average signal for each sample. 2 ml of each sample were afterwards put in test tubes with the help of a plastic syringe. Both the spatula and the plastic syringe were carefully cleaned with deionized water between each step to avoid cross-contamination. The samples were

subsequently prepared according to standard procedure as presented by Faegri et al. (1989).

The samples were put in a hot water bath, whereafter two *Lycopodium* tablets were added to each sample, with 9666 spores in each tablet ($s = \pm 671$, $V = \pm 6.94\%$, where s = STD deviation and V = STD deviation %). The technique of adding a known number of *Lycopodium* spores to a known volume was developed by Stockmarr (1971), and it allows calculation of pollen concentrations. The number of tablets added are determined by the fact that the ratio between counted pollen and counted exotic spores should be around 1:1 (Regal & Cushing 1979). After that, 10% NaOH were added to each sample for the dissolution of humus. For a couple of the samples, 10% HCl were thereafter added for the removal of carbonates. The following step included treatment of the samples with glacial acetic acid. This step is carried out for the removal of water, which allows for acetolysis to be carried out. For the acetolysis, 9 parts acetic anhydride and 1 part concentrated sulphuric acid are mixed to-

gether and applied for the removal of cellulose and polysaccharides. For the final step, the samples were washed with acetic acids to stop the acetolysis process. Between each step, the samples were washed with water, decanted and centrifuged. When the pollen preparation was finalized each sample was mixed with a few drops of glycerol. One drop of the sample was put on a microscope slide and sealed in with a cover glass. More than 500 pollen grains were aimed to be counted and identified for each sample under a light microscope with x400 magnification. Ralska-Jasiewiczowa & Berglund (1986) highlights the importance of counting a minimum of 500 tree pollen, as it reduces statistical errors. Three of the samples would have a total sum slightly below 500 counted pollen grains, as a result of miscalculation. Pollen were identified with the help of the reference collection available at Department of Geology, Lund University, and literature including Faegri et al. (1989), the Northwest European pollen flora book series (e.g. Clarke et al. 1984) as well as the website databases of The Global Pollen Project (2020) and PalDat (2020). Grass pollen were classified as either Poaceae (<40 µm) or Cerealia (>40 µm) based on their size. All of the samples were counted twice, but the second time only added *Lycopodium* spores and a few selected taxa that were ambiguously identified the first time, were counted.

When the pollen counts were completed all data were transferred into Microsoft Excel for the calculation of pollen sums, percentages and concentrations. All calculations were done following the criteria suggested by Ralska-Jasiewiczowa & Berglund (1991). Before calculating the sums, all taxa were divided into groups (trees, shrubs, dwarf shrubs, herbs and graminids, ferns, aquatic plants and others). *Salix* can be placed both within the group trees and shrubs in pollen diagrams, but it was decided to place *Salix* within the tree category based on the trend of *Salix* seen in the pollen diagram. *Salix* behaves very similar to some of the other trees (e.g. *Carpinus*, *Tilia*, *Fraxinus* and *Ulmus*) and therefore it was suspected that *Salix* rather was represented pollen from tree species (for example *S. caprea*) than shrub species. The pollen sum included the following groups: trees, shrubs, dwarf shrubs, and herbs and graminids. Percentages for taxa belonging to these terrestrial groups were calculated by dividing the number of the counted pollen taxa with the pollen sum and multiplying it with 100. For non-terrestrial groups (ferns, aquatic plants and others) percentages were calculated by dividing the counted number with the pollen sum combined with the sum of relevant group and multiplying with 100. Pollen concentrations were calculated with the equation:

$$\frac{\text{Lycopodium spores added}}{\text{Lycopodium spores counted}} \times \frac{\text{Pollen counted}}{\text{Volume (cm}^3\text{)}}$$

When all calculations were complete the data was transferred into the software Tilia (Grimm 2007) for the construction of pollen diagrams. The exaggeration curve for each taxon was set at x10 and the different groups were colour-coded for a simpler overview. Depth (cm) and age (CE) were added to the y-axis.

Pollen assemblage zones were constrained with the help of the in-program cluster analysis CONISS.

4.3 Macrofossil preparation and analysis

The macrofossil sample sizes were assessed with the help of water displacement. A measuring cylinder with a known volume was filled with water whereupon the still frozen samples were individually put in the measuring cylinder, and the new volume was noted down. After the volume was defined, each sample was placed in a sieve with mesh size of 0.5 mm on top of another with mesh size 0.25 mm below. The sediment was rinsed through the sieves with water. Larger leaves and other coarse organic material were initially removed with tweezers during the sieving to minimize fragmentation, and when the sieving was complete, this material was put back together with the rest of the remaining material in a sample box. This process was repeated for all individual samples.

Macrofossil analysis was conducted on 44 samples from the mesh size fraction of 0.5 mm. Some samples of the 0.25 mm size fraction were inspected, but the material found in the 0.5 mm samples was considered sufficient for analysis. The material was inspected while being submerged in water under a stereo microscope. Some material was picked out of the water to let dry. This allowed for the surface structure to become more visible, which facilitated identification. For each sample, *Fagus sylvatica* leaves >1/3 of a whole leaf was initially identified, counted and put into a separate container. *Fagus sylvatica* fragments (<1/3 of a whole leaf) were later identified, counted and put into the same container. The separation was made at 1/3 of a whole leaf because larger fragments than that were not preserved in the sediment samples, probably due to the size of the cross-sectional area of the freeze-corer, and the distinction was made to minimize the effect of fragmentation of larger leaves. All leaf fragments that were below a certain size

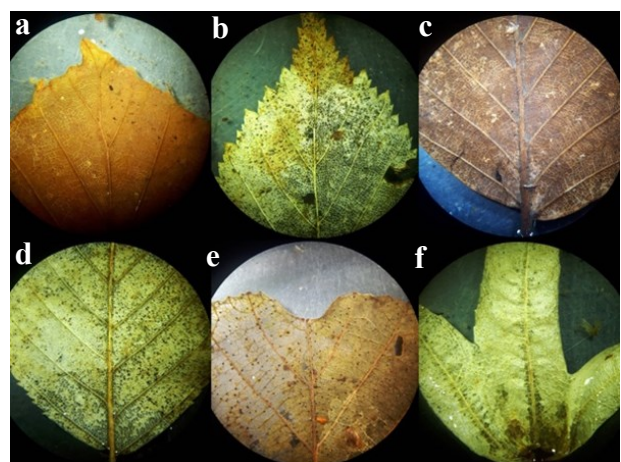


Fig. 12. Photographs taken through a stereo microscope of parts of the reference collection collected at the site on 21 February 2020. The photographs illustrate some of the distinct features of the leaves for prominent taxa at the site. Taxa included: a) *Fagus* b) *Carpinus betulus* c) *Fagus* d) *Carpinus betulus* e) *Alnus* f) *Carpinus betulus*. Photo: Maja Damber.

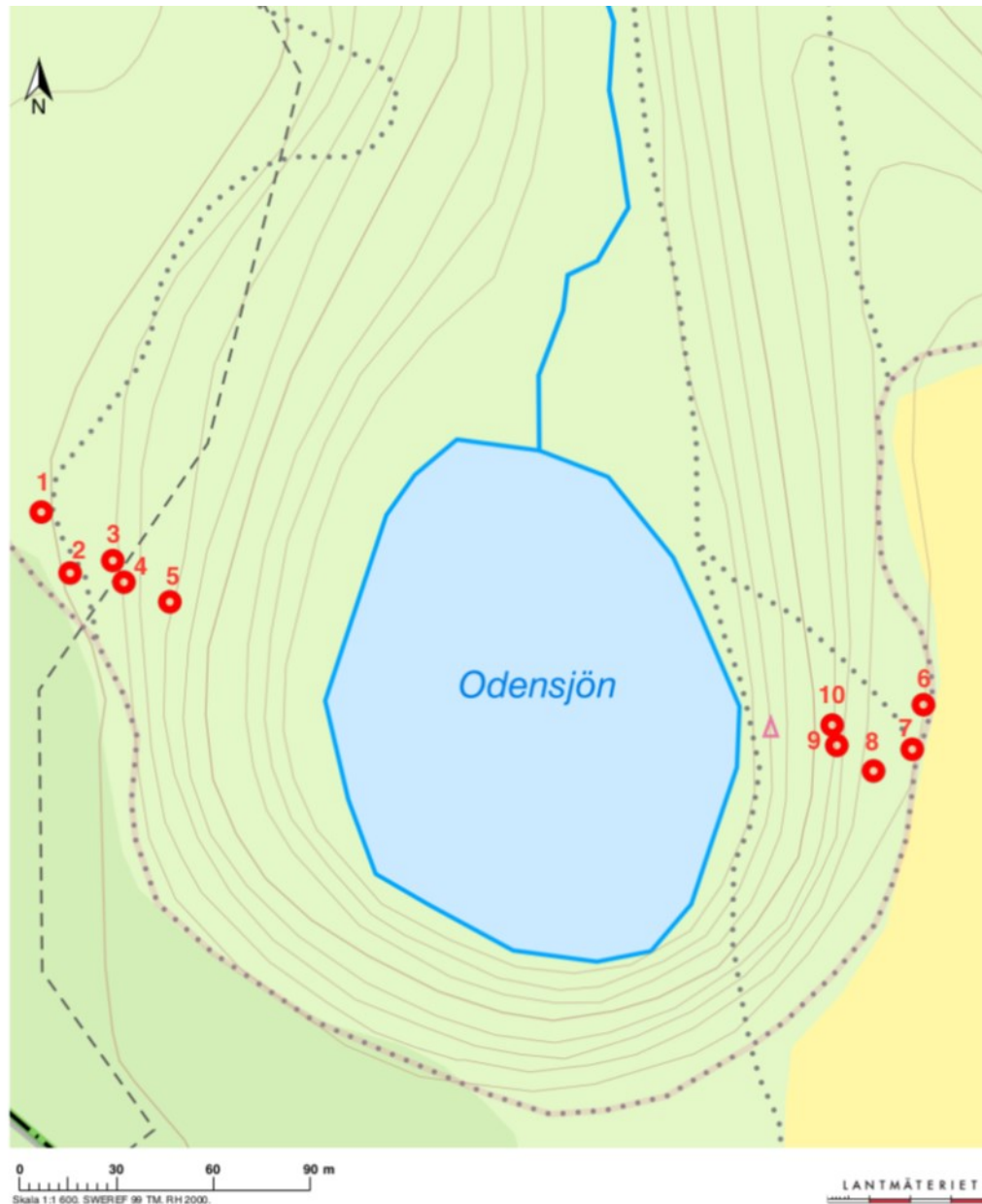


Fig. 13. Map depicting the location of drilling sites for the dendrochronological analysis. Tree 1 through 5 were positioned on the west part of the slope and Tree 6 through 10 were positioned on the east part of the slope. Modified from Lantmäteriet (2020a).

(around a couple of mm) were categorized as unidentified leaf fragment. Even though some of these leaf fragments were suspected to be *Fagus sylvatica*, it was considered too uncertain to classify them to a specific taxon due to their small size.

All other material was identified and counted individually, except *Sphagnum spp.* stems and *Sphagnum spp.* leaves. Due to the sometimes very high abundance of this material, making accurate counting and quantification difficult, they were put in the categories of ≤ 20 or > 20 . Material that was considered irrelevant for the purpose of this study was not counted (e.g. insect parts and different kinds of grasses). Leaves were mainly further identified to species level when leaf edges and other distinct features were visible that allowed for identification (eg. in Fig. 12a-f). For the relevance of this study, focus was put on iden-

tification of *Fagus sylvatica*. Apart from the distinct leaf edges and texture, *Fagus sylvatica* could also easily be identified due to its very distinct colour in the samples, with the leaves being orange with dark brown veins. Reference material used for help of identification includes the reference collection of seeds and nuts at Department of Geology, Lund University. A reference collection of partly decomposed leaves and buds was also constructed based on material collected on the ground in the area around Lake Odensjön on 21 February 2020, consisting of the present dominating species in the area (*Fagus sylvatica*, *Quercus robur*, *Carpinus betulus*, *Betula pendula*, *Betula pubescens*, *Alnus glutinosa*, *Tilia cordata* and *Corylus avellana*). Additional reference work used includes Cappiers et al. (2012), Birks (2007), Mauquoy & Van Geel (2007), Nilsson (1952) and Mossberg (1992).

When all the macrofossil data had been

collected, concentrations were calculated using Excel. Concentrations for each taxon and type of remain (e.g. leaves) were calculated by dividing the counted number of finds for each taxon with the sample volume (ml) and multiplying it with 1000 to make the bars in the diagram larger and thus easier to observe. The data was thereafter transferred into Tilia (Grimm 2007) for the creation of a macrofossil diagram. All data are presented as histograms, except *Sphagnum spp.* data, which are presented with + (present) and ++ (present in abundance). Depth (cm) and age (CE) were added to the y-axis. Macrofossil assemblage zones were constrained with the help of the in-program cluster analysis CONISS.

4.4 Dendrochronological analysis

Fieldwork for the dendrochronology was carried out on 11 May in 2020. The management of the Söderåsen National Park only allowed drilling of one core from each of ten *Fagus* trees growing next to Lake Odensjön. This sample size is on the smaller side to provide a representative picture of the establishment and development of the local *Fagus* population. Moreover, the fact that only one core was allowed to be drilled from each tree implies that the data may be more difficult to interpret because of the risk of getting damaged cores, cores that are far away from the tree center, or cores that are difficult to measure. Normally, multiple cores are taken from each tree in this type of studies to minimize the effect of these problems.

As *Fagus sylvatica* is growing all around the lake, it was decided to focus the drilling on two different clusters of trees growing on the east and west side of the lake respectively (Fig. 13). This decision was made due to the fact that it was desirable to capture older trees in our samples, as older trees would give a better indication of how far back in time the local *Fagus* population established itself, as well as to get an indication if the establishment of *Fagus* would have occurred at the same time on different parts of the slope. The trees picked out for drilling were chosen based on their older looking appearance, with features indicative of old age such as a large trunk diameter and tallness. Trees with different kinds of disturbances such as the trunks of two trees grown together or visible damage on the outside of the tree were avoided since it would be more likely that these would show tree-ring disturbances. An increment borer was screwed into each tree for extraction of the cores at breast height (around 1.4 m above the forest floor) on the uphill side of the tree. As seen in Fig. 13, all the trees selected for analysis grow on the steep slopes immediately surrounding Lake Odensjön. When trees are growing on an inclined surface, the central rings are usually offset from the geometrical center of the tree, so by coring on the uphill side of the tree, there is a greater chance to get the central rings included in the core.

When all ten cores had been extracted, they were taken back to the Laboratory for Wood Anatomy and Dendrochronology at Lund University, where they were filed down to make the rings more visible as well as glued to a piece of wood to make them more stable. The rings were counted manually from the bark inwards on a measuring table under a stereo microscope.

As the tree rings were counted, talc and water were applied to the cores to make the tree rings more visible. For most cores, the central tree ring was not visible and an estimation of the number of tree rings left towards the center was made. It was also decided that around 10 years should be added to each core, to compensate for the years it took for each tree to grow up to breast height (Edvardsson, personal communication 2020). Tree-ring width was not measured, as this information was considered unnecessary for the purpose of this study.

When the tree rings had been counted for each core, the data was transferred into Excel, and a chart showing the tree ring counts, estimated missing rings and remarks was made. Thereafter, a diagram illustrating the results was also constructed using Excel.

5 Results

5.1 Pollen

The results from the pollen analysis are presented in the pollen percentage diagram (Fig. 14a and 14b). Total pollen concentration ($\times 10\,000$ grains/cm³) and the terrestrial pollen sum data are also shown. Six pollen assemblage zones were identified with CONISS. The zones were named based on the most prominent taxa in each zone.

5.1.1 Oden-Pol1 86-73 cm (1504-1575 CE)

Fagus-Betula-Alnus

The lowermost zone is characterized by maximum *Fagus* percentages within the analysed sequence, including a large increase from 45% to 65% at 76 cm, which is the level with the highest recorded *Fagus* percentage. *Betula* starts off with 20% but decreases to 12% at 76 cm. *Alnus* retains a steady percentage of 8% throughout this zone, except for a small decrease from 15% at the beginning of the zone. *Quercus* and *Pinus* decrease from 3.2% and 3.6% respectively, to 1.9% and 1.5% at 76 cm. *Carpinus*, *Tilia* and *Salix* retain average values of 1.2%, 0.5% and 0.3% respectively throughout this zone. *Picea* (1%) is also present. *Calluna* (0.5%) is present, but in fairly small amounts. Both Poaceae (<40 μm) and Polypodiaceae show steady values of 4% throughout this zone, except for a slight initial Polypodiaceae decrease from 6%. Total pollen concentration peak ($\sim 150\,000$ grains/cm³) at around 76 cm, which corresponds to the peak of *Fagus*.

5.1.2 Oden-Pol2 73-54 cm (1575-1722 CE)

Fagus-Alnus-Betula-Juniperus-Poaceae

This is the stratigraphically widest zone within the sequence. *Fagus* shows drastically decreasing percentages, landing at 28% towards the top of the zone (54 cm). A small break is seen in the decrease of *Fagus* at 60 cm, where it temporarily increases up to 67%. *Alnus* shows an increase of up to 20% at 64 cm, but subsequently decreases to around 15%. *Betula* is fairly stable in this zone with values around 13%. At 64 cm *Juniperus* starts to increase from 3%, and it reaches 21% at 56 cm. *Quercus* increases to 6.5% at 68 cm, and *Tilia*, *Fraxinus* and *Ulmus* are present (all around 0.5%) but disappear completely at around 64 cm. Taxa

belonging to the herbs and graminids group generally occur in fairly high percentages (15%) in the middle of this zone (64 cm). *Sphagnum* (0.5-1%) is also present in steady quantities throughout this zone.

5.1.3 Oden-Pol3 54-48 cm (1722-1769 CE)

Fagus-Juniperus-Betula-Alnus

This is the stratigraphically narrowest zone within the sequence, and it features a steep *Juniperus* increase. *Juniperus* increases to 53% towards the top of the zone (48 cm) which is the maximum percentage of *Juniperus* throughout the sediment sequence. *Fagus* continues to decrease along with *Alnus* (both down to around 8%), although *Fagus* decreases somewhat more rapidly. Taxa belonging to the herbs and graminids group are present in fairly high percentages (15%) in this zone, with both Cerealia (2%) and Cyperaceae (2.2%) reaching their highest percentages throughout the sequence. *Sphagnum* also reaches its highest numbers and is present at 1.5%.

5.1.4 Oden-Pol4 48-35 cm (1769-1867 CE)

Juniperus-Betula-Alnus-Fagus

Zone Oden-Pol4 is characterized by very high values of *Juniperus* and low values of *Fagus*. *Juniperus* maintains high values throughout this zone, but is steadily decreasing and reaches 24% at 35 cm. *Fagus* is consistently at a low percentage, and at 36 cm it reaches its minimum of 6%. *Betula* starts to increase in the beginning of this zone, and peaks at 37% at 36 cm. *Alnus* remains at a somewhat steady percentage (8-9%). *Tilia* (0.5%), *Salix* (0.6%) and *Fraxinus* (0.2%) make a reappearance in this zone, and *Picea* (0.2%) appears towards the top of the zone (36 cm). Taxa belonging to the herbs and graminids groups decrease to 11% in this zone. *Sphagnum* remains stable at 1%.

5.1.5 Oden-Pol5 35-20 cm (1867-1975 CE)

Betula-Fagus-Alnus-Poaceae

Zone Oden-Pol5 shows higher percentages of *Fagus*, *Betula*, *Alnus* and Poaceae compared with the previous zone, along with lower percentages of *Juniperus*. *Fagus* starts to increase in percentages in the bottom of the zone, but from 30 cm and towards the top of the zone *Fagus* remains fairly constant at around 23%. *Betula* remains at higher percentages (34%), but declines slightly towards the top of the zone at 22 cm (to 27%). The tree group as a whole shows an increase of up to 79%, including increasing percentages of *Alnus* (18%), *Quercus* (5%), *Pinus* (5%), *Picea* (4%), *Carpinus* (3%), *Fraxinus* (0.4%) and *Ulmus* (0.6%) towards the top of the zone. *Salix* initially increases to 1% at 27 cm but decreases to 0.2% towards the top of the zone. *Juniperus* continues to decrease in percentages throughout the zone and reaches 2% at 20 cm. *Calluna* (1%) increases slightly and Ericaceae undiff. (0.2%) makes its first appearance in this zone. Herbs and graminids (13%) see an increase altogether as a group, with median values of Poaceae at 8% and Cerealia at 1%. Both *Potamogeton* (0.2%), *Nymphaea alba* (0.2%) and *Sphagnum* (0.4%), which have been present in the previous zones, starts to decline. Some charcoal fragments (0.3%) were also found.

5.1.6 Oden-Pol6 20-0 cm (1975-2016.5 CE)

Betula-Fagus-Alnus-Pinus

The tree group as a whole maintain high percentages in the uppermost zone within the sequence, with *Fagus* (26%) continuing to increase somewhat and *Betula* showing a minor decrease with a median value of 29%. *Alnus* (16%), *Quercus* (6%) and *Picea* (3%) remain at stable percentages throughout this zone, all being somewhat higher than in the previous zone. *Pinus* remains at similar percentages as within the previous zone up until 8 cm, where it starts to increase, reaching 14% at the top of the zone. *Juniperus* and *Corylus* continue to decrease further, reaching very low percentages towards the top of the zone (0% and 0.4%, respectively). *Calluna* (0.2%) is present, but in small amounts, and Ericaceae undiff. (0.2%) is present in somewhat higher percentages compared with the previous zone. The herbs and graminids group show lower percentages, including median values of Poaceae (6%), Cerealia (0.05%), Cyperaceae (0.3%), *Plantago* (0.2%) and Chenopodiaceae (0.2%). Charcoal (0.1%) is also present in this zone.

5.1.7 Main features of the pollen record

The most dominant taxon in the pollen data set is *Fagus* (Fig. 14a and 14b). *Fagus* is increasing from the bottom of the sediment sequence and reaches its highest pollen percentages throughout the sediment sequence in zone Oden-Pol1 at 76 cm (1554 CE). Above this depth, *Fagus* is continuously decreasing in percentages until 36 cm (1860 CE) where it reaches its lowest percentages throughout the sediment sequence. *Fagus* subsequently increases in percentages up to 28 cm in zone Oden-Pol5 (1929 CE) where it remains relatively stable until the top of the sediment sequence. Other tree taxa (*Carpinus*, *Tilia*, *Salix*, *Fraxinus* and *Ulmus*) show a similar trend of *Fagus*, with values beginning to decrease around the top of zone Oden-Pol1, which increases again in zone Oden-Pol5. *Betula* retains relatively low percentages in the bottom half of the sediment sequence, but increases at 48 cm (1769 CE), and reaches its highest percentages at 32 cm (1891 CE). *Alnus* shows an initial increase in percentages at the beginning of zone Oden-Pol2 at 72 cm (1581 CE), but subsequently decreases until the top of zone Oden-Pol3 at 48 cm (1769 CE). *Alnus* starts to increase again at 36 cm (1860 CE) where the values remain high until the top of the sediment sequence. Both *Quercus* and *Pinus* increase in percentages in the beginning of zone Oden-Pol2, but values subsequently decrease and do not begin to increase again until the beginning of zone Oden-Pol5. *Picea* is absent in the lower half of the sediment sequence, apart from some low percentages in the beginning of zone Oden-Pol1. In the beginning of zone Oden-Pol5 *Picea* enters the pollen record again and increase in percentages until the top of the sediment sequence. Shrubs, dwarf shrubs and the herbs and graminids group show a general trend with increased percentages throughout zone Oden-Pol2 to Oden-Pol5. This trend is particularly prominent for *Juniperus*, which reaches its highest values at the end of zone Oden-Pol3.

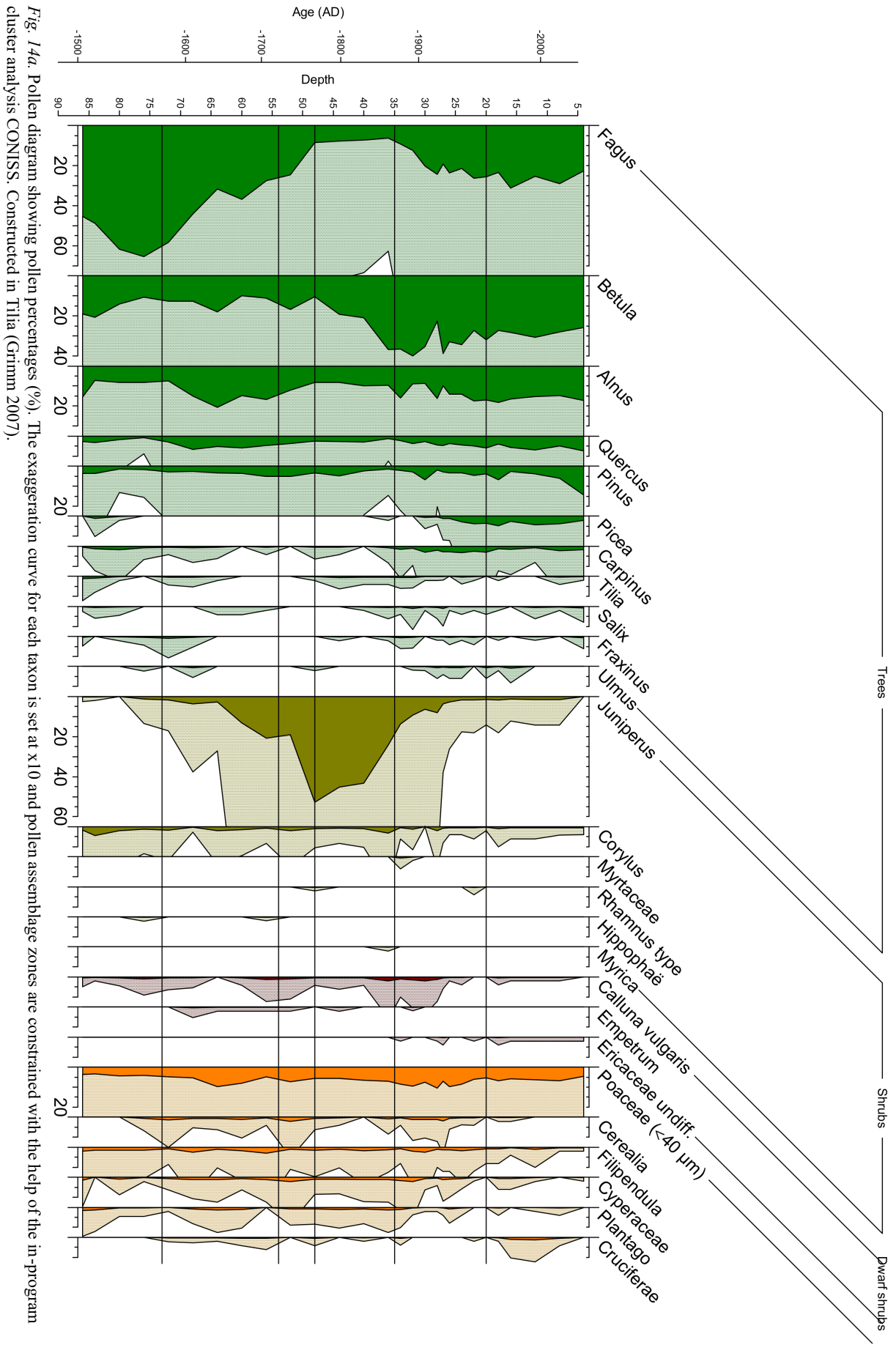


Fig. 14a. Pollen diagram showing pollen percentages (%). The exaggeration curve for each taxon is set at x10 and pollen assemblage zones are constrained with the help of the in-program cluster analysis CONISS. Constructed in Tilia (Grimm 2007).

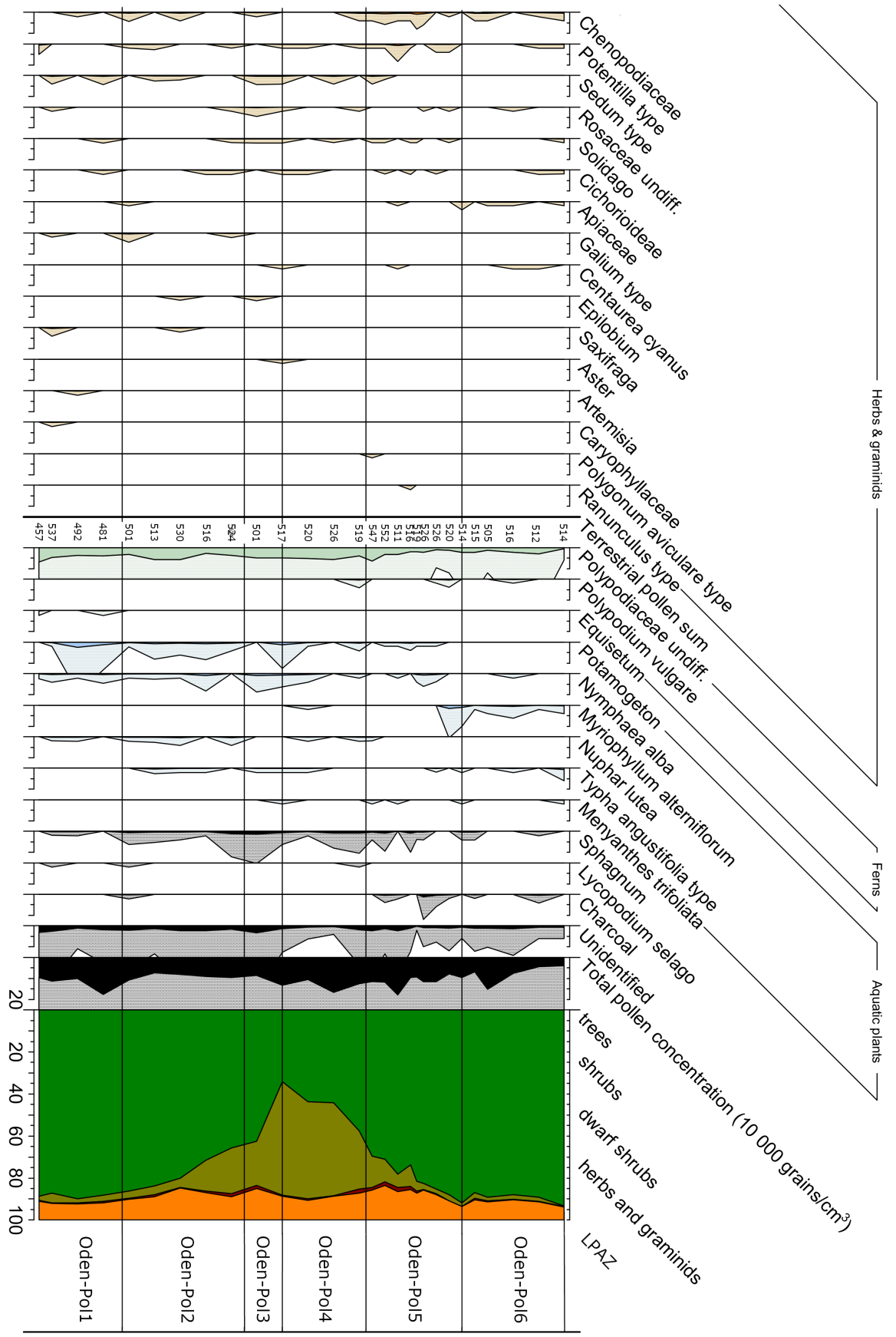


Fig. 14b. Continuation of Fig. 14a.

5.2 Macrofossils

The results from the macrofossil analysis are presented in the diagram in Fig. 15. The bars show concentration (number of finds per cm³ x 1000). *Sphagnum* data are shown by the following symbols: (present) + and ++ (present in abundance). Five macrofossil assemblage zones were identified with CONISS and are described below.

6.2.1 Oden-Ma1 86-71 cm (1504-1588 CE)

The lowermost zone is characterised by a relatively rich macrofossil record. *Fagus sylvatica* (leaves >1/3, leaf fragments and buds) is the most prominent taxon present in this zone. Some *Betula pendula* and *Betula pubescens* fruits are also present, although no female catkin scale or leaves were found. Fruits of *Alnus glutinosa* occur at 72 cm, and both fruits and leaves of *Carpinus betulus* are found at 74 cm. *Sphagnum* spp. (leaves and stems) are present in smaller amounts, and unidentified material (buds, seeds, leaf fragments) generally occur in quite high amounts.

5.2.2 Oden-Ma2 71-56 cm (1588-1706 CE)

This zone is characterised by generally lower amounts of plant remains, except for an increase in *Sphagnum* spp. Macrofossils of *Fagus sylvatica* (leaves >1/3, leaves, buds) are present throughout the zone in lower amounts than the previous one. The only exception is a peak of *Fagus sylvatica* leaf fragments at 58 cm. *Betula* (*pendula* and *pubescens*) is mostly absent, although a few fruits were found at 58 cm, 68 cm and 70 cm. *Sphagnum* spp. (stems and leaves) are abundant throughout this zone. Unidentified leaf fragments show steadily decreasing concentrations and are absent in the uppermost samples belonging to this zone. Both unidentified buds and seeds are present.

5.2.3 Oden-Ma3 56-37 cm (1706-1852 CE)

This zone is characterised by generally low concentrations or absence of most taxa previously recorded, apart from *Sphagnum* spp. *Fagus sylvatica* is completely absent in this zone, which makes it the only zone without presence of *Fagus sylvatica*. Some fruits of *Betula pubescens* and *Betula pendula* were found. *Betula* fruits that could not be separated into *Betula pendula* or *Betula pubescens* were found in relative abundance throughout the zone, implying continuous presence of either one of these species, or both of them. *Sphagnum* spp. (leaves and stems) continues to be present in a relative abundance and some *Sphagnum* spp. sporangia were also found. Unidentified leaf fragments are only recorded at low concentrations in a few samples in this zone.

5.2.4 Oden-Ma4 37-18 cm (1852-1983 CE)

This zone forms the stratigraphically widest zone, and also shows the highest concentration of macrofossils seen in the core. *Fagus sylvatica* makes a reappearance with buds and leaves at 30 cm, and leaves >1/3 appearing at 26 cm. The highest concentrations of *Fagus sylvatica* macrofossils are found in this zone. Both *Betula pendula* and *pubescens* increase strongly in this zone, and some *Betula* spp. leaves were also found. An

especially large amount of *Betula pendula* fruits is found at 22 cm and 30 cm. *Alnus glutinosa* (fruits and cones) reappears and is present at four different depths (30 cm, 27 cm, 20 cm and 18 cm). Fruits of *Carpinus betulus* were found, and *Quercus robur* is present for the first time in the sediment sequence. *Sphagnum* spp. decreases in abundance and is absent from 27 cm. Unidentified twigs, buds and seeds are present in this zone, and there is an abundance of unidentified leaf fragments, peaking at 27 cm.

5.2.5 Oden-Ma5 18-0 cm (1983-2017 CE)

The uppermost zone is characterised by high concentrations of terrestrial macrofossils, although lower than in zone Oden-Ma4. *Fagus sylvatica* continues to show relatively high concentrations, although somewhat lower compared to the previous zone. *Betula pendula/pubescens* also remain present but in lower amounts, and *Betula pendula* leaves were found at three depths (12 cm, 10 cm and 8 cm). *Alnus glutinosa* is scarcely present with leaves and cones, and both *Carpinus betulus* and *Quercus robur* leaves were found. Single *Sphagnum* spp. leaves were found in two samples (16 cm and 8 cm), and charcoal is present at 16 cm. Unidentified twigs, buds, seeds, and leaf fragments are all present in relatively large amounts.

5.2.6 Main features of the macrofossil record

The macrofossil data show that the most dominant species present in the sediment sequence is *Fagus sylvatica* (Fig. 15). The *Fagus sylvatica* records show a clear pattern of relatively high values in the lowermost part of the sediment sequence, followed by declining values and complete absence at 56 cm, corresponding to 1706 CE. At around 30 cm (1910 CE) *Fagus sylvatica* reappears and increases strongly between 26 cm and 18 cm (1946-1968 CE), reaching its highest abundance throughout the sediment sequence. Most records of the other taxa in the macrofossil data set show a similar trend to that of *Fagus sylvatica*, with an absence of material in zone Oden-Ma3, covering the depths of 56 cm – 37 cm (1706-1851 CE). This trend is, apart from the *Fagus sylvatica* records, especially apparent for unidentified leaf fragments, although this record indicate that some trees were continuously present at the site. The *Betula pubescens* and *Betula pendula* records show a similar trend to one another, with the exception of the high abundance of *Betula pendula* fruits at 30 cm and 22 cm. The majority of *Betula* material is found in the uppermost part of the sediment sequence, from 30 cm. However, the *Betula* spp. fruit record reflects presence of either both of these species, or one of them, between 55 cm and 30 cm. Both *Carpinus betulus* and *Alnus glutinosa* are present in the lower and upper zones of the sediment sequence (Oden-Ma1, Oden-Ma4 and Oden-Ma5), while *Quercus robur* is only present in the upper part of the sediment sequence (Oden-Ma4 and Oden-Ma5). *Sphagnum* spp. is mainly present in the middle and lower part of the sediment sequence (Oden-Ma1, Oden-Ma2, Oden-Ma3 and Oden-Ma4). It seems like *Sphagnum* spp. increases in abundance during the period when other species are declining, considering its highest abundance is at 32 cm – 68 cm, and that it disappears

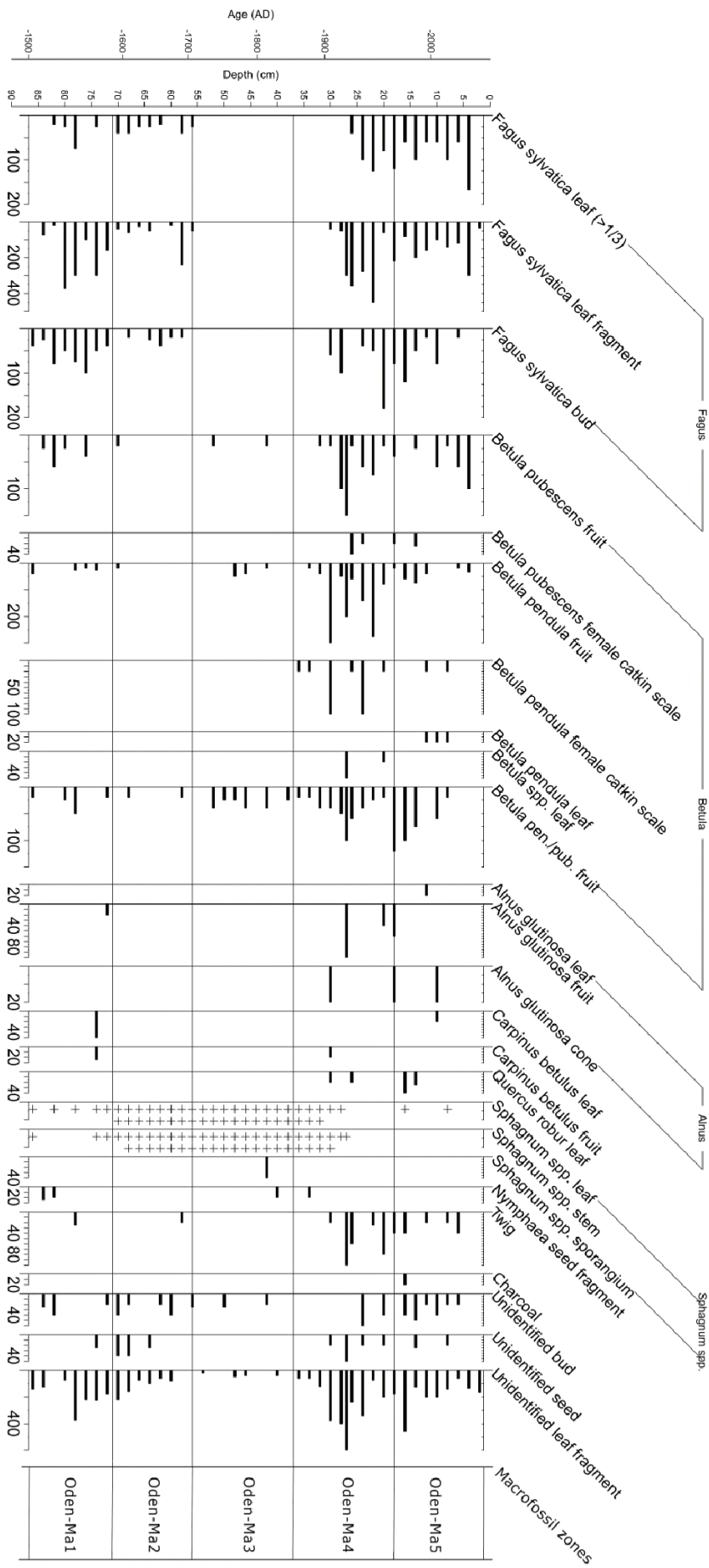


Fig. 15. Macrofossil diagram constructed in Tilia (Grimm 2007). Bars show concentration (number of finds per cm³ x 1000). *Sphagnum* data are shown by the following symbols: (present) and ++ (present in abundance). Zones are constrained with the help of the in-program cluster analysis CONISS.

almost completely from the sediment sequence at 27 cm (1938 CE).

5.3 Dendrochronology

The results from the tree-ring analysis are shown in Table 1 and Fig. 16. In Fig. 16, the tree number is shown on the y-axis, and the age (CE) on the x-axis. Orange vertical line (age 1900 CE) represents the average value for counted tree-rings and blue vertical line (age 1886 CE) represents the average age for counted tree-rings with estimated years included, both excluding tree-rings with estimated years included, both excluding Tree 1. Each sample was given two different ages, one age derived from the counted rings (dark green), and a second age derived from the counted rings but with the estimated rings to the tree center and the estimated years for growth to breast height included in the age (light green). Both these ages are shown due to the fact that the age including estimated years is far more uncertain than the age only derived from the actual tree ring counts. However, there is also an uncertainty associated with the counted tree rings as an effect of possibly missing rings or counting errors. Therefore, it is wise to consider both of these ages as rough estimates rather than absolute ages. For the sake of simplicity, only the counted age will be used in the description below.

According to the counts, Tree 1 (age 1959 CE) is the youngest sampled tree, but the reason for the low age is that this sample showed damaged on the inner tree rings close to the core, creating a hiatus after the 61st ring counted outwards up until the damage. Because of this hiatus, this age should be viewed as a minimum age, and the tree is undoubtedly older in reality. Excluding Tree 1, Tree 7 is the youngest tree, dating back to 1947 CE, followed by Tree 6 (age 1927 CE). Tree 2 contained very clear and easy distinguishable rings, making the ring counts for this sample far more certain than for the other trees. Tree 2 is dated to 1918 CE. Tree 3 (1900 CE), 4 (1898 CE), 9 (1902 CE) and 10 (1888 CE) are all very close to each other in age, and Tree 5 (1880 CE) is slightly older. Tree 8 is by far the oldest tree in the sample group and dates back to 1844 CE, which makes it 36 years older than the second oldest tree.

6 Discussion

6.1 Comparison of the pollen and macrofossil data

Zonation of the pollen and macrofossil diagrams using the in-program cluster analysis CONISS in Tilia resulted in a total of six pollen assemblage zones and five macrofossil assemblage zones, respectively. Even though the number of zones in the two different data sets is different, the zone boundaries are positioned at similar depths in the sediment sequence (Fig 14a and 14b, Fig. 15). Moreover, the taxon representation in both data sets also shows a large resemblance. Comparing the zonation of the two different data sets, the main difference is that the interval with low *Fagus* pollen values in the mid part of the sequence is represented by two zones (Oden-Pol3 and Oden-Pol4) in the pollen record (Fig. 14a and 14b), while the corre-

sponding interval with *Fagus* absence in the macrofossil record only is represented by one zone (Oden-Ma3) (Fig. 15). Zone Oden-Pol3 appears to primarily be constrained by the large increase of *Juniperus* pollen, a taxon that is not represented in the macrofossil data, which partly may explain this difference in zonation.

The largest difference between the pollen data and the macrofossil data is that the pollen data contains a larger number of taxa compared to the macrofossil data. The abundance of pollen is usually significantly larger compared to the abundance of macrofossils in a data set (Birks & Birks 2000). Moreover, the sediment sequence was retrieved from the deepest part of Lake Odensjön (Hertzman in prep.). Birks (2002) suggests that coring should preferably be executed in the littoral zone for retrieving an optimal amount of plant remains, since plant remains do not readily reach the center part of lakes. Presumably, presence of some species that were growing at Lake Odensjön are not possible to document with the studied sediment sequence, and perhaps a higher quantity as well as variety of plant remains could have been retrieved if the coring was executed in the littoral zone. Other factors that determine the presence of macrofossil remains include that a lack of macrofossils of a specific taxon can be the result of that specific taxon not producing much plant remains, or that the taxon was not present locally at the site. For example, *Juniperus* is strongly represented in the pollen data (Fig. 14a and 14b), but no macroscopic *Juniperus* remains were found. *Juniperus* is not an uncommon taxon found in macrofossil data if it is growing locally (Birks 2007), and therefore it is unlikely that the main part of the *Juniperus* pollen is derived from individuals growing on the slopes surrounding the lake.

Fagus is the taxon with the strongest representation in both the macrofossil data and the pollen data (Fig. 14a and 14b, Fig. 15). In the pollen diagram, *Fagus* is increasing from the bottom of the sediment sequence up to 1554 CE in zone Oden-Pol1, where the *Fagus* pollen reach their highest percentages throughout the sediment sequence (Fig. 14a and 14b). From 1554 CE *Fagus* is decreasing in percentages, but still retain relatively high percentages up to 1738 CE in zone Oden-Pol3, whereafter a steep decrease is seen. *Fagus* percentages remain low until 1860 CE in zone Oden-Pol4, where the percentages begin to increase, and will remain at relatively high percentages up to the top of the sediment sequence. A similar pattern for *Fagus* is seen in the macrofossil diagram (Fig. 17). Macrofossils of *Fagus* retain high concentrations up to around 1569 CE in zone Oden-Ma1, whereafter they begin to decrease and reach complete absence after 1706 CE, in the beginning of zone Oden-Ma3. Macrofossils of *Fagus* begin to reappear in 1910 CE, and remain at high concentrations up to the top of the sediment sequence. One difference between the *Fagus* trend in the macrofossil data and pollen data, is that the peak of *Fagus* percentages/concentrations is reversed in the different data sets (fig. 17). In the pollen data, *Fagus* reaches its highest percentages in zone Oden-Pol1, in the lower part of the sediment sequence, whereas the highest *Fagus* macrofossil concentrations are reached in zone Oden-Ma4, in the upper part of the sediment sequence. Considering that macrofossils re-

Table 1. Table showing the collected data from the dendrochronological analysis. Two different ages are constrained, one including counted rings and another one including estimated rings to the tree center and estimated years for growth to breast height.

Trees	Counted rings	Estimated rings to center	Estimated years for growth to breast height	Age (counted rings)	Age (including estimated rings)	Remarks
1	61	n/a	10	1959	1949	87 rings counted, but there is a major hiatus after ring 61 with the following rings being very unclear
2	102	5	10	1918	1903	Very clear rings
3	120	3	10	1900	1887	Last 10 rings were quite un-
4	122	0	10	1898	1888	Tree center is visible in the
5	140	5	10	1880	1865	
6	93	10	10	1927	1907	
7	73	3	10	1947	1934	
8	176	3	10	1844	1831	
9	118	5	10	1902	1887	
10	132	5	10	1888	1873	

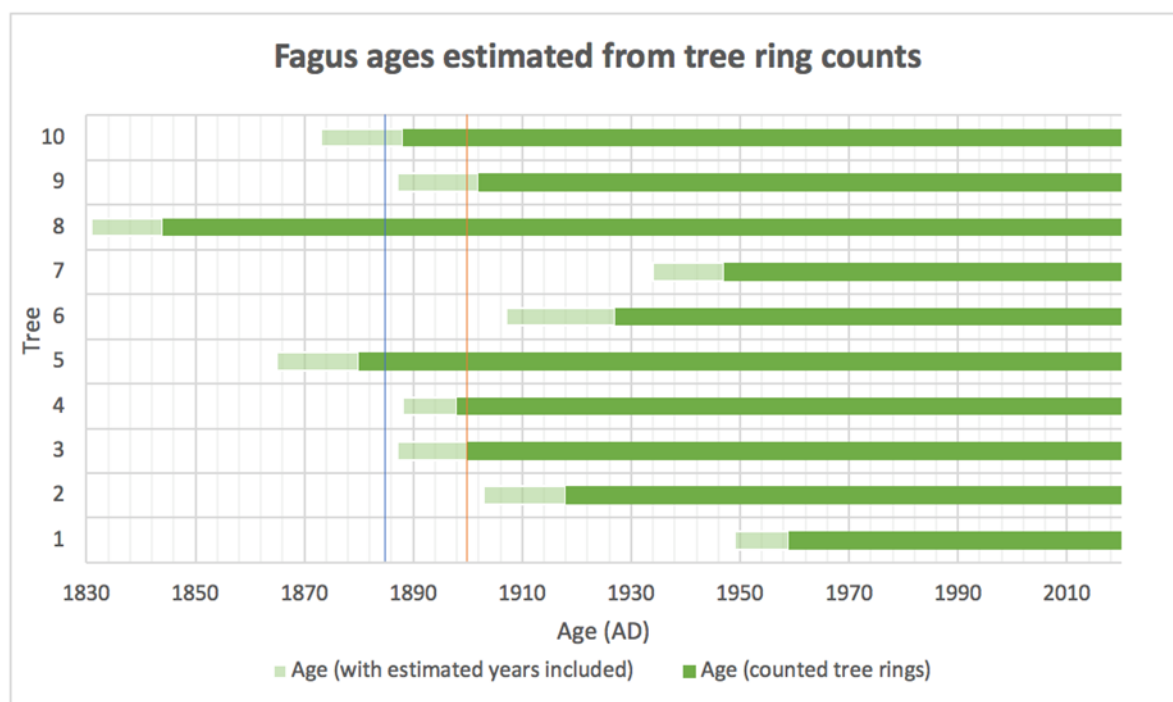


Fig. 16. Figure illustrating the estimated ages from the tree-ring counts. Dark green bars shows the age of the counted rings and light green bars shows the age of the counted rings with estimated rings to the tree center and the estimated years for growth to breast height included in the age. Orange vertical line (age 1900 CE) represents the average value for counted rings excluding Tree 1 and blue vertical line (age 1886 CE) represents the average age for counted rings with estimated years included, excluding Tree 1.

flect a local signal, as they tend to almost exclusively be deposited locally, it is possible that the high pollen percentages in the lower part of the sediment sequence reflect a more regional signal compared to the upper part of the sediment sequence, as the macrofossil content is lower in the lower part of the sediment

sequence.

Another aspect with regard to the *Fagus* content in the macrofossil data, is the unidentified leaf fragment content. As mentioned in section 5.3, many of the leaf fragments found in the macrofossil samples were suspected to represent *Fagus sylvatica* solely

based on their distinct colour. However, due to their small size (a couple of mm in size) it was deemed too uncertain to draw this conclusion. In the macrofossil data set, unidentified leaf fragments show a very similar trend to *Fagus sylvatica* macrofossils (Fig. 17). Assuming that the unidentified leaf fragment record represents *Fagus sylvatica*, the periods characterized by decreasing and minimum values of *Fagus*, would rather span the time period of around 1569 - 1860 CE, instead of 1569 – 1910 CE. This assumption allows for an even stronger resemblance between the *Fagus* content in the pollen and macrofossil data.

The *Betula* macrofossil and the pollen records shows a very similar trend to one another, with lower percentages/concentrations in the lower part of the sediment sequence, which increase in the upper part of the sediment sequence (Fig. 18). *Betula* percentages begin to increase around the second half of the 18th century in the pollen data, and around the beginning of the 20th century in the macrofossil data, respectively. The strong presence of *Betula* in the upper part of the sediment sequence (zone Oden-Pol5, Oden-Pol6, Oden-Ma4 and Oden-Ma5, respectively) for both datasets supports that *Betula* had a strong local presence

during this period. As mentioned earlier, macrofossils tend to be deposited locally, but macrofossils of *Betula* fruits make an exception, as they may be dispersed by wind over relatively large distances (Lowe & Walker 2014). Taking this into account, it appears as though *Betula pendula* was more common around Lake Odensjön than *Betula pubescens*, as the concentration of *Betula pendula* macrofossils (female catkin scale and leaves) excluding *Betula pendula* fruits, show higher concentrations than macrofossils of *Betula pubescens*.

Macrofossils of both *Alnus* and *Quercus* primarily occur in the upper part of the sediment sequence, in zone Oden-Ma4 and Oden-Ma5 (Fig. 15). In the pollen data, both these taxa show an initial increase in the lower part of the sediment sequence around 1605 CE in zone Oden-Pol2, with a second increase in the upper part of the sediment sequence beginning around 1875 CE in zone Oden-Pol5. Considering that very few or no macrofossils were found in the corresponding part of the macrofossil record, this pollen percentage increase likely represents a more regional signal for these taxa. Macrofossils of *Carpinus* appear both in the lower and upper part of

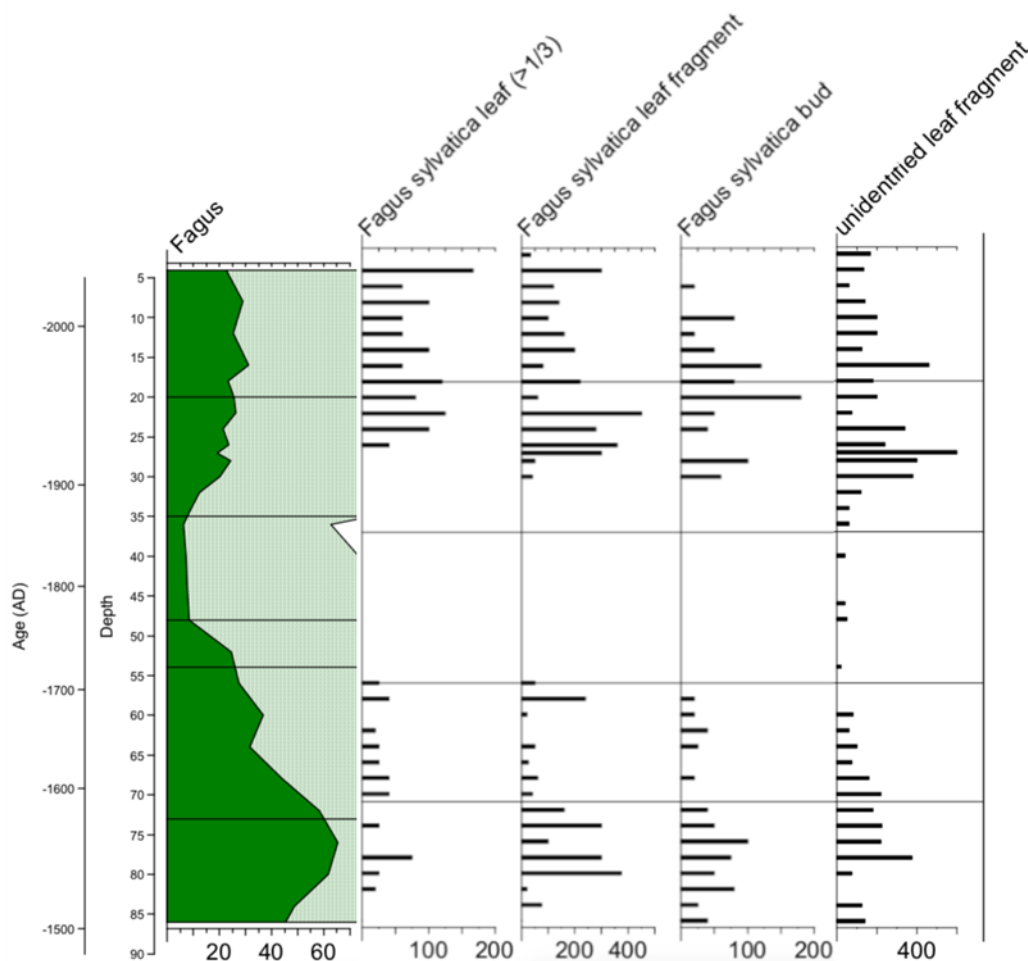


Fig. 17. Diagram comparing pollen and macrofossil data of *Fagus* and unidentified leaf fragments macrofossil data. Pollen diagram (to the left) shows pollen percentages (%) and have an exaggeration of x10. Macrofossil diagrams (to the right) is represented by bars that show concentration (number of finds per cm³ x 1000). Zones for each data set are constrained with the help of the in-program cluster analysis CONISS. Both data sets are constructed in Tilia (Grimm 2007).

the sediment sequence (zones Oden-Ma1 and Oden-Ma4 to Oden-Ma5) (Fig. 15). In the pollen data, *Carpinus* follows this trend, with an increase in percentages in zone Oden-Pol1 and Oden-Pol5 to Oden-Pol6 (Fig. 14a and 14b). Due to the similarities in the trend of *Carpinus* of both the pollen data and the macrofossil data it can be concluded that *Carpinus* was present locally on the site.

Charcoal is present in the pollen data primarily in zone Oden-Pol5 and Oden-Pol6 (Fig. 14a and 14b). In the macrofossil data, charcoal is present in zone Oden-Ma5 (Fig. 15). The presence of charcoal in both these data sets suggests local human disturbances at the site. *Sphagnum* is also present in both the macrofossil data and the pollen data, primarily in zones Oden-Pol2 through Oden-Pol5 (Fig. 14a and 14b) and Oden-Ma2 through Oden-Ma4 (Fig. 15), respectively. The high percentages/concentrations of *Sphagnum* suggest that *Sphagnum* was expanding locally during this period, probably in the fen area sur-

rounding the outlet of Lake Odensjön where fen peat occurs today. *Sphagnum* increases simultaneously as the tree cover is reducing in the area based on the data sets, suggesting a linkage between these two trends. Perhaps the reduced tree cover on the fen allowed for more damp conditions, favoring the expansion of *Sphagnum*. A reduced tree cover also allows for increased sunlight in the fen, which also possibly favored an expansion of *Sphagnum*.

6.2 Implications of the dendrochronological data

In combination with the macrofossil and pollen data, the dendrochronological data can give implications of the establishment of the local *Fagus* population around Lake Odensjön. Because of the high uncertainty of the ages obtained from the tree samples, both the ages obtained from the counted rings and the ages obtained from the counted rings with assumed rings

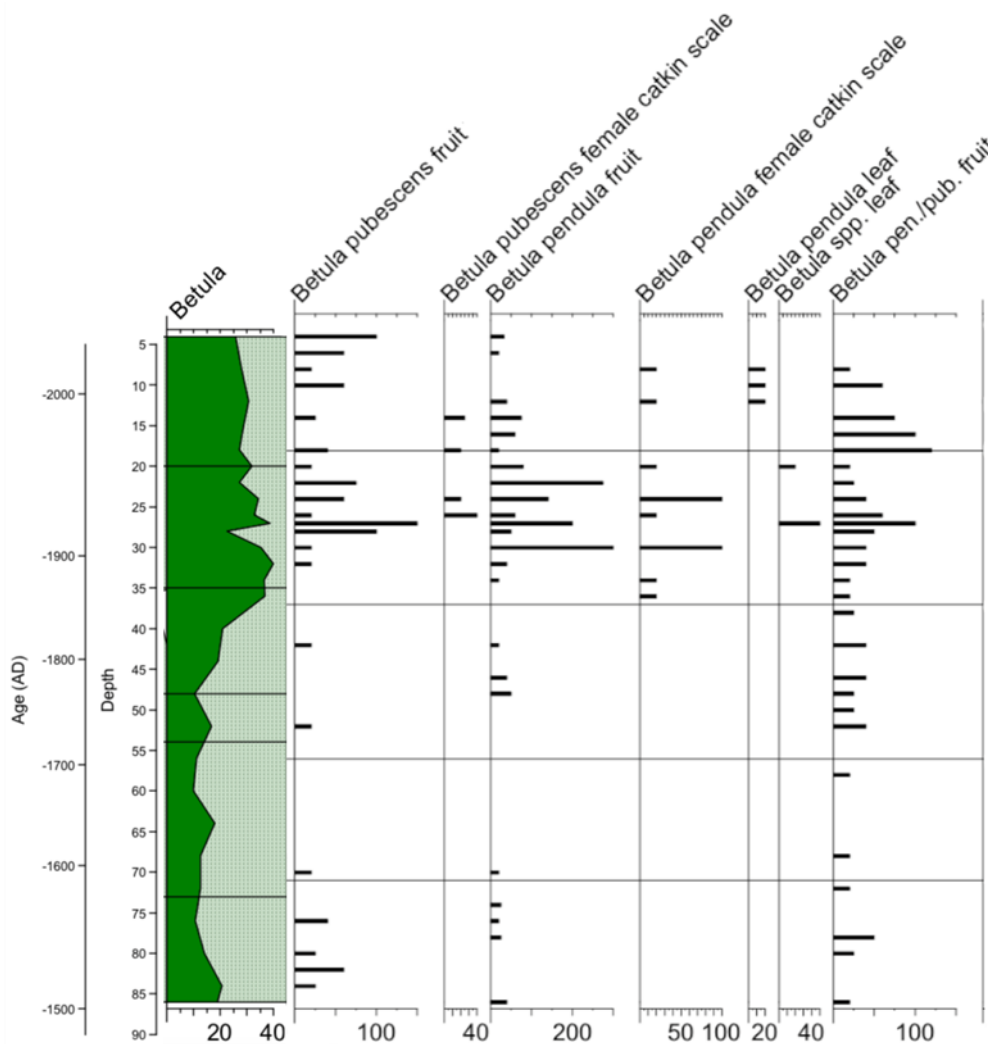


Fig. 18. Diagram comparing *Betula* pollen and macrofossil data. Pollen diagram (to the left) shows pollen percentages (%) and have an exaggeration of x10. Macrofossil diagrams (to the right) is represented by bars that show concentration (number of finds per $\text{cm}^3 \times 1000$). Zones for each data set are constrained with the help of the in-program cluster analysis CONISS. Both data sets are constructed in Tilia (Grimm 2007).

included are included in this discussion.

The average age for all the trees that were analyzed apart from Tree 1 (for which the core was damaged near the central ring, resulting in a lower number of rings counted) is 1900 CE for the exact tree rings counted, and 1886 CE for the exact tree rings counted with assumed additional rings included (Fig. 16). Tree 8 is by far the oldest cored tree, with an age from 1844 CE to 1831 CE. Although there is a margin of error to these ages, it is interesting to note that all the trees, except for Tree 8, fall into the timespan of when the forest is assumed to be growing denser again after 1860 CE, following the period of openness. An important factor to take into consideration when interpreting this data is the location of the trees that were selected for analysis. The selected trees were chosen based on seemingly being the oldest and largest looking trees in the area. As seen in Fig. 13, all of these trees were growing in the topmost part of the slope, leading down to the lake. Further downhill, in the steeper parts, the ground probably is too unstable to successfully support development of large trees. But further uphill, where the slope is less steep and the ground is more stable and not covered by talus, they could have sustained. Perhaps this fairly stable part of the slope could have acted as a refuge for these early emerging *Fagus* trees around the late-19th century, as the ground they were growing on was not really of any use for the humans living in the area, along with the fact the tree-resources were becoming less scarce due to a shift in human activity during this period. Already in the beginning of the 19th century this land is described in maps as “incompetent land” (Lantmäteriet 2020i). However, based on the presence of Tree 8 in this limited sample size, it can be assumed that at least a small *Fagus* population was present around Lake Odensjön at least as early as the mid-19th century.

6.3 Forest and landscape development at Lake Odensjön

6.3.1 Opening of the forest with a decline of *Fagus* from the late 16th-century

Based on the palaeoecological data, the forests around Lake Odensjön were relatively dense during the beginning of the 16th century, with *Fagus* being the dominating species, and shrubs, herbs and graminids being suppressed. In the pollen data, *Fagus* is steadily increasing in zone Oden-Poll from 1504 CE to 1554 CE, where the percentages of *Fagus* seem to peak (Fig. 14). This peak of *Fagus* has its counterpart in the macrofossil diagram in zone Oden-Ma1 around 1535 - 1569 CE (Fig. 15). Other trees such as *Quercus*, *Pinus*, *Carpinus*, *Tilia*, *Salix*, *Fraxinus* and *Ulmus* were making up small stands in the region. As mentioned in section 5.2, *Salix* was included in the tree group because it shows a similar trend in the pollen diagram to some of the recorded trees taxa (e.g. *Carpinus*, *Tilia*, *Fraxinus* and *Ulmus*), but it is important to keep in mind that *Salix* could very well represent shrubs instead of trees. *Alnus* would retain relatively low percentages during zone Oden-Poll. Low percentages of *Alnus* could reflect that the damp meadows where *Alnus* would thrive were used for hay production. Barely

any macrofossils of *Alnus* were found during this period, suggesting that the local population of *Alnus* was more scarce during this period, compared to after the 20th century. *Corylus* and *Calluna* appear to have been present in the shrub layer, and in the herbaceous layer Poaceae and *Filipendula* were present in relatively scarce amounts.

Forest grazing was probably one of the major factor as to why *Fagus* could expand in the forest, not only because *Fagus* is the least sensitive deciduous tree towards grazing (Rackham 1980), but also because of the extensive use of *Fagus* forests for pigs grazing and the resulting burial of nuts, promoting rejuvenation (Sjöbeck 1927). Forest grazing is described to have influenced the expansion of *Fagus* at many localities in southern Sweden during the last millennia (Björkman 2001). At the same time as *Fagus* reaches its highest percentages during the mid-16th century, *Quercus* is decreasing in pollen percentages, which could be attributed to the interdependency of pollen percentage data (Fig. 14a and 14b). Considering that *Fagus* reaches its highest percentages during this period, it is possible that the decrease most visible for *Quercus* and *Pinus* in zone Oden-Poll is just a function of this interdependency. The decrease of *Quercus* could arguably also be attributed to *Quercus* being a light demanding species, and with a denser forest cover it would have a hard time to thrive. Another factor that could cause a decrease in *Quercus* concerns the new laws being put into place during this time, with *Fagus* and *Quercus* being declared property of the state in 1558 CE. *Quercus* was highly demanded as timber for building warships, and Eliasson (2002) explains that this would lead to a dramatic decline of *Quercus* during the 16th to mid-17th century in Scania.

Following the mid-16th century, the forest mosaic was drastically changing, and a more open landscape was emerging. *Fagus* strongly decreases in pollen percentages at the end of zone Oden-Poll (around 1554 CE), and continues to decrease until the late 18th century in zone Oden-Pol3 (around 1769 CE) (Fig. 14a and 14b). This decrease is followed by a stable period of low *Fagus* percentages up until the mid-19th century in zone Oden-Pol4 (1769 – 1860 CE). In the macrofossil data, *Fagus* remains are not present during this low period (Fig. 15). This indicates that the pollen record mainly represents a regional signal. But considering that the unidentified leaf fragments present in scarce amounts during this period could represent *Fagus*, along with Tree 8 being dendrochronologically dated to 1831 – 1844 CE (Table 1), it is probable that *Fagus* was growing around Lake Odensjön during this period, although in scarce amounts. The first map ever constructed over the area, by Buhrman in 1684, shows an area rich in *Fagus* forests on the ridges of Söderåsen, with fields mainly occurring on the flat surrounding plains. The map suggests that the forest cover around Lake Odensjön was relatively dense during the 17th century. Although this map presumably is heavily generalized (Troedsson 1966), the pollen data supports the presence of a still fairly prominent *Fagus* forest during these times.

The tree species assemblage was changing drastically, with tree species including *Carpinus*, *Tilia*, *Salix*, *Fraxinus* and *Ulmus*, that were present during

the 16th to early 17th century, declining or disappearing completely along with the decrease of *Fagus*. Considering that the forests were growing more open during this period, the regional pollen signal is likely to have become stronger. A weaker pollen signal of these taxa during this open phase indicates that they were also decreasing in numbers. Another factor that could act to suppress the percentages of these taxa are the high pollen percentages of *Juniperus*, which increase at the same time as these tree taxa show decreasing percentages (Fig. 14a and 14b). In contrast to *Fagus* and the other tree taxa mentioned above, *Quercus* and *Alnus* show increasing pollen percentages as the landscape was becoming more open. In zone Oden-Pol2, from the late 16th to the late 17th century, *Quercus* increases. No *Quercus* macrofossils were found in the corresponding interval (Fig. 15), indicating that the pollen percentage increases during this time probably primarily represents a regional pollen signal. The dramatic decline of *Quercus* that Eliasson (2000) explains happened during the mid-17th century is not reflected in the pollen diagram. The stronger regional pollen signal associated with the opening of the landscape appears to have a stronger effect on the *Quercus* pollen record. The expansion of *Alnus* occurring during the 17th century in zone Oden-Pol2, was probably linked to human activity. The macrofossil data reveals that *Alnus* did not have a strong local presence during this time (Fig. 15), and that the increase of *Alnus* pollen percentages rather represents a more regional pollen signal. Macrofossils of *Alnus* fruit are present in zone Oden-Ma1, and it is likely that *Alnus* was growing locally on the fen north of Lake Odensjön during this time, although in scarce amounts. Along with the pollen signal growing stronger as an effect of a more open landscape, *Alnus* would also have better opportunities to expand on the wetlands where they thrive, as the wetlands would not be exploited for cultivation to the same extent anymore. The farmers would gain new, better soil with the decrease of *Fagus* forests, and could in turn abandon the wet meadows where *Alnus* grow.

Species indicative of a more open landscape, including Poaceae, *Filipendula* and *Plantago*, are all continuously present from the beginning of the 16th century (Fig. 14a and 14b). However, none of these taxa appear to peak in connection to the opening of the landscape following the 17th century. Considering the high percentages of *Juniperus* during this period, it is possible that this is an effect of a very large deposition of *Juniperus* pollen from populations expanding along with the decrease in forest cover in the lake surroundings, which would suppress percentages of other pollen taxa. *Calluna*, which thrives in open landscapes, is also expected to increase in connection to the increase of *Juniperus*. Instead, *Calluna* appears to decrease in zone Oden-Pol4, between the 18th – 19th century, when the landscape is expected to be at its more open stage, and *Juniperus* is at its highest percentages (Fig. 14a and 14b). As mentioned earlier, this effect could be the result of the *Juniperus* having very high values during this period. Another explanation could be that the expansion of *Juniperus* was so widespread on the more open landscapes where *Calluna* would thrive, that the lower growing dwarf-shrub simply could not compete

alongside *Juniperus*. Cerealia follows the trend of *Juniperus*, entering the pollen diagram in zone Oden-Pol1 during the mid-16th century and being present throughout the open period. The simultaneous increase of *Juniperus* and Cerealia support that the pollen transport for these taxa, which closest source presumably was on the plateau above Lake Odensjön, increases. Map material reveal that the plateau above Lake Odensjön would be relatively free from trees at least from 1810 CE, and the percentages of Cerealia remain similar from the mid-16th century until the early 20th century, where it is likely that Cerealia was growing a couple of 100 m east of Lake Odensjön, as arable land is drawn out on map material (Fig. 8a and 8b). Because of the even values of Cerealia throughout this period it is suspected that Cerealia would grow at a similar distance from the lake throughout this time. However, the distinction between Poaceae and Cerealia done during the pollen analysis was solely based on grain size. If the grass pollen grain was under 40 μ m it was classified as Poaceae, and if it was larger than that (but never larger than 60 μ m), it was classified as Cerealia. This is a very crude basis for distinction, and in reality, the distinction between these groups can be much more intricate (Tweddle et al. 2005). Therefore, it is important to note that these two records do not necessarily reflect the real development of these two groups.

One of the more peculiar records in the pollen diagram is that of *Juniperus*. The values of *Juniperus* start to increase in zone Oden-Pol1, around the mid-16th century, and see a drastic increase in zone Oden-Pol3, around 1769 CE (Fig. 14a and 14b). The values of *Juniperus* remain high until the mid-19th century, followed by a steady drop. The expansion of *Juniperus* is probably related to the intense grazing and clearance of the forest occurring during this time. When old *utmark* became over-exploited with regard to its tree content, this allowed for a dominating shrub layer. Intensive grazing would prevent the forest from an immediate recovery. Macrofossils of *Juniperus* are not found in the corresponding interval, indicating that *Juniperus* did not become common on the slopes surrounding Lake Odensjön during this time. Still, the very high pollen percentages indicate a source relatively close to the lake. Therefore, the expansion may have occurred on the plateau above the lake as an effect of transformation of forest to pasture. It also appears as though the high percentages of *Juniperus* is suppressing the percentages of other taxa in the pollen diagram, due to the interdependency of the records. A map from Gillastig (around 3.2 km WSW of Lake Odensjön) (Fig. 5) in the late 18th century shows how the *Fagus* forest had become extremely sparse, and *Juniperus* played a dominant role in the shrub layer in places (Håkansson 1948). This depiction of an open landscape with *Juniperus* being a dominant species is also shown in a map from Toarp, Billinge parish in 1743 CE (Lantmäteriet 2020f) (Appendix 1). The dominance of *Juniperus* seen in the pollen diagram probably reflects the evolution of landscapes such as those illustrated on these maps, becoming all the more common in the surrounding area. Björkman (2001) conducted a pollen study on the Kullaberg horst ridge (ca 36 km NW of Lake Odensjön) which covers approxi-

mately the same timespan as the data set from Lake Odensjön, and recorded an opening of the forest around the same time. The data set from the study conducted by Björkman (2001) shows high values of *Juniperus* during the open period from 1650 – 1800 CE, although in the study by Björkman (2001) the high values of *Juniperus* are accompanied by high values of *Calluna* as well as Poaceae.

Exploitation of the forest is described to be extensive particularly in the beginning of the 18th century, reaching its culmination in the mid-19th century (Håkansson 1948; Brunet 1995; Persson 1971). The population was increasing swiftly, and industry and trade likewise. The grazing pressure became more intense and the *Laga skifte* reform was implemented in the area around 1830 CE, which is confirmed by map material (Lantmäteriet 2020g; Lantmäteriet 2020h). Previously, the silviculture concerning important trees such as *Fagus* and *Quercus*, was in the hands of the Swedish state. But in 1793 CE, the silviculture regarding *Fagus* would be in dispose of the farmers. This shift is described in the literature as to have had a large impact on the *Fagus* forests, as the farmers easily could over-exploit their resources (Persson 1971). All of these human-induced changes appear to have had a strong effect on the regional vegetation as well as the local vegetation around Lake Odensjön. The decrease of the forest cover shown in the data sets from Lake Odensjön corresponds well with when human activities were becoming more dominant in the landscape, suggesting these activities to have been the major factor for reducing the forest cover and creating a more open landscape.

The landscape appears to have reached its most open stage around the mid-18th to mid-19th century, which is also supported by literature describing the surrounding area (Håkansson 1948; Brunet 1995; Persson 1971). *Juniperus* along with the herbs and graminids groups all retain high percentages during this period, indicating a stronger human influence on the vegetation during this period, in particular more intense grazing. In the pollen data, *Fagus* reaches its lowest percentages in 1860 CE in zone Oden-Pol4 (Fig. 14a and 14b). At the corresponding depth in the macrofossil diagram (zone Oden-Ma3), tree macrofossils are at one of its lowest concentration (Fig. 15). General maps over Scania were conducted in both 1810 CE (Fig. 6) and 1865 CE (Fig. 7). Both of these maps show a sparse forest cover in the area surrounding Lake Odensjön, although the map conducted in 1810 CE appears to depict a somewhat more open landscape compared to the map conducted in 1865 CE. However, the map from 1810 CE has a higher resolution compared to the map conducted in 1865 CE, which makes it difficult to compare them directly. Some tree taxa (*Carpinus*, *Tilia*, *Salix* and *Fraxinus*) are starting to reenter the pollen diagram during the mid-19th century, but they retain low percentages. No macrofossils are found of these tree taxa in this interval, which could indicate that their pollen signal is predominantly regional. It is uncertain whether these taxa actually became more important in the regional vegetation during this time, or if their pollen values had previously just been suppressed by the high values of *Juniperus*.

Both *Quercus* and *Pinus* have an apparent dip in their percentages around 1860 CE (Fig. 14a and 14b), around the time when the landscape is presumed to be at its most open stage. The farmers had already gotten their right to dispose of the silviculture with respect to *Fagus* in 1793 CE, but it was not until 1830 CE that they were legally allowed to freely dispose of *Quercus* (Bergman 1965). Hemberg (1918) describes that along with the rise cultivation and water regulation in the 19th century, the soil would dry up on some of the wetter *Quercus* forests persisting in Scania. This in itself would promote *Fagus* immigrating into *Quercus* forests, outcompeting it. Nevertheless, both of these tree species are in decline during this period, so if this scenario would take place in the vicinity of Lake Odensjön, is hard to say. Whether or not the decline of *Quercus* is a reflection of farmers beginning to exploit *Quercus*, a reaction of a shift in soil moisture in places due to water regulation, or a combination of both, cannot be inferred from the available data. *Betula* also retains fairly high percentages during this period, so perhaps the apparent decline of *Quercus* is just a reflection of the interdependency of these percentage records.

6.3.2 A denser forest emerges with an increase of *Fagus* from the mid-19th century

After the forests had reached their most open stage during the mid-18th to mid-19th century, *Fagus*, along with many other tree species, are starting to increase in percentages in the pollen diagram (Fig. 14a and 14b). From 1860 CE, *Fagus* is steadily increasing and reaches a relatively stable high point in zone Oden-Pol5 around 1929 CE. In zone Oden-Ma4, around 1910 CE, macrofossils of *Fagus* begin to reappear (Fig. 15). The macrofossil content of *Fagus* is increasing rapidly, and between 1946 and 1968 CE they possess their highest concentrations. The unidentified leaf fragments are likewise heavily increasing already from 1860 CE, reaching their highest concentration at 1910 CE. Furthermore, the macrofossil content of *Fagus* occurs in far higher concentrations during this period, compared to the lower part of the sediment sequence, confirming that *Fagus* has a stronger local presence during this period compared to the 16th and 17th century. *Fagus* appears to have managed to reestablish at rapid rate, which Persson (1971) attributes to pannage, which was common in the surrounding area up to 1930 CE at the most.

The dendrochronological data suggests that the average age for all trees (with Tree 1 excluded) is 1900 CE for the exact tree rings counted, and 1886 CE for the exact tree rings counted with assumed rings included (Table 1). These ages suggest that the local establishment of *Fagus* around Lake Odensjön corresponds well with when the tree cover is inferred to increase locally, based on the macrofossil and pollen data. Map material suggests that *Fagus* forests were dominating in the area around Lake Odensjön from at least 1905 CE (Fig. 8b), and photographs taken of Lake Odensjön around 1902 CE, 1906 CE and 1927 CE confirms that the slopes leading down to the lake would have a dense tree cover at this time (Fig. 9a-c). Whether the unidentified leaf fragments give an accurate depiction of the *Fagus* content or not, it is clear that *Fagus syl-*

vatica was a dominant local species around Lake Odensjön from the early 20th century and onwards.

The tree taxon assemblage would change drastically as a whole following the mid-19th century. *Alnus* and *Betula* increased on wetter soils, and according to the macrofossil data both these species had a much stronger local presence during this time compared to the 16th to 17th century (Fig. 15). Presumably these taxa were expanding on the wetland just north of Lake Odensjön where they are dominating in present time. *Quercus*, *Carpinus*, *Tilia*, *Salix*, *Fraxinus* and *Ulmus* were all present in the regional forest mosaic. Macrofossils of *Quercus* occur for the first time in the data set in zone Oden-Ma5 and Oden-Ma6 (Fig. 15), confirming that *Quercus* was established locally during this time. Macrofossils of *Carpinus* are also present in these zones, confirming its local presence.

From the second half of the 19th century, *Picea* was planted to a greater extent in Scania (Persson 1971). *Picea* would mainly be planted on fields previously dominated by *Juniperus*, but also replace *Fagus* and *Quercus* on land where they were previously dominating (Brunet 2007). Due to this alternation of tree taxa, around 40 % of the forest area in Scania would consist of planted *Picea* in 2005 CE (Brunet 2005). This planting of *Picea* is reflected by the pollen data, with *Picea* emerging in zone Oden-Pol5 and remaining present in the diagram up until present time (Fig. 14a and 14b). The earliest map material capturing planting of *Picea* in the vicinity of Lake Odensjön is from 1910-1915 CE (Fig. 8a), and it appears as though the planting is primarily occurring on the plateau NW of the lake. As *Picea* started to dominate in areas with former *Fagus* forests, the Swedish government decided to take measures for the preservation of *Fagus* forests. In 1974, The Beech Forest Act came into force, and it became forbidden to convert *Fagus* forests into forests consisting of other tree species (Brunet 2005). As seen in Fig. 10, the area of the planted *Picea* growing a couple of 100 m W of Lake Odensjön had expanded considerably from 1910-1915 CE (Fig. 8a), and is decreasing in size from 1960 CE, possibly due to these governmental actions. *Fagus* forests became important for outdoor activities and the landscape image of Scania, and nature reserves started to emerge. Many areas now belonging to the Söderåsen National Park became protected in the late 20th century, but Lake Odensjön and Nackarpsdalen would not be included until 2000 CE (Söderåsens nationalpark 2020). If it were not for these laws, palaeoecological data for the last century would probably look drastically different.

Taxa indicative of a more open landscape are decreasing throughout the 20th to 21st century, suggesting that the forests grew denser during this time. *Juniperus* is continuously decreasing throughout zone Oden-Pol5 and Oden-Pol6, and *Calluna* shows an initial increase between zone Oden-Pol4 and Oden-Pol5 (Fig. 14a and 14b), probably as an effect of the interdependency of the percentage data. However, as the tree taxa increase in percentages, *Calluna* also starts to fall back, reaching its lowest percentages seen in the sediment sequence. Possibly as an effect of meadows and arable fields decreasing in size or disappearing at places, there is a shift in dominating taxa within the herbs and graminids group, with Cruciferae, Chenopo-

diaceae, and Apiaceae being more prominent in the pollen diagram than before, and *Filipendula*, Cyperaceae and *Plantago* decreasing. In addition, Cerealia is decreasing followed by absence in zone Oden-Pol6 (Fig. 14a and 14b). Today, the closest arable land is positioned only 200 m east of Lake Odensjön, and many other areas of arable lands are found within a 1 km radius, primarily on the flat ground in the Nackarpsdalen valley, below the ridge of Söderåsen. Perhaps the disappearance of Cerealia in zone Oden-Pol6 is related to a denser emerging tree cover, considering that the arable land closest to Lake Odensjön appears to have been present at least since the beginning of the 20th century (Lantmäteriet 2020k; Lantmäteriet 2020l). If this is the case, the absence of Cerealia in turn gives an indication of the extent of the pollen transport of Cerealia to the site in relation to the tree cover. Charcoal also appears to be continuously present in zone Oden-Pol5 and Oden-Pol6, suggesting continuous human activity at the site. The vegetation growing around Lake Odensjön with an increased tree cover emerging during this time has subsequently developed into the vegetation seen around Lake Odensjön today.

The changes seen in the landscape in Scania during the second half of the 19th century are described by Wallerman (1995) as a transition from a hay and grazing landscape to an agricultural and forest landscape. New innovations seen in agriculture allowed for smaller parcels of land to be used by the farmers for growing their crops. Soil-improving agents, like marl, were commonly used, and commercial fertilizer became common to use in the beginning of 1950 CE. Grazing was becoming less intense, and the forests were able to expand. The rapid increase of a forest cover with *Fagus* dominating reflected by the collected data from Lake Odensjön, can be attributed to the changes in human activity during this period. The timespan of when human activity would shift to benefit a denser growing forest, instead of hindering it, corresponds well with when the forest cover is inferred to grow denser based on these data.

The data collected within this study do not necessarily confirm that the culmination of the change from an open landscape to a dense forest covered landscape happened exactly around 1930 CE. The pollen diagram shows that the percentages of *Fagus* pollen peak around 1930 CE (Fig. 14a and 14b), after the period with a more open landscape. However, this peak in pollen percentages could be a representation of changes happening in the landscape on a regional scale, rather than locally at the lake. The apparent change seen in the sediment sequence at 1930 CE, with a boundary between sediment rich in *Fagus* leaves and sediment devoid of *Fagus* leaves, is not clearly visible from the macrofossil analysis either. Macrofossils of *Fagus sylvatica* reappears at around 1910 CE, and the culmination of plant remains of *Fagus* occurs at around 1950-1970 CE (Fig. 15). The unidentified leaf fragments, which are believed to predominantly represent *Fagus*, are heavily increasing from 1860 CE, and reach their highest concentrations around 1940 CE. *Fagus sylvatica* leaves (>1/3) are reintroduced latest of all *Fagus* remains, around 1940 CE, and it is possible that the apparent change seen in

the sediment sequence in 1930 CE is mainly represented by *Fagus sylvatica* leaves (>1/3) together with bigger *Fagus* leaf fragments a bit further down in the sediment sequence. Compared with pollen data, macrofossil data provide a clearer picture of what is occurring in the landscape on a local scale. Although macrofossils are present throughout this time period, there is no indication that a major increase in tree cover occurred exactly around 1930 CE. Map material suggests that the close surroundings of Lake Odensjön had a relatively dense tree cover from at least 1905 CE (Lantmäteriet 2020), and photographs taken at the site confirms a dense tree cover in the slopes from at least 1906 CE (Fig. 9a), suggesting that forest expansion in the area occurred somewhat earlier than anticipated. The collected data within this study suggest that both the local and regional vegetation would already have a relatively dense *Fagus* forest cover in the beginning of the 20th century, although the expansion of the forest would continue until the mid-20th century, but to be more specific than that is not possible based on the available data.

6.4 Comparison with other palaeoecological studies in the Söderåsen area

The data sets collected from Lake Odensjön may be compared with two other palaeoecological studies in the close vicinity, one conducted by Bergman (2000) on the sites of Höja and Skärålid, and another conducted by Göransson (2000) on the sites of Härsnäs East and Härsnäs West.

Bergman (2000) conducted pollen studies on the peat sites Höja (ca. 3.1 km NW of Lake Odensjön) and Skärålid (ca. 3.7 km NW of Lake Odensjön). Three ¹⁴C-datings were performed on the sediment sequence from Höja to build up a chronology and four ¹⁴C-datings were used for the chronology on the Skärålid data set. The major tree taxa in the pollen diagrams produced by Bergman (2000) show strong similarities to the Lake Odensjön diagram. *Fagus* shows high percentages in the diagrams from Höja and Skärålid before the mid-16th century, whereafter *Fagus* begins to decline. At Skärålid, *Fagus* reaches its lowest percentages around the 18th-19th century, whereas in the Höja diagram, *Fagus* reaches its lowest percentages around the 19th century. *Fagus* increases somewhat at both Höja and Skärålid following the 19th century, which corresponds to the increase seen in the diagram from Lake Odensjön occurring after 1860 CE. At Höja, the increase of *Fagus* after the 19th century is accompanied by increased percentages of similar tree taxa as seen in the diagram from Lake Odensjön, including *Betula*, *Pinus*, *Alnus*, *Quercus*, *Ulmus*, *Tilia*, *Fraxinus*, *Carpinus* and *Picea*. At Skärålid, relatively few tree taxa are recorded following the 19th century *Fagus* increase, with only *Betula*, *Pinus*, *Alnus*, *Quercus* and *Ulmus* represented. Considering that both Höja and Skärålid are two small peatlands probably reflecting a more local signal than is the case for the diagram from Lake Odensjön, the more regional signal of these tree species inferred from the Lake Odensjön pollen record would probably not have had as strong effect at these localities. *Betula* is present with far higher percentages at both Höja and Skärålid (both

around 75%) at the time of the decline of *Fagus* compared with the percentages seen in Lake Odensjön during this period. Following the 16th century, herbs and graminids appear to reach their highest percentages around the late 18th century at Höja, and in the mid-17th century at Skärålid. Following this peak, herbs and graminids reach their lowest percentages in the mid-19th century at both Höja and Skärålid. Furthermore, *Juniperus* is completely absent at Höja and Skärålid at the time when herbs and graminids pertain high percentages. It appears as though the local peatlands at Höja and Skärålid grew denser with *Betula* well before the regional development of dense forests dominated by *Fagus*. The high values of *Betula* at Höja and Skärålid probably dominated the local pollen signal, and perhaps a regional signal of a more open landscape, as shown for Lake Odensjön during the mid-19th century, is therefore not visible.

Göransson (2000) conducted two pollen diagrams, Härsnäs West (ca. 2.3 km NW of Lake Odensjön), and Härsnäs East (ca. 250 m east of Härsnäs West). Only one reliable ¹⁴C-dating was obtained from the Härsnäs fen, which makes it difficult to tie the stratigraphic changes in the diagrams to specific ages. Nevertheless, the diagrams from Härsnäs show many similarities to the Lake Odensjön pollen diagram, and with the knowledge that *Picea* immigrated to the Härsnäs area around 100 years ago (Göransson 2000) approximate correlations can be made. In the diagram from Härsnäs West the major pollen taxa are similar to the Lake Odensjön diagram, although the pollen percentages of the major taxa, along with their emergence in time, appears to vary somewhat. Considering that the peat sequences from Härsnäs were retrieved from an *Alnus* fen, it is not surprising that *Alnus* pollen dominate these pollen diagrams and that the *Alnus* curve shows a different signal than in the Lake Odensjön diagram. The *Fagus* curve in Härsnäs West is similar to the Lake Odensjön diagram, with initially increasing percentages, which decreases rapidly towards the top of the peat sequence. In the Härsnäs West diagram *Fagus* does not appear to increase in percentages during the late 19th-early 20th century, which would be around the time when *Picea* enters the diagram, as is seen in the Lake Odensjön diagram. Considering that *Betula* and particularly *Alnus* are dominant during this period in the Härsnäs diagrams, the regional *Fagus* signal in these diagrams is probably not very strong. In the Lake Odensjön diagram the *Fagus* increase during this period is considered to be primarily local. The *Juniperus* increase shown in the Lake Odensjön diagram is seen in the diagrams from Härsnäs, but here they are accompanied by *Calluna* and strong values of Poaceae as well. At Härsnäs West, the *Calluna* signal is stronger than at Härsnäs East, and the Poaceae signal is weaker than at Härsnäs East and peaks after the *Juniperus* peak, while it peaks somewhat before the *Calluna* and *Juniperus* peak at Härsnäs East. The *Juniperus* peak appears to occur during the 20th century in the Härsnäs diagrams based on the *Picea* curve, which is somewhat later as compared with the diagram from Lake Odensjön. The openness at Härsnäs would primarily be controlled by the local fen population mainly consisting of *Alnus*. In both the diagrams from Härsnäs, *Alnus* retains high

percentages (ca. 50% in Härsnäs West and ca. 80% in Härsnäs East) prior to the emergence of *Juniperus*, and when *Alnus* decreases, *Juniperus* begin to increase. The delayed signal of an open landscape could be explained by *Alnus* blocking out the regional signal of an open landscape to the site. However, the resolution of the Härsnäs diagrams is quite low, so it is difficult to say if there is in fact a delay, and how big that delay is.

6.4 Limitations and suggestions for further studies

In this study, focus was on transferring the collected palaeoecological and dendrochronological data, in combination with interpretation of historical maps and literature, into changes in vegetation cover. With regard to the pollen data used, vegetation reconstructions were based directly on percentages, but these do not directly reflect the real composition of the actual vegetation, as pollen production and dispersal vary strongly between species and sites. Although differences in the relationship between pollen production and dispersal depending on site were taken into consideration during the interpretation of the pollen data, available methods taking these factors into consideration for estimation of the vegetation cover were not applied. The focus of this study was to reconstruct vegetation development around Lake Odensjön, but to obtain more secure estimates of regional as well as local vegetation cover and how it has changed through time, it is recommended that a few other sites in the close vicinity are studied and that the LRA (Landscape Reconstruction Algorithm) is applied to these data (Sugita 2010). Unlike making interpretations from pollen percentages alone, the LRA gives a more confident estimation of the composition of both arboreal and non-arboreal taxa (Hultberg et al. 2014). The LRA includes two steps, with the first one being the REVEALS (Regional Estimates of VEgetation Abundance from Large Sites) model, which reconstructs the regional vegetation based on pollen records from large sites (around 100-500 ha in size). Previous studies (eg. Sugita 2007, Sugita et al. 2010) suggests that the reliability of the REVEALS estimates increases if pollen records from multiple large sites are used. Sugita (2007) explains that if smaller lakes are used for the analysis, the pollen assemblages are significantly different amongst sites, and the estimated abundance of regional vegetation could vary extremely from expected values. However, there are some studies that suggest that the REVEALS model works on smaller lakes as well. Trondman et al. (2015) conducted a study with small lakes, and the results showed that the model performed well in reconstructing the vegetation cover. The study showed that standard errors from a study with multiple small sites were larger compared to a study with multiple large sites, but this uncertainty decreased with an increase in the number of pollen counted as well as an increase in the number of small sites included (Trondman et al. 2015). The second step of the LRA is the LOVE (LOcal VEgetation Estimates) model, which reconstructs the local vegetation within the relevant source area of pollen in smaller sites based on regional plant abundance retrieved with REVEALS. Application of the LRA would mean that several more lakes in the vicinity of Lake Odensjön needs to be studied, but

by doing so, the estimates of the regional and local vegetation cover would be far more secure compared to estimates of vegetation cover based solely on pollen percentages. The LRA potentially could reveal interesting details about the landscape development at the site during the studied timespan which are not visible in the pollen percentages alone.

7 Conclusions

Based on the present study, it is possible to make the following conclusions about forest development at Lake Odensjön:

- The initial decline of the *Fagus* forest started in the mid-16th century. The decline probably occurred due to a combination of overexploitation, over-grazing, population increase, increased industry and trade along with the implementation of land reforms such as the *Laga skifte*. The decline resulted in a shift in the tree species assemblage, with the majority of the tree species being present prior to the mid-16th century decreasing or disappearing completely.
- The forest reached its most open stage during the mid-18th to mid-19th century. *Fagus* reaches its lowest percentages in zone Oden-Pol4 around 1860 CE, at the same time as *Fagus* is absent from the macrofossil record. Pollen taxa indicative of an open landscape such as Poaceae, *Juniperus*, *Filipendula* and *Plantago* are all present at relatively high percentages during this period, in particularly *Juniperus*. Maps conducted in 1810 CE and 1865 CE reflect an open landscape, although the landscape appears to be somewhat more open on the map from 1810 CE.
- The forest cover grew denser during the second half of the 19th century, and in the beginning of the 20th century *Fagus* would be well established both regionally and locally at the site. This is reflected by increasing concentrations of *Fagus* macrofossils as well as increasing pollen percentages of the majority of the tree taxa, in particularly *Fagus*, while *Juniperus* and most herbs and graminids show decreasing numbers. Maps from 1910-1915 CE illustrate a sufficient forest cover in the area and photographs taken at the site from 1902 CE and 1906 CE reveal that *Fagus* was prominent on the slopes leading down to the lake.
- The local species composition of the forest around Lake Odensjön would change following the second half of the 19th century. *Fagus* became more dominant locally, compared with the 16th to 17th century. *Betula* and *Alnus* expanded locally, probably on the fen peat north of Lake Odensjön, and *Quercus* would probably also expand locally for the first time during the examined period. The regional vegetation would also change, with *Carpinus*, *Tilia*, *Salix*, *Fraxinus* and *Ulmus* increasing in pollen per-

centages and *Picea* being introduced for the first time.

- Changes in human activity occurring during the second half of the 19th century, such as new innovations seen in agriculture, emerging soil improving agents along with decreased grazing, are all attributed to have played a part in allowing the forests to grow denser once again after the mid-19th century. The use of pannage and planting of trees are believed to have facilitated this process. Forest regulations and formation of nature reserves would have had, and has, an impact in maintaining the forest we see today, with *Fagus* still being a prominent tree in the area.
- The dendrochronological data suggests that the local *Fagus* population growing around Lake Odensjön today was established after 1860 CE, which is around the time when the forest is believed to have expanded after the previous open phase.
- The shift from a more open landscape, to a denser forest, does not necessarily date back to exactly 1930 CE, as indicated by the abrupt increase in *Fagus* leaves visible in the core. Based on the data collected, the area around Lake Odensjön would have an established *Fagus* forest both locally and regionally in the beginning of the 20th century, which continued to expand until the mid-20th century.

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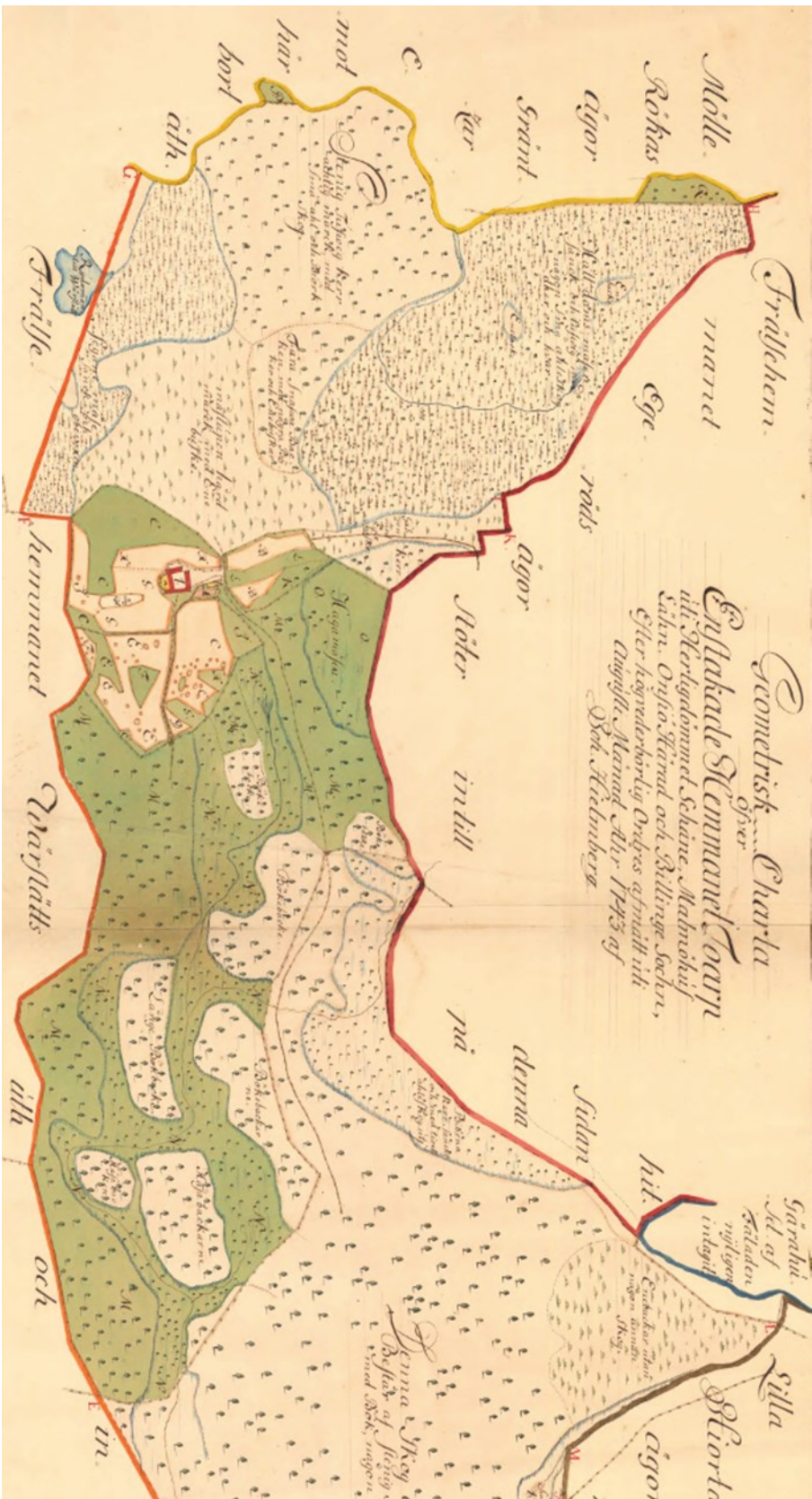
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10 Appendix



Appendix 1. Map from 1743 CE depicting Toarp in Billingje parish (ca. 4 km NNE of Lake Odensjön). The map depicts a sparse *Fagus* forest cover (depicted as bigger trees on the map, predominantly towards the right on the map) and a dominant shrub layer of *Juniperus* (depicted as smaller bushes, e.g. in the left side of the map). Forests of *Alnus* and *Betula* are also present at the site (smaller trees, e.g. in the central left edge of map a). Modified map from Lantmäteriet (2020c).

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