Pollen analytical and landscape reconstruction study at Lake Storsjön, southern Sweden, over the last 2000 years

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Åkesson, C., 2013: Pollen analytical and landscape reconstruction study at Lake Storsjön, southern Sweden, over the last 2000 years. *Dissertations in Geology at Lund University*, No. 360, 37 pp. 45 hp (45 ECTS credits).

Abstract: This thesis reports the results from a pollen analytical and quantitative landscape reconstruction (REVEALS model) study in the drainage area of the Botorpsströmmen River in southern Sweden as a part of the project *The archaeology and ecology of collapse: social and agricultural change following the Black Death* and the project *Managing Multiple Stressors in the Baltic Sea*. The focus of this study was on the vegetation and land-use development in the area during the last 2000 years and on how the land-use changes affected the Baltic Sea. Six sediment cores were retrieved from Lake Storsjön, Småland, and three of those cores (SSK, SS1a and SS1b) were used for further analyses. The sediment cores were sampled for pollen analysis, LOI, ^{14}C-dating and ^{210}Pb-dating; the dating results are still pending. Pollen diagrams from other studies in southern Sweden along with a low resolution pollen diagram based on all the six retrieved cores have been used for tentative dating. A high resolution pollen diagram and a vegetation cover diagram were constructed using data from cores SSK and SS1a. The diagrams were divided into five landscape periods (A-E), where period C further was divided into four sub-periods (C1-C4). Period A probably represents the time interval between approximately AD 250 and AD 500 and shows the establishment of *Picea*, the first finding of *Secale t.* and the first appearance of a continuous cereal pollen curve. Period B is characterised by reforestation and farm abandonment and most likely represents the reforestation event during the 6th century. Sub-period C1 shows an expansion of agriculture and is interpreted as the Medieval expansion around AD 800-1300. This is followed by reforestation and farm abandonment in sub-period C2 that suggest that this represents the Medieval decline during the 14th century. Sub-periods C3 and C4 are characterised by a re-expansion of agriculture and probably represent the 16th century. The introduction of buckwheat and a peak in cereal pollen in period D suggest that this period represents the vegetation and land-use during the 17th to 19th centuries. Period E is characterised by a reforestation of *Picea* and *Pinus*, decline in species diversity and high values of cereals that probably represent the late 19th to 20th centuries. Based on literature, periods of hypoxia in the Baltic Sea during the last 2000 years have been correlated with intense agricultural periods and periods of more oxic conditions have been correlated with periods of agricultural decline. This study gives an insight into the vegetation and land-use changes in an area of southern Sweden that has not been subject to previous studies and indicates that the agriculture during the last 2000 years was characterised by periods of intensified land-use and periods of reduced land-use.

Keywords: Pollen analysis, REVEALS model, land-use changes, Småland, Baltic Sea

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Subject: Quaternary Geology

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Landskapsutvecklingen i östra Småland, södra Sverige, över de senaste 2000 åren

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Sammanfattning: Pollenanalys och landskapsrekonstruktionsmodellering (modellen REVEALS) användes för att undersöka landskapsutvecklingen i Botorpsströmmens dräneringsområde i södra Sverige över de senaste 2000 åren. Studien ingår i två större projekt, *The archaeology and ecology of collapse: social and agricultural change following the Black Death* och *Managing Multiple Stressors in the Baltic Sea*. Resultaten från studien kopplades till hur Östersjön har påverkats av markanvändningsförändringar under de senaste 2000 åren. Tre av sex insamlade borrkärnor (SSK, SS1a och SS1b) från Storsjön, Småland analyserades och provtogs för pollenanalys, LOI, ^{14}C-datering och ^{210}Pb-datering. Dateringarna är ännu inte färdiga och därför användes pollendiagram från andra studier i södra Sverige tillsammans med ett lågupplöst pollendiagram sammansatt från alla de erhållna borrkärnorna från Storsjön för att upprätta en relativ kronologi av de studerade sedimenten. Resultaten från pollenanalysen sammanställdes i ett högupplöst pollendiagram och i ett vegetations-fördelningsdiagram. Diagrammen indelades sedan i fem perioder (A-E) där period C delades in i fyra delperioder (C1-C4). Etableringen av *Picea*, det första pollenkornet av *Secale t.* och det första uppträdandet av en kontinuitet i sädesslagspollenkurvan antyder att period A representerar tidsintervallet mellan 250-500 e.Kr. Period B karakteriseras av en nedgång i odling och en succession av träd som förmodligen representerar återbeskogningen under 500-talet. Delperiod C1 utmärks av en expansion av jordbruk vilket tolkas som den medeltida expansionen 800-1300 e.Kr. En återbeskogning och en nedgång i odling kännetecknar delperiod C2, vilken bör representera den medeltida nedgången under 1300-talet. Delperioderna C3 och C4 karakteriseras av en förnyad expansion av jordbruk och representerar troligtvis 1500-talet. Höga värden av sädesslag och introduktionen av bovete i period D antyder att perioden representerar 1600-talet till 1800-talet. En återbeskogning av *Picea* och *Pinus*, nedgång i artrikedom och höga värden av sädesslag kännetecknar period E vilket tyder på att perioden representerar sent 1800-tal till 1900-tal. Ökad markanvändning under de senaste 2000 åren har kopplats till perioder av syrefattiga bottenförhållanden i Östersjön och perioder av minskad markanvändning har kopplats till perioder av mer syrerika bottenförhållanden i Östersjön. Denna studie ger en ökad förståelse för landskapsutvecklingen i södra Sverige inom ett område som tidigare inte har varit föremål för studier och vidare indikerar studien att markanvändningen under de senaste 2000 åren i södra Sverige kännetecknades av perioder av ökad markanvändning och perioder av minskad markanvändning.

Nyckelord: pollenanalys, modellen REVEALS, markanvändningsförändringar, Småland, Östersjön

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1. Introduction

Fossil records are well-used tools within palaeo-ecology that record past climate changes and corresponding ecological responses (Willis et al. 2010). The analysis of pollen grains in lake, fen and bog deposits is an often used proxy for analysing climate changes, vegetation changes and human impact (e.g. Lagerås 1996a; Lagerås 1996b; Björkman 1997; Jessen et al. 2005; van der Linden & van Geel 2006; Berglund et al. 2008).

The Quaternary period is characterised by shifts between glacial and interglacial conditions (Cronin 2010). As the latest glacial period, the Weichselian, ended, the Earth entered the present interglacial period called the Holocene. The Holocene introduced human impact to the environment and it was no longer only climate variations that triggered vegetation changes (Lagerås & Sandgren 1994). The human impact on the landscape has been significant for at least 6000 years with the introduction of agriculture during the Mid-Holocene (Neolithic period) (Lagerås & Sandgren 1994; Williams 2000). Humans started to clear forests, cultivate, cut off tree sprouts and limbs for fodder and intensify grazing, all of which have had major effects on the vegetation (Williams 2000).

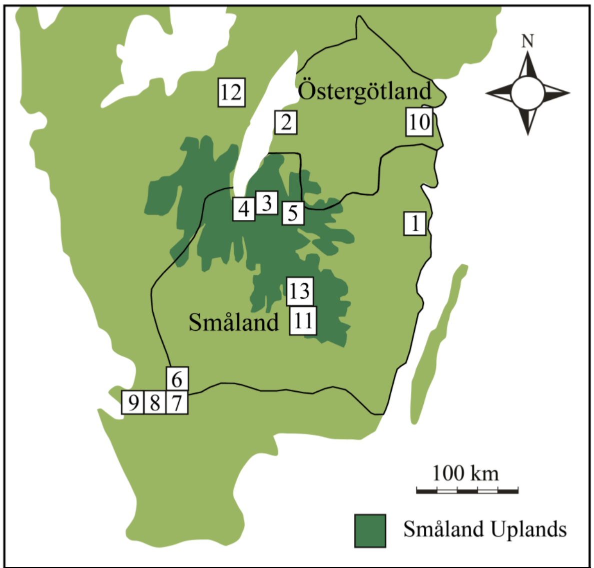
The human impact on the environment reached its maximum during the latest 3000 years as a consequence of an increased population, cultural trade and knowledge exchange, technological development and urbanisation (Williams 2000). The increased intensification of human impact did not only affect the terrestrial environment but also the aquatic environment (Zillén & Conley 2010). The Baltic Sea has been affected by humans and severely suffers from hypoxia associated with eutrophication; which can be linked to both climate variability and human impact such as population dynamics, land-use changes and technological developments (Zillén et al. 2008).

Both investigations in the Baltic Sea and terrestrial analyses show that changes in population dynamics affect the environment (Williams 2000; Zillén et al. 2008). The vegetation responds rapidly to population decreases with regrowth and forest expansion once the human pressure has decreased (Williams 2000). Examples of major events in the past that have triggered these vegetation regrowth effects are plagues and wars. The Eurasian plague pandemic, also known as the Black Death (AD 1347-1353), resulted in a major population decrease and settlement abandonment (Yeloff & van Geel 2007). In Europe, the population decreased by 30-60 %. However, the effects of the plague seem to have had varied geographical impact across Europe; studies have shown evidence of agricultural continuity at several sites at the same time that other studies have shown evidence of settlement abandonment and forest regrowth (Yeloff & van Geel 2007).

This study presents the results from a pollen analytical and landscape reconstruction modelling study at Lake Storsjön in a coastal area in Småland, Sweden. The aim is to determine how the vegetation and land-use has changed during the last 2000 years. The study have been correlated with other studies in southern Sweden and the geographical position of these are illustrated in Fig. 1.

The study is part of the project *The archaeology and ecology of collapse: social and agricultural change following the Black Death in Sweden* and the main focus of this study will be on the time periods before, during and after the Black Death in order to further understand the effect of the pandemic in southern Sweden. The study is also part of the project *Managing Multiple Stressors in the Baltic Sea* and the results will therefore be connected, in a literature study, to how land-use changes affected the Baltic Sea over the last 2000 years. The objectives of this project are:

- Establish an accurate chronology and locate the Medieval time period in the investigated sediment sequence.
- Investigate if there are changes in land-use during the Medieval time period and if there are any signs of a decline in the cultivation and a succession of grasses, shrubs and trees, that could be linked to the Black Death.
- Relate the results given by this thesis with how land-use changes affected the Baltic Sea, based on a literature study.



Study sites:
1. Lake Storsjön
2. Dags Mosse (Göransson 1989)
3. Axlarp area (Lagerås et al. 1995)
4. Lake Femtingagölen (Lagerås 1996a)
5. Lake Avegöl (Lagerås 1996b)
6. Bjärabygget (Lagerås 2007)
7. Värsjö Utmark (Lagerås 2007)
8. Grisavad (Lagerås 2007)
9. Östra Ringarp (Lagerås 2007)
10. Mabo Mosse (Göransson 1988)
11. Lake Helgasjön (Olsson & Lemdahl 2009)
12. Lake Igelsjön (Jessen et al. 2005)
13. Lake Fiolen, Lake Åbodasjön and Lake Lindhultsgöl (Fredh 2012; Fredh et al. 2012)

Figure 1. Map showing the two provinces Småland and Östergötland along with the location of the study site Lake Storsjön and other study sites from southern Sweden referred to in this thesis. The Småland Uplands is marked by the dark green colour (modified after Lagerås 1996b).

2. Background

2.1 Project: The archaeology and ecology of collapse: social and agricultural change following the Black Death in Sweden

The archaeology and ecology of collapse: social and agricultural change following the Black Death in Sweden is a project running from 2011 to 2013 (Sweden ScienceNet 2013). It uses archaeological, anthropological, palaeoecological and dendro-chronological data to give new insights into social and ecological change in connection to the Late Medieval crisis and the Black Death in Sweden (Sweden ScienceNet 2013; Lagerås unpublished). The scientific coordinator of this project is Per Lagerås (Riksantikvarieämbetet, Lund) (Sweden ScienceNet 2013).

2.2 Project: Managing Multiple Stressors in the Baltic Sea

Managing Multiple Stressors in the Baltic Sea is a project running from 2010 to 2015 and involves a team of researchers from different departments and scientific fields (Conley et al. 2010). The project leader is Daniel Conley (Department of Geology, Lund University, Sweden).

The project investigates how different stress factors together contribute to the environmental problems in the marine ecosystem of the Baltic Sea and further emphasize the importance of a multiple approach (Conley et al. 2010). A multiple approach is crucial in order to develop effective solutions to environmental problems that stress many marine ecosystems. The traditional approach, to investigate how different stress factors separately disturb a marine environment, has failed but a combination of many fields could give a new understanding of the environmental problems in the Baltic Sea.

The project combines ecological, geological and biogeochemistry science with large-scale modelling, and has the ambition to further develop the knowledge for a sustainable use and management of terrestrial and marine ecosystems. The environmental problems are treated in a historic and present perspective as well as projections for the future.

One part of the project is to investigate how land-use has affected the coastal area Gåsfjärden over the last 2000 years. The study at Lake Storsjön is one part of this investigation along with a study of the marine environment in Gåsfjärden. Five marine cores have been retrieved from Gåsfjärden (Khan 2013).

2.3 The Baltic Sea

Variations in climate, deglaciation processes, global sea level changes and regional land-uplift have affected the Baltic Sea since the last deglaciation (Björck 1995). The Baltic Sea has gone through a number of stages but today it is a semi-enclosed brackish water-body consisting of a number of sub-basins, for example the Bothnia Bay, the Bothnia Sea, the Gulf of Finland, the Gulf of Riga and the Baltic Proper (Fig. 2) (Zillén et al. 2008). The Baltic Sea is one of the largest brackish waters in the world and has a drainage area that is four times larger than the sea itself, which releases large amounts of freshwater to the basin (Elmgren 2001; Zillén et al. 2008). The brackish sea is surrounded by nine countries (Fig. 2) and a population of over 85 million in the coastal region.

The Baltic Sea is highly vulnerable to hypoxia due to the circulation patterns of the basin which retains nutrients and organic matter (Zillén & Conley 2010). This leads to high nutrient availability, eutrophication and hypoxic conditions (Fig. 2) (Zillén et al. 2008; Zillén & Conley 2010).

Hypoxia is the lack of oxygen in bottom waters and is defined as dissolved oxygen levels of < 2 ml O_2/l (Diaz & Rosenberg 2008). Hypoxic conditions have severe effects on the ecosystems; benthic faunas abandoning burrows and when the dissolved oxygen decreases to values below 0.5 ml O_2/l the effects cumulate to mass mortalities and the development of so called dead zones. Dead zones have spread exponentially since the 1960's in coastal marine waters and exist in for example the Baltic Sea, Kattegat, the Black Sea and East China Sea (Diaz & Rosenberg 2008; Conley et al. 2009). Hypoxia also alters the biogeochemical cycles of nutrients (Conley et al. 2009). Hypoxic conditions are distinguished by laminated sediments which indicate that the sediments have been free from bioturbation and thus the sedimentation stratigraphy has been preserved.

Hypoxic conditions in the Baltic Sea can also be linked to changes in nitrogen inputs, phosphorus inputs and cyanobacteria blooms (Zillén & Conley 2010). The frequency and magnitude of cyanobacteria have increased, potentially due to eutrophication in the Baltic Sea (Vahtera et al. 2007). This has led to increased sedimentation of organic material, increased extent of anoxic bottoms and an increased internal loading of phosphorus.

2.4 The vegetation and cultural landscape history of Middle and Late Holocene in southern Sweden

The following review of the vegetation and cultural landscape history of the Middle and Late Holocene in southern Sweden is primarily based on other pollen analytical studies in southern Sweden (Fig. 1).

2.4.1 The development of the cultural landscape in southern Sweden

The landscape before 4000 BC was characterised by natural forests, dominated by *Pinus* (pine) but also consisted of more thermophile plants such as *Tilia* (lime), *Hedera* (ivy) and *Viscum* (mistletoe)

(Göransson 1989). *Alnus* (alder) was also abundant during this time period which indicates the presence of fens. *Betula* (birch) and *Populus* (aspen) increased on dry areas and open areas were favoured by *Corylus* (hazel), *Lonicera* (honeysuckle) and *Viburnum* (viburnum). The primary sources of openness in the landscape were forest fire, wind and animal grazing (Berglund et al. 2002). The human culture during this period was based on a hunting, fishing and gathering economy and there is not enough evidence to confirm whether there was any form of cultivation in the area. If there was, it occurred on a small scale.

The dominance of a *Pinus* forest during the early part of the Mid-Holocene shifted around 4200-2400 BC towards a forest dominated by deciduous trees in southern Sweden (Olsson & Lemdahl 2009). This is indicated by the increase of a beetle fauna feeding on bark and wood of *Betula*, *Quercus* (oak), *Ulmus* (elm), *Fraxinus* (ash), *Populus* and *Salix* (willow). The human settlements during 4000-1000 BC were mobile and the same applied to cultivation (Berglund et al. 2002). This influenced the deciduous forest and the landscape was partly transformed into a coppicing forest with mobile agriculture.

This time period was not just affected by a change in forest composition but also by a major event that can be traced in a range of pollen diagrams around northern Europe; the *Ulmus* decline (Göransson 1989). The abundance of *Ulmus* started to drop and reached a

Figure 2. Map of the Baltic Sea, its major sub-basins and its surrounding countries. The location of the maximum hypoxic area in the Baltic Sea is shown by the red lines (modified after Zillén & Conley 2010) and the location of Lake Storsjön is shown by the black and white circle.

minimum at around 4000 BC. It had a geographical range from Ireland in the west, to Poland in the east and up to middle Sweden in the north. The cause of the *Ulmus* decline is still under debate but theories have suggested climate changes, elm disease and changes in the feeding of domestic animals. None of these theories have however been validated and the cause of the *Ulmus* decline is still unknown.

A possible first indicator of human impact in southern Sweden is shown in the Småland Uplands by the appearance of *Plantago lanceolata* (ribwort plantain) during the beginning of the Sub-Boreal, around 3900 BC (Lagerås 1996b). This is followed by a regeneration of deciduous trees in Östergötland around 3250 BC that shows an increase in *Juniperus* (juniper), *Plantago lanceolata* and cereal taxa (Göransson 1989). Around 2800-2600 BC the Småland Uplands were affected by a decrease in tree species, especially *Ulmus* (Lagerås 1996b). After this decline, the number of herb taxa increased along with light-demanding taxa such as *Betula*, *Salix* and Poaceae (grasses), which resulted in an increase in the palynological richness. These changes are interpreted as intensified forest clearance, grazing and browsing. The forest still dominated the area, but the forest clearance resulted in a decrease of shading trees, which favoured the expansion of light-demanding trees like *Acer* (maple), *Fagus* (beech) and *Carpinus* (hornbeam) (Göransson 1989; Lagerås 1996b). The dense forest areas that earlier characterised the landscape of southern Sweden were now transformed into open forest areas with patches of small pasture lands.

Trends toward lower organic carbon content and $\delta^{18}O_{sed}$ ($\delta^{18}O$ of bulk carbonates) around 2450-1450 BC in southern Sweden indicate a gradually cooler and wetter climate (Jessen et al. 2005). Around 2200 BC a distinct drop in *Ulmus* and *Tilia* is visible in the pollen diagram from Östergötland followed by an increase in *Corylus*. This is interpreted by Göransson (1989) as a shifting of the earlier coppicing forest land-use, which included *Tilia*, *Quercus*, *Alnus* and *Corylus*, to a dominance of a *Corylus* coppicing forest. The increases in *Corylus*, along with an increase in *Quercus*, are also indicated by Lagerås (1996a) in the Småland Uplands. The increase of *Quercus*, which is followed by a decrease of *Tilia*, might be an effect of human impact but could also be due to a shift in the favouring of food source for pigs in the form of acorns.

At approximately 1700 BC the first evidence of grazing is found in the Småland Uplands along with indications of forest clearance (Lagerås 1996a). The area is characterised by a decrease in *Ulmus* and *Tilia* and an increase in the light-demanding species *Betula*, *Plantago lanceolata*, Cyperaceae (sedges) and Poaceae.

The time period between 1000 BC and AD 1000 was in southern Sweden characterised by an expansion of agriculture and pastures along with deforestation and enlargement of open areas (Berglund et al. 2002). This is reflected by a decrease in *Quercus*, *Corylus* and *Pinus* and the increase in *Plantago lanceolata*, Cyperaceae and Poaceae (Lagerås et al. 1995; Lagerås 1996b). Pasture lands increased during this time period in Östergötland and an increase in Poaceae coexists with a decrease in *Tilia* and *Corylus* and the establishment of *Carpinus* (Göransson 1989). Airborne mineral particles increased in the area which is an indication of larger agricultural areas (Göransson 1989). The first beetle species associated with heather-dominated heathlands occurred around 800 BC in southern Sweden, which coincides with an increase in *Calluna* (heather) (Olsson & Lemdahl 2009).

The first deforestation in the Småland Uplands occurred around 700 BC (Lagerås et al. 1995). This is supported by an increase in peat accumulation. After 600 BC, the presence of *Rumex* (sorrels) and *Polygonum* (knotweed) in Östergötland and the increase of *Rumex* in the Småland Uplands indicates clearing for cultivation or cattle grazing (Lagerås 1996b; Olsson & Lemdahl 2009). The *Rumex* species may have grown as weed in fields (Lagerås 1996b). The expansion of open areas was a consequence of intensified grazing, gradual deforestation and browsing in semi-open pastures (Lagerås 1996b). Pollen grains from *Hordeum* (barley) have also been found during this period, which indicates farming (Lagerås et al. 1995). High values of microscopic charcoal particles were also found, which further indicates human activity. After 350 BC the cereal values from Östergötland become continuous with both *Hordeum* and *Triticum* (wheat) (Göransson 1989). *Plantago lanceolata* appears regularly after 270 BC and *Triticum* was found at 300 BC in the Småland Uplands (Göransson 1989; Lagerås 1996b).

The establishment of an infield and outfield system started around 500 BC to AD 500, and the transformation to permanent settlements and cultivations started after AD 200 in coastal areas and closer to AD 1000 in the highlands (Berglund et al. 2002). Reforestation during the 6^{th} century is shown by pollen diagrams and was likely caused by farm abandonment (Lagerås 2007). That could have been caused by a decreasing European population due to the plague epidemics that haunted Europe during the 6^{th} century. However, it has not been proven that the plague epidemic reached Sweden and the reforestation could also have been caused by climates change or soil deterioration (Harrison 2000; Berglund et al. 2002; Lagerås 2007). After the decline in the 6^{th} century, Europe went through an agricultural expansion and a population growth, known as the Medieval expansion, that started in the 7^{th} century (Lagerås 2007). The period AD 600-1100 called the Medieval Warm Period was characterised by a step-wise increase in temperature (Lagerås 2007). An expansion of *Juniperus* around AD 800 in Östergötland coincided with a decline in *Quercus* and an establishment of *Fagus* between AD 800-1050 (Göransson 1989).

2.4.2 Medieval colonisation, expansion and decline

During the Medieval period, AD 1050-1500, the landscape went through an agricultural and cattle-breeding expansion (Berglund et al. 2002). The succession towards permanent settlements and agriculture was now established, production of iron on a large scale had started and along with technical development these factors contributed to changes in the society (Lagerås 2007). This is shown in the Småland Uplands where an expansion of herb and grass taxa occurred around AD 1000-1200 (Lagerås 1996b).

At the end of the Medieval Warm Period a trend towards a cooler climate started, which today is referred to as the Little Ice Age (Lagerås 2007). The temperature reached minimum values during the 16th and 17th centuries but has since then gradually increased.

The Småland Uplands experienced an expansion and establishment of a *Picea* (spruce) forest around AD 1150 (Lagerås et al. 1995). During AD 1200-1300 there was an enlargement of the expansion of pastures and meadows and a decline in tree species, with the exception of *Picea*, *Pinus* and *Alnus*. There was an increase of *Pinus* in Östergötland during this time that is interpreted by Göransson (1989) as a landscape development towards a more open landscape; an increase of *Pinus* pollen grains can reflect an increase of pollen dispersal. There are high values of *Juniperus* during this time period, indicating *Juniperus* growth on pastures on acid soils (Lagerås 1996a). The more permanent pastures and continuous and intensified grazing gave rise to nutrient depletion and soil leaching which are favourable conditions for *Juniperus*. During this period there was an intensification of crop cultivation, interpreted by the relatively high percentage of cereal taxa, including *Hordeum*, *Triticum*, *Secale* (rye) and *Cannabis sativa* (hemp). The Medieval expansion in Europe was most prominent during the 12th century which was the result of social changes; including urbanisation, development of agriculture tools and techniques, the spread and acceptance of Christianity and the establishment of the feudal monetary systems (Lagerås 2007).

The Medieval expansion was followed by a Medieval decline in the late 14th and early 15th centuries characterised by stagnation, population decrease and increase in farm abandonment (Lagerås 2007). Farm abandonment was more common in marginal areas than in central agricultural districts. The crisis affected all of Europe, on all levels of society. This is seen in pollen diagrams where cereals disappeared at the same time as there were signs of overgrowth. The agricultural production on poor soils in the marginal areas, that were colonised during the Medieval expansion, could not be sustained in the long term, which resulted in the exhaustion of agricultural production in marginal areas. Crop failure in marginal areas along with increased grain prices and starvation could explain the Medieval decline. However, this period was also affected by the Black Death, which probably was the most important influence on the Medieval decline.

The Black Death was a plague disease caused by the bacteria *Yersina pestis* that spread by infective flea bites from the flea *Xenopsylla cheopis* to its host animal the black rat (Harrison 2000). This caused a plague epizootic in the rat population and forced *Xenopsylla cheopis* to search for other individuals to feed on. The black rat, unlike the more reserved brown rat that was first established in Europe during the 18th century, often shared residence with humans, which made it possible for the flea to feed from and infect humans. Three main types of plague exist; bubonic plague that affects lymph nodes, pneumonic plague that affects the lungs and septic plague that affects blood vessels. The origin of the Black Death is uncertain but was probably spread from Asia. The first outbreak came to Europe in AD 1347-1352 but would be followed by a long series of plague outbreaks (Harrison 2000; Lagerås 2007). The first outbreak in Sweden occurred in AD 1350 which was followed by a range of outbreaks during the 14th to the 18th centuries; the last outbreak occurred in AD 1710-1713. The Black Death struck Sweden very hard, not just because of the high mortality rate but also by the upper classes' effort to protect their incomes which made the depression even worse for the society (Myrdal 2012).

2.4.3 Re-expansion during the 16th century and the Industrial Revolution

The Medieval decline was followed by an expansion during the 16th century with increasing population, agricultural production and re-establishment of abandoned farms (Lagerås 2007). The transition from a one-course to a two or three-course cropping system is supposed to have taken place during the 16th century which contributed to the re-expansion along with changes in the society and technological developments (Lagerås 1996a; Lagerås 2007; Olsson & Lemdahl 2009). This period is characterised by a decrease in *Juniperus* and high percentages of microscopic charcoal particles in the Småland Uplands (Lagerås 1996a). This indicates that the decrease in *Juniperus* could have been caused by fire clearance in pastures. The drop in *Juniperus* coincides with a rise in *Betula* which indicates decreased grazing pressure. This relationship could be interpreted as replacement of grazing in outfields to the infields, which is a logical effect of a transition from one-course to a two or three-course cropping system, especially since *Juniperus* could not have grown on cultivated land.

There was a regression in the *Picea* forest around AD 1800 and an expansion of open areas (Lagerås et al. 1995). The cereal pollen grains increased which probably was a direct consequence of the reform "*Storskiftet*" (the large land exchange) that occurred in the Småland Uplands at AD 1803. The ard was replaced by the plough during the 19th century and there is a decrease in species diversity, and thereby a decrease in the palynological richness, notable at circa AD 1850 (Lagerås et al. 1995; Olsson & Lemdahl 2009). This is probably linked to a change in land-use in the investigated area and the introduction of more efficient agriculture techniques (Olsson & Lemdahl 2009). Wood pastures and hay meadows were abandoned during the 20th century and often planted with *Pinus* and *Picea*, which resulted in decreasing values of *Rumex*, *Plantago lanceolata*, *Juniperus* and Poaceae (Lagerås 1996b; Olsson & Lemdahl 2009).

3. Study area

3.1 Present day conditions

Lake Storsjön is situated 30 km west of the Baltic Sea coast in the province of Småland, southern Sweden (57° 42' N, 16° 14' E) (Fig. 3). The lake has a diameter of 800 m, an area of 2.1 km^2 (Fig. 4) and is situated 90-100 m above sea level (VISS 2013). The maximum water depth of the lake is 14 m; with a mean water depth of 5 m. Lake Storsjön is located in the drainage area of the Botorpsströmmen River, which is a part of the southern Baltic Sea water district. Botorpsströmmen River flows into the coastal area of Gåsfjärden (Fig. 3b).

Eight vegetational zones can be distinguished in Sweden and the study area is situated in the Boreo-Nemoral zone (Fig. 3a) (Barklund 2009). The mean annual temperature (1961-1990) is 6.0-6.5 °C and the mean annual precipitation (1961-1990) is 556.5-559.5 mm/year (the meteorological stations Vimmerby and Västervik were used to provide the meteorological data from the Swedish Meteorological Institute). The landscape surrounding the lake is dominated by forestry, mainly coniferous trees, with patches of clear-felled areas and cultivated areas (Fig. 5).

The lake reached the environmental requirement for the ecological status of Swedish lakes in 2009 but due to acidification there is a risk that the ecological status goal for 2015 will not be reached (VISS 2013).

3.2 Geology

3.2.1 Bedrock

The bedrock surrounding Västervik and Vimmerby is part of the Fennoscandian Shield's crystalline bedrock and dominated by 1.8 billion years old intrusive and volcanic rocks (Jonsson et al. 2011). The intrusive rocks are found in the whole area and have a granite composition that varies from monzogranite to syenogranite. The volcanic rocks are located southwest of Vimmerby and belong to the Transscandinavian igneous belt. Sedimentary bedrock can be found in the coastal areas surrounding Västervik and mafic intrusive rocks are mostly found north of Västervik but also in the southern part of the area (Jonsson et al. 2011).

3.2.2 Quaternary deposits

The Quaternary sediments found in the study area are characterised by the location below the highest coastline. The highest coastline is defined as the highest level the sea, or in this case the Baltic Ice Lake, reached during or after the Weichselian glacial

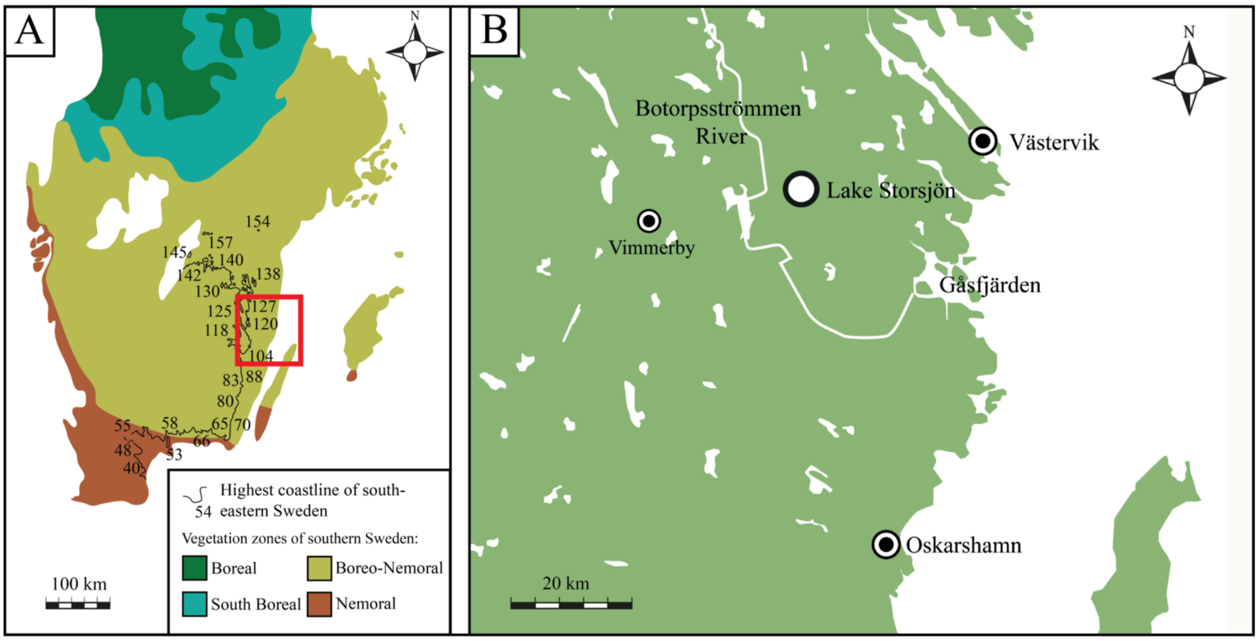


Figure 3. (A) Map showing the vegetation zones of Sweden (modified after Barklund 2009) and the location of the highest coastline in south-eastern Sweden (modified after Agrell 1976). The study area is marked by the red square. (B) Map of the study area showing the location of Lake Storsjön, the Botorpsströmmen River and the coastal area Gåsfjärden.

retreat. The highest coastline is situated west of the investigated area at 125-130 m above sea level, approximately 40 km west of the study site (Fig. 3A) (Svantesson 1999a).

The western part of the area is dominated by a thin, discontinuous soil cover consisting of till, littoral sediments and peat (Fig. 6) (Svantesson 1999a; Lindén 2010a & 2010b). The eastern part, closer to the coastline, is dominated by exposed bedrock (Fig. 6) (Svantesson 1999a). Exposed bedrock is a common landform in landscapes below the highest coastline due to wave erosion. The sediments that once covered the bedrock were eroded away which left the bedrock exposed. Glacial striations can be found on the exposed bedrock, especially in the archipelago, and show an ice direction that varies between 310° and 320° (Lindén 2010a & 2010b). Till can be found in the whole area and has a composition that varies between sandy and gravely (Svantesson 1999a). Fine grained sediments are common in the eastern part of the area and consist of silt and clay sediments but can also be found in the western part of the area. Glaciofluvial sediments are spread in the whole area and have in many cases been exposed to wave erosion. Peatlands of various sizes are scattered in the area (Svantesson 1999a; Lindén 2010a & 2010b).

The area closest to Lake Storsjön consists of a thin or discontinuous soil cover, exposed bedrock and a few peatlands (Lindén 2010a & 2010b).

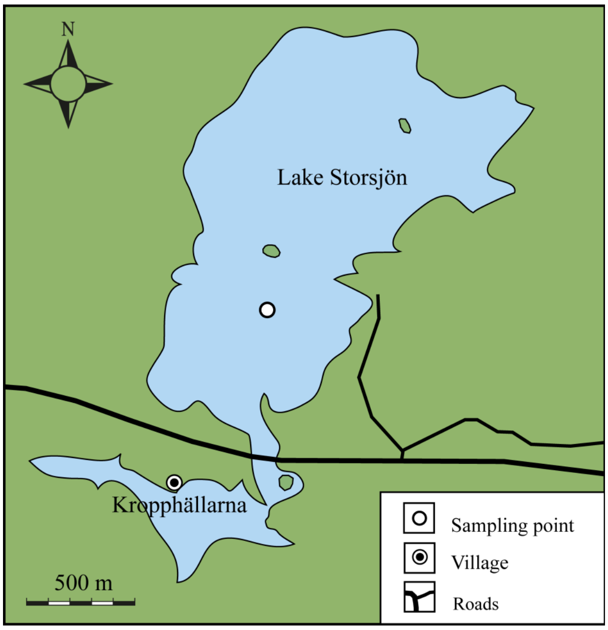


Figure 4, Map of the Lake Storsjön area showing the sampling point.

4. Material and methods

4.1 Site selection

The site selection for this study had two limitations, (1) the lake had to be situated in the central part of the drainage area of the Botorpsströmmen River and (2) have an area representative for a regional pollen signal.

The most suitable lake in the drainage area of the Botorpsströmmen River was Lake Storsjön. The lake has a size that will represent a regional signal (Sugita 2007a) and a further advantage is that the lake is more circular than other size-suitable lakes in the area (Fig. 4).

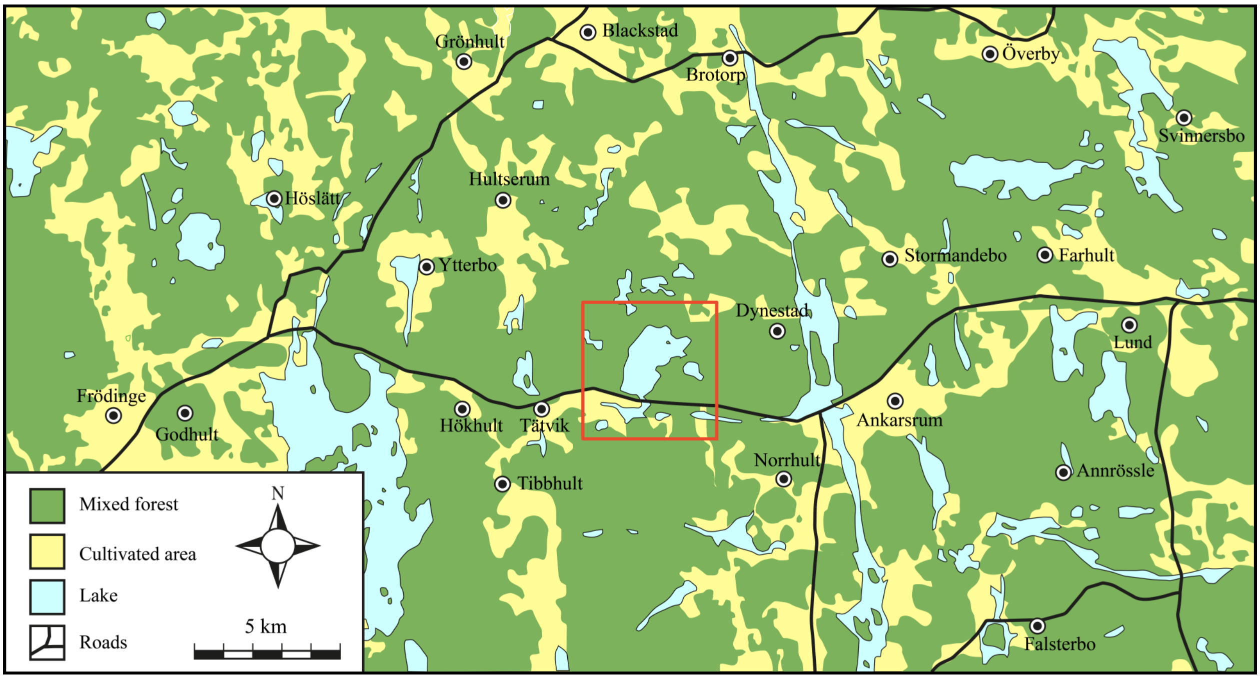


Figure 5. Map showing areas dominated by mixed forest and areas dominated by cultivated areas in the study area. The red square marks the location of Lake Storsjön (modified after Google Earth).

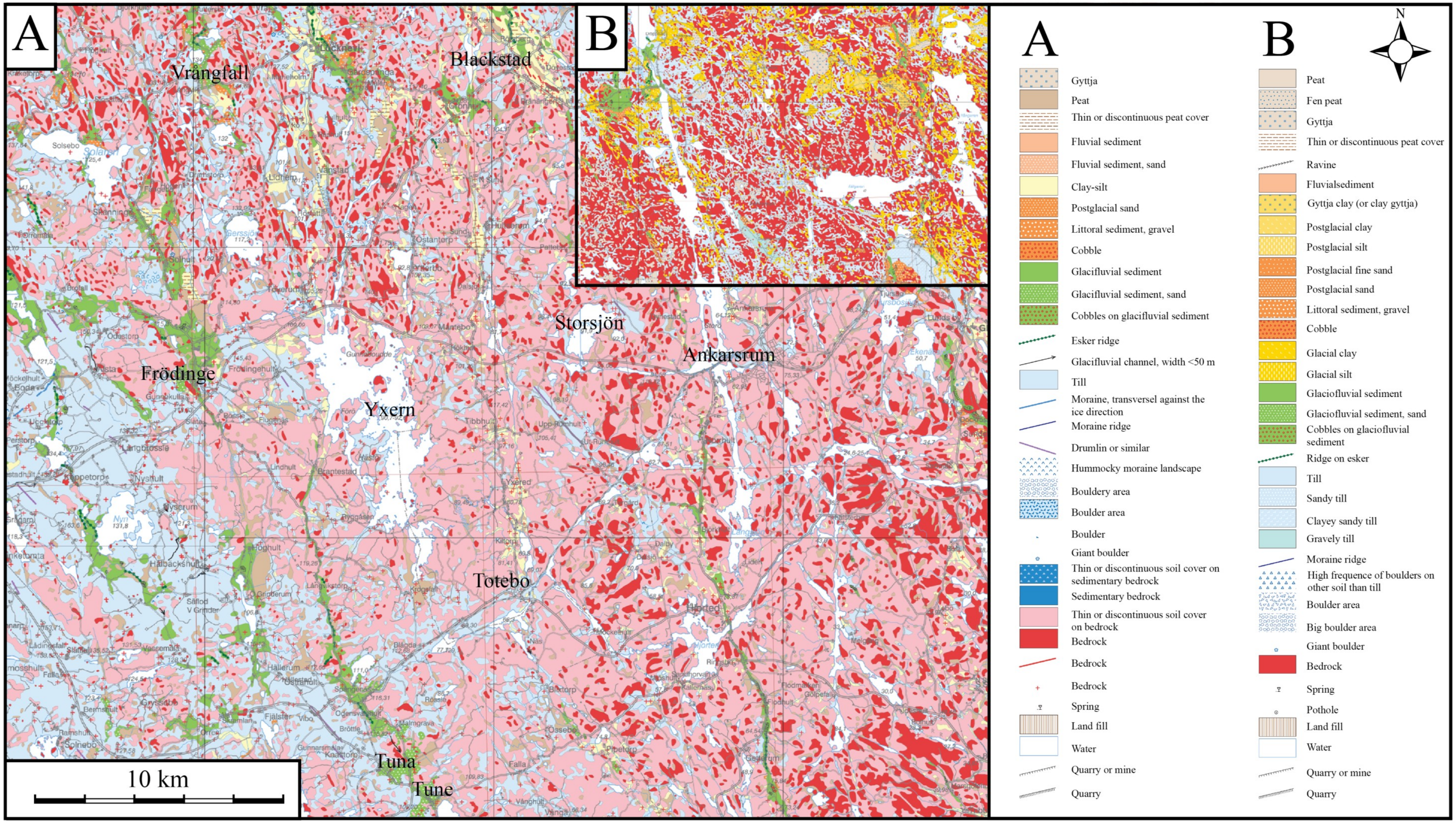


Figure 6. (A and B) Quaternary map of the study area with legends A and B, respectively (modified after Svantesson 1999b; Lindén 2010c ;Lindén 2010d; Svantesson 2010).

4.2 Fieldwork, subsampling, core selection and core description

Six sediment cores (SSK, SS1a, SS1b, SS2, SS3 and SS4) were retrieved from Lake Storsjön in April 2012, using a gravity corer (Kajak, Renberg 1991) and a Russian corer (diameter: 7.5 cm) (Fig. 4, 7, Table 1). The sampling location was situated 350 m from the nearest shore, and 250 m south of a small island in the lake at a depth of 6.6 m (Fig. 4). The gravity corer was used to collect the uppermost 30 cm of the sediment sequence (SSK). (Fig. 7B). After the collection of the Kajak core, the core was sectioned in 5 mm intervals in the field and placed in plastic bags for further analyses in the laboratory. The Russian corer was used

Table 1. Top depth and bottom depth below the water surface for all retrieved cores from Lake Storsjön. The water depth of the sampling point was 660 cm.

Cores	Top depth (cm)	Bottom depth (cm)
SSK	660	690
SS1a	672	760
SS1b	680	770
SS2	740	840
SS3	820	920
SS4	900	10000

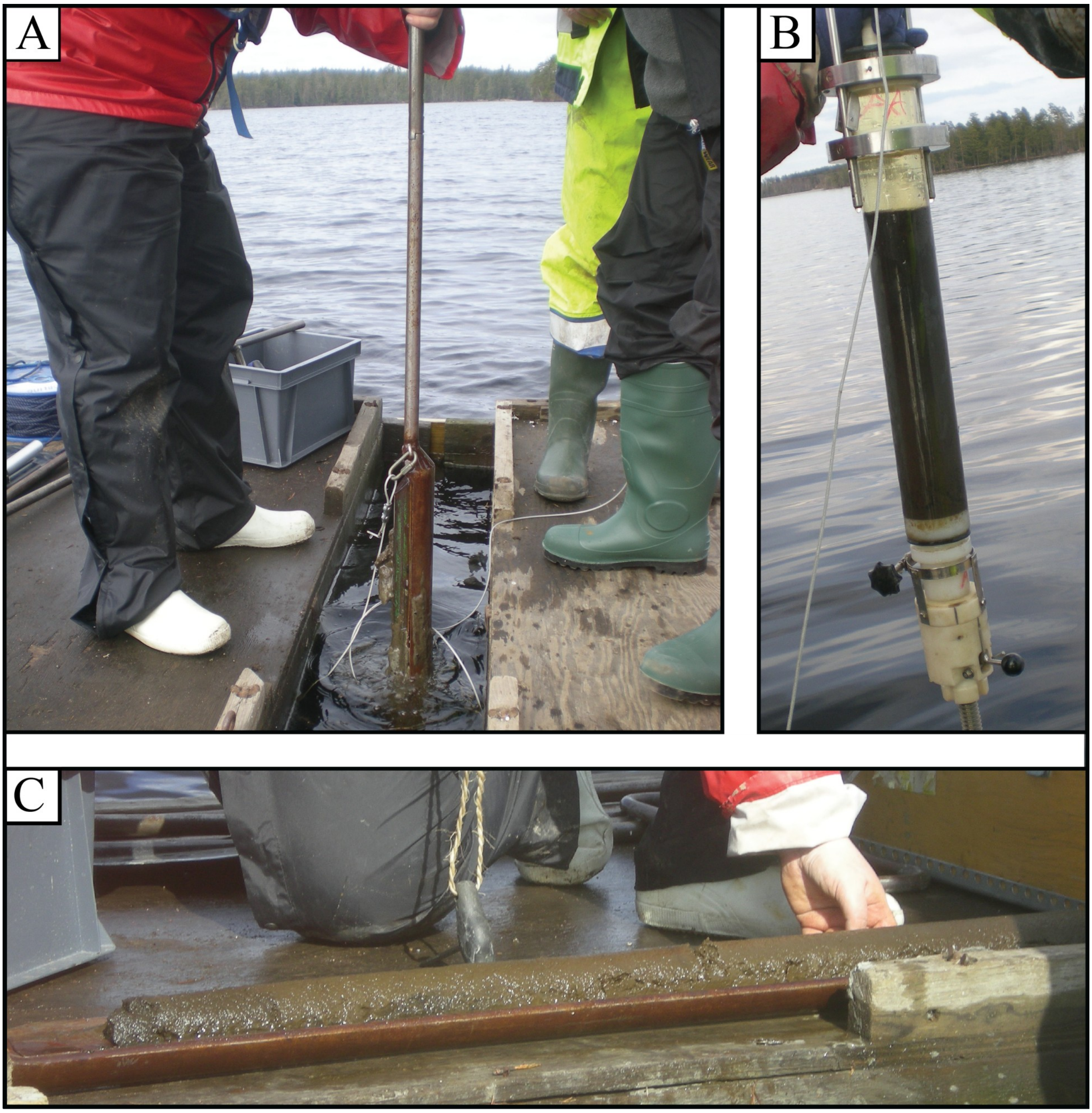


Figure 7. (A) Sediment sampling in Lake Storsjön in April 2012 and (B) the collection of sediment cores using a gravity corer and (A & C) a Russian corer (Photographs: Christine Åkesson 2012).

to collect the lower part of the sediment sequence (SS1a, SS1b, SS2, SS3 and SS4) (Fig. 7A & C). The 1 m core sections were then sealed in plastic for further analyses in the laboratory.

The laboratory work included core descriptions and subsampling for pollen analysis, loss on ignition, ^{210}Pb dating and ^{14}C dating.

The whole sediment column represents a time sequence that has a range from present day back to the early Holocene. This study focused on the last 2000 years and therefore only cores SSK, SS1a and SS1b are analysed here. This is based on the assumption that a 1 cm sediment section represents 30 years (Broström, A. & Nilsen A. B. personal communication). This assumption is only used for core selection and not for any dating analyses.

Cores SSK, SS1a and SS1b consist of a dark brown, highly humified detritus gyttja with very few macrofossils.

4.3 Dating

4.3.1 ^{14}C-dating

There exist tree isotopes of carbon; the two stable isotopes ^{12}C and ^{13}C and the unstable isotope ^{14}C (Walker 2005). ^{12}C comprises approximately 98.9 % of all naturally existing carbon, ^{13}C approximately 1.1 % and ^{14}C approximately one part in 10^{10} %. ^{14}C-atoms are formed through the interaction between cosmic ray neutrons and nitrogen in the upper atmosphere and become part of the global carbon cycle. ^{14}C is absorbed by plants through the photosynthetic process and by animals through ingestion of plants or other animals. The absorption of ^{14}C ends when an organism dies, which makes it possible to calculate the age by measuring the ^{14}C/^{12}C ratio after the death of the organism. The half-life of the unstable ^{14}C isotope is 5730 years and the upper age limit for dating is around 45 000 years (Walker 2005).

Core SS1b was divided into 1 cm sections and sieved through a 500 μm and a 250 μm sieve for the collection of terrestrial macrofossils. Very few macrofossils were found in the sieve residues. The macrofossils of a terrestrial origin were carefully extracted using a binocular microscope at 15 times magnification (Olympus SZX12). Five samples were collected and submitted for dating at the ^{14}C-laboratory, Department of Geology, Lund University, Sweden. The results are still pending.

4.3.2 ^{210}Pb-dating

Radon (^{222}Rn) is an unstable isotope with a half-life of 22.26±0.22 years and decays through a series of daughter isotopes to ^{210}Pb (Walker 2005). ^{210}Pb-dating is based on the emission of radon gas from the earth to the atmosphere and is primarily used to date lake sediments within the time range of 150 years. ^{222}Rn is embedded into lake sediments through precipitation and the age of the sediments can be calculated by measuring the ratio of ^{210}Pb and ^{206}Pb in a lake sediment sequence (Walker 2005).

^{210}Pb-dating was used for the uppermost part of the sediment sequence (core SSK) and every cm of the sequence was sampled. The samples were then submitted for dating at the Department of Geology, Lund University, Sweden. The results are still pending.

4.4 Loss on ignition

Loss on ignition (LOI) is used to estimate the organic content of sediments (Heiri et al. 2001). Samples from every cm of cores SSK, SS1a and SS1b were collected, weighed and oven-dried at 50 °C for approximately 12-24 h. After the oven-drying, the samples were once again weighed in order to determine the dry weight. The samples were then heated to 550 °C in a muffle furnace, and after cooling weighed again in order to estimate the organic content by calculating the weight loss of the samples.

4.5 Pollen analysis

4.5.1 Biological and ecological patterns of pollen grains

A pollen grain consists of two layers; the internal layer intine, composed of cellulose, and the external layer exine, composed of sporopollenin and polysaccharides (Moore et al. 1991). The exine is the part of the pollen grain that shows the characteristic sculpturing and structuring. When a pollen grain is deposited in a lake, fen or a bog the exine is the only part of the pollen grain that resists decomposition.

The understanding of pollen transportation is crucial in order to understand pollen analysis and to interpret the results given by the analysis (Fægri & Iversen 1989). The transport can be divided into five main components (Tauber 1965); the canopy component (Cc), the rain component (Cr), the trunk space component (Ct), local or gravity component (Cl) and the secondary component (Cw) (Fig. 8) (Moore et al. 1991). Pollen grains produced within the canopy (Cc) can be transported above the canopy by air currents or become a part of the trunk space component by sinking through the canopy. Pollen grains can also be removed from the atmosphere by water droplets (Cr) or be transported by sub canopy air movements (Ct). Pollen grains produced from aquatic plants are a part of the local component and the gravity component consists of pollen grains falling straight down from its source (Cl). The final component, the secondary component (Cw), is when pollen grains are transported with surface water.

The strategies for the transport and dispersal of pollen grains differ between species and wind pollination is the most essential pollen transport for pollen analysis (Fægri & Iversen 1989). Great pollen quantities are produced and mechanisms scatter the grains effectively from the anthers. The pollen grains are then dispersing into the air as a pollen rain. Some pollen grains settle on a stigma, but the majority do not

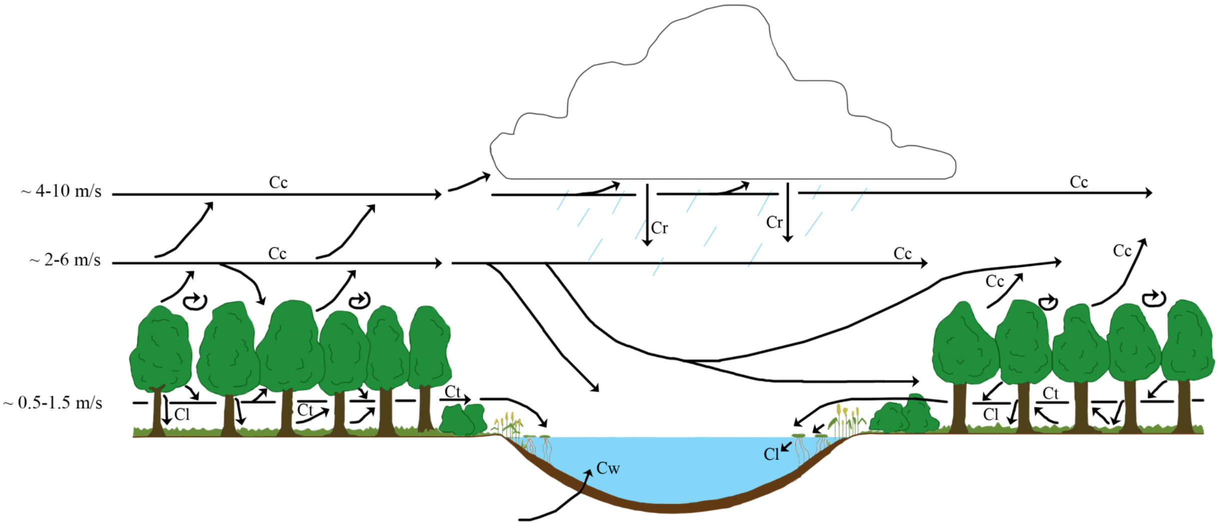


Figure 8. An illustration showing the different types of pollen transport in a forest area and the wind velocity at various elevations. The transport of pollen grains can be divided into five main components; the canopy component (Cc), the rain component (Cr), the trunk space component (Ct), local or gravity component (Cl) and the secondary component (Cw) (modified after Tauber 1965).

and can instead be deposited in a lake, fen or bog. The individual pollen grains of anemophilous plants are often separated and dry (Fægri & Iversen 1989). The grains' exines are poorly structured and smooth.

Several plants use animals, for example insects, birds or bats, as external pollinators and they are called zoophilous plants (Fægri & Iversen 1989). The pollen grains of zoophilous plants differ from wind-pollinated plants, in that the grains are bigger and they have a strong sculpturing with layers of sticky oil which makes it easier for the grains to stick to the body of the pollinating animal, or to each other. Pollen grains from many zoophilous plants are extremely rare in pollen data and the absence cannot conclude anything about their presence in the vegetation. Zoophilous plants can also show great quantities in pollen records (Fægri & Iversen 1989). For example, bee's collection methods can release pollen grains into the air and some insect pollinated plants produce great amounts of pollen, which are comparable with the pollen productivity of wind-pollinated plants.

Several plants are never, or at least rarely, represented in pollen data; pollen grains from self-pollinated plants like autogamous and cleistogamous plants or apogamous plants, which are able to produce plant embryo without a previous fertilization, are rarely represented in pollen data (Fægri & Iversen 1989). Some aquatic plants are pollinated under water and they are also heavily underrepresented in pollen data due to the fact that aquatic plants often have very thin exines and are often too corroded to be recognisable.

The quantity of pollen production, both by individual plants and by the whole plant community is not a constant value (Fægri & Iversen 1989). Variations in ecological patterns of plant species affect the pollen productivity, for example flowering and pollen production. The relation between pollen produced by undergrowth vegetation and trees is used as an indication of the density of a forest or a non-forested area.

The establishment of pioneer tree species like *Betula*, *Corylus* and *Alnus* can be used to interpret the landscape. Pioneer species quickly establish themself in abandoned pastures, meadows and arable lands and create conditions suitable for other trees. Pioneer species are also good indicators of reforestation.

The location of trees is an important factor for pollen productivity (Fægri & Iversen 1989). Trees situated in exposed areas, for example in a field, produce much more pollen than trees that grow in a dense forest. Young or suppressed trees that do not reach above the canopy produce very little pollen. Many of the shrubs and herbs that grow in the lower strata of a forest are insect pollinated and produce very small amounts of pollen. The wind velocity in the lower strata of a forest is also very low (Fig. 8), which often has the consequence of immediate deposition of pollen grains from the undergrowth vegetation.

While the shrubs and herbs have a secondary part of the pollen productivity in a forest area, in an open, non-forested area it has a pollen production equal to the production of tree pollen in a forest area (Fægri & Iversen 1989). In an open area such as a meadow, the amounts of shrubs and herbs are greater than in a forest which increases the pollen productivity of undergrowth vegetation. The wind velocity is higher and can thus transport the pollen grains. The pollen grains of insect pollinated plants also have a greater chance to spread in an open area.

4.5.2 Preparation of samples and performed pollen analysis

Samples extracted, at an interval of 1 cm, from the two uppermost cores SSK and SS1a (660-769 cm) were prepared for pollen analysis according to the standard pollen methodology (Berglund & Ralska-Jasiewiczowa 1986). *Lycopodium* spores were added to the samples in order to estimate pollen concentration and influx values.

Pollen grains, spores and algae from 29 samples were counted and identified to species or family level using the reference collection at the Department of Geology, Lund University, pollen keys and illustrations in Fægri & Iversen (1989), Moore et al. (1991) and Beug (2004). At least 1000 pollen grains were counted in each sample using a light microscope (Olympus BX41) at 400 times magnification. Microscopic charcoal particles (>25 µm) were also counted. Pollen sums including pollen taxa, were used for the calculation of percentage and the percentage value of the remaining taxa (algae and spores) were calculated in relation to the pollen sum. Pollen data from 26 samples were used to construct a pollen diagram using the computer program Tilia (Version 1.5.12). The remaining three samples (SS1a-683, SS1a-684 and SS1a-685) were used for core correlation between SSK and SS1a. The data from the correlating depths (SS1a-623/SSK-623, SS1a-624/SSK-624 and SS1a-625/SSK-625) were compared to each other.

The P/E ratio of 1.25 was used to distinguish different cereal taxa from each other; P/E ratio is defined as the ratio of the length of the polar axis (P) to the (E) equatorial axis of a pollen grain. *Triticum* and *Avena t.* (oat) pollen grains, with a P/E ratio of <1.25), where distinguished from *Secale t.* pollen grains, with a P/E ratio of >1.25. Cereals *Triticum*, *Avena t.* and *Hordeum* are in the pollen diagrams illustrated in a combined group named *Cerealia t*.

4.6 Landscape Reconstruction Algorithm (LRA)

4.6.1 REVEALS model and LOVE model

The framework Landscape Reconstruction Algorithm (LRA) is used to quantify the vegetation composition across various spatial scales and consists of two steps; (1) the Regional Estimates of Vegetation Abundance from Large Sites (REVEALS) model and (2) the Local Vegetation Estimates (LOVE) model (Fig. 9) (Sugita 2007a).

Sugita (1994) defined the relevant source area of pollen (RSAP) as the distance from a pollen deposition point (for example a bog or a lake) beyond which the correlation between pollen loading and vegetation composition does not continue to improve. Background pollen are the pollen grains transported from beyond the relative source area of pollen and influences pollen analysis samples (Hellman et al. 2008). Pollen productivity estimates (PPE) and pollen dispersal ability of taxa are crucial in order to calculate background pollen abundance (Broström et al. 2004). PPE is calculated from ERV models using modern pollen and vegetation data. The REVEALS model is the first step in LRA and is used to reconstruct the composition of regional vegetation (Sugita 2007a). The model uses pollen percentage data, relative pollen productivity and dispersal of pollen types to estimate past regional plant abundance (Nielsen & Odgaard 2010). Unlike the Extended R-Value (ERV) model, the REVEALS model disregards background pollen from outside the relevant source area of pollen.

Two pollen dispersal/deposition models are developed for the REVEALS model; the Prentice's model (Prentice 1985) and the ring-source model (Sugita et al. 1999). The Prentice's model, appropriate for bogs and fens, calculates pollen deposition from one source point of a basin whereas the ring-source model calculates pollen deposition over the entire surface of a basin. The ring-source model is appropriate for lakes and makes some basic assumptions, for example that the sedimentary basin is a circular opening in the canopy, pollen grains are transported by wind above the canopy and no source plants exist in the basin (Sugita et al. 1999).

A relationship exists between the extent of the RSAP of pollen and the size of the pollen deposition point (Broström et al. 2004). An increase of the basin size increases the proportion of pollen grains transported from a longer distance and thus increases the size of the RSAP. The vegetation surrounding a large basin (>1 km^2) is reflected in pollen data as homogeneous and large basins are therefore used to represent a region vegetation signal. It is possible to quantify the background pollen input once the composition of a regional vegetation cover of $\geq 10^4$-10^5 km^2 is known (Hellman et al. 2008).

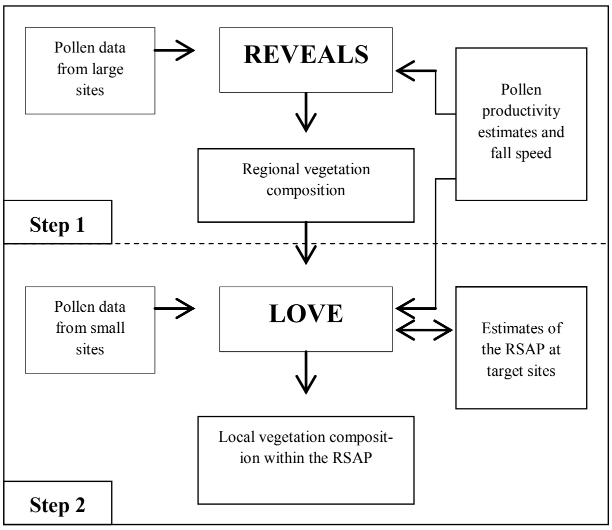


Figure 9. Flow chart illustrating the LRA framework (Landscape Reconstruction Algorithm) and its two steps; REVEALS (Regional Estimates of Vegetation Abundance from Large Sites) model and LOVE (Local Vegetation Estimates) model (modified after Sugita 2007b).

The LOVE model is the second step in the LRA framework and is used to reconstruct local vegetation within the RSAP of a smaller basin (Sugita 2007b). The model has similar assumptions as the REVEALS model. The parameters required for the LOVE model are pollen counts from investigated sites, the RSAP for these areas, PPE data and the regional vegetation composition within 10^4-10^5 km^2 (obtained by the REVEALS model using data from large sites). In order to quantitatively reconstruct local vegetation (2-20 km^2), the LOVE model quantifies and subtracts background pollen (Sugita 2007b; Fredh 2012).

4.6.2 Input data for REVEALS model

The basin size of Lake Storsjön represents a regional vegetation signal and therefore only the first step REVEALS was used in the LRA framework. The REVEALS model (Sugita 2007a) is expressed as:

$$\hat{V}_i = \frac{n_{i,k}/\hat{\alpha}_i \int_R^{Z_{max}} g_i(z)dz}{\sum_{j=1}^{t} n_{j,k}/\hat{\alpha}_i \int_R^{Z_{max}} g_j(z)dz}$$

$\hat{V}_i$	the proportion of the regional vegetation composition of species *i*
$n_{i,k}$	the pollen count of species *i* at site *k*
$\hat{\alpha}_i$	the relative pollen productivity of species *i*
R	the radius of the basin
Z_{max}	the maximum range of the regional vegetation
z	the distance from the centre of the basin
$g_i(z)$	the pollen dispersal and deposition model of species *i*
t	the total number of species included in the analysis

Collected pollen data ($n_{i,k}$), fall speed data, PPE data and standard errors for 21 taxa (t) were used as input to the REVEALS model (Version 4.2.2) (Table 2). The Ring-Source-model (Sugita et al. 1999) for lakes was used in order to calculate pollen deposition on the entire surface of the lake. The radius (R) of the lake was set to 800 m, the maximum spatial extent of the regional vegetation (Z_{max}) was set to 100 km and the wind speed was set to 3 m/s. The vegetation composition, calculated by the REVEALS model, was illustrated using the computer program Tilia (Version 1.5.12).

4.7 Principal Component Analysis (PCA)

Principal Component Analysis (PCA) is a linear ordination technique that can be used to investigate the relationship between pollen taxa and landscape components at different sites or depths (Broström et al. 1998). The analysis is illustrated by a co-ordinate system where the original variables are redefined by the PCA as linear combinations of taxa. Major patterns are represented by four principal component axes (λ_n), where the first axis (λ_1) best represents the variations in the data set. The second and later axes are restricted by being uncorrelated with previous PCA axes and therefore account for a decreasing amount of variation in the data set (ter Braak 1987; Broström et al. 1998). The amount of variation in the third and fourth axes is usually very small and the axes are seldom of importance when interpreting the data (Broström et al. 1998).

A PCA analysis was performed on 26 samples and 22 pollen taxa from Lake Storsjön in Vimmerby and illustrated by the first (λ_1) and second (λ_2) axes.

Table 2. Used PPE data, fall speed of pollen values and standard error values for 21 taxa.

Plant taxa	Relative pollen productivity (PPE)	Fall speed of pollen (m/s)	Standard errors (SE)
Alnus	4.2^a	0.021^a	0.140^d
Artemisia	3.48^e	0.021^a	0.190^e
Betula	8.867^d	0.024^a	0.134^d
Calluna	1.102^c	0.038^c	0.054^d
Carpinus betulus	2.533^d	0.042^a	0.070^d
Cerealia t.	0.747^c	0.060^c	0.039^d
Corylus	1.4^c	0.025^a	0.042^d
Cyperaceae	1.002^d	0.035^a	0.164^d
Fagus sylvestris	6.667^d	0.057^a	0.173^d
Fraxinus excelsion	0.667^d	0.022^a	0.027^d
Juniperus	2.067^d	0.016^a	0.036^d
Picea	1.757^d	0.056^a	0.000^d
Pinus	5.663^d	0.031^a	0.000^d
Plantago lanceolata	0.897^c	0.029^b	0.235^d
Poaceae	1^c	0.035^a	0.000^d
Quercus	7.533^d	0.035^a	0.083^d
Rumex acetosa	1.559^c	0.018^b	0.089^d
Salix	1.267^d	0.022^a	0.313^d
Secale t.	3.017^d	0.060^a	0.052^d
Tilia	0.8^c	0.032^a	0.029^d
Ulmus	1.267^c	0.032^a	0.050^d

[a] Sugita et al. 1999, [b] Broström et al. 2004, [c] Nielsen 2004, [d] Fredh 2012a and [e] Poska et al. 2011.

5. Results

5.1 Dating, chronology and loss on ignition

The results from the ^{14}C- and ^{210}Pb analyses are still pending and pollen diagrams from other studies from southern Sweden have thus been used for age estimation (e.g. Göransson 1989; Lagerås et al. 1995; Lagerås 1996a & 1996b; Lagerås 2007). Furthermore, a pollen diagram based on cores SSK, SS1a, SS2, SS3 and SS4 has been used with the pollen diagram from this study in order to identify known vegetation events during the Holocene and thus, approximate ages of the sediment sequence (Fig. 10) (Appendix A). Known pollen vegetation events used for the approximate ages were the rise of *Corylus* pollen and disappearance of *Betula nana* pollen at approximately 7450 BC

(Göransson 1988 & 2010), the appearance of *Alnus* at 6550 BC, the *Ulmus* pollen decline at 4000 BC (Göransson 1988 & 1989), the *Picea* pollen rise at AD 250 (Göransson 1988 & 2010) and the introduction of *Fagopyrum esculentum* (buckwheat) pollen in the 17th century (Campbell 1997). The ages inferred from the vegetation events only give an approximation of the sediment age and the results are dependent on sediment deposition variations and the compaction rate of the sediments.

Pollen analysis was also used for the correlation between cores SSK and SS1a. Three samples from each of the cores were analysed from the same depth (SS1a-623/SSK-623, SS1a-624/SSK-624 and SS1a-625/SSK-625) and could thereby be used to analyse if the results from the two cores correlated with each other. The percentage values of different taxa from cores SSK and SS1a could in most cases be correlated with each other, but for some taxa there exist some smaller differences. It is however hard to interpret if these differences are the cause of a fault in the core correlation since the correlation only is made over 3 cm of the cores. It is thereby hard to locate any trends and impossible to correlate the remaining parts of the cores by just using these six samples.

The loss on ignition results from SSK, SS1a and SS1b cores are shown in Fig. 11. The results from the loss on ignition show two decreases in organic content in core SSK at 661 cm and 673 cm, two decreases in organic content in core SS1a at 673 cm and 732 cm and a general trend towards a lower organic content in core SS1b. The results from the loss in ignition are used for the core correlation. Cores SSK and SS1a can be correlated at 673 cm where both cores show a decrease in the organic content. Data does not exist for core SS1b for this depth interval but the start of SS1b at 680 cm follows the same trend as the curves of SSK and SS1a. SS1a and SS1b continues to correspond between 680-727 cm. The cores thereafter follows the same trend towards an increase in the organic content.

5.2 Pollen analysis and the REVEALS model

The counted pollen data are presented in a pollen percentage diagram and the data delivered from the REVEALS model are presented in a reconstructed land cover percentage diagram (Fig. 12 & Fig. 13). A total of 40 pollen taxa were identified and used in the pollen percentage diagram. PPE data and fall speed data at present only exist for 21 of these 40 identified taxa, thereby only 21 taxa could be used in the REVEALS model. Only dominant or indicator taxa are presented in the text, but all pollen types are included in the calculation sums and are presented in the two diagrams. The diagrams are divided into five different landscape periods (A-E) and four sub-periods (C1-C4) for period C. Differences in pollen assemblage were used for the zonation of the diagrams.

5.2.1 Pollen analysis

5.2.1.1 Period A (725-710 cm)

This period is characterised by high pollen percentage values of *Pinus*, increasing pollen percentage values of *Betula* and decreasing pollen percentage values of *Corylus* and *Alnus*. *Pinus* pollen has a percentage representation between 40-65 %. The highest pollen percentage representation of *Corylus*, 20 %, is visible

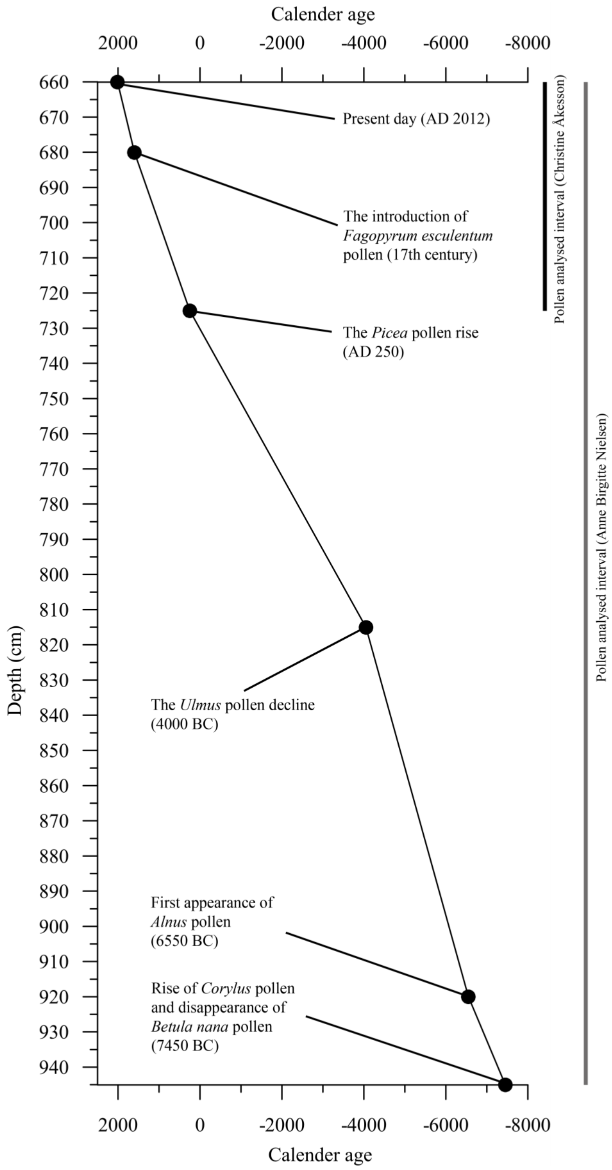


Figure 10. Relative chronology diagram developed by using known pollen events delivered from pollen diagrams from Lake Storsjön using cores SSK, SS1a, SS2, SS3 and SS4 (Fig. 12, 13 & Appendix A). Known pollen events used for the approximate ages were the rise of *Corylus* pollen and disappearance of *Betula nana* pollen at circa 7450 BC (Göransson 1988 & 2010), the appearance of *Alnus* at 6550 BC, the *Ulmus* pollen decline at 4000 BC (Göransson 1988 & 1989), the Picea pollen rise at AD 250 (Göransson 1988 & 2010) and the introduction of *Fagopyrum esculentum* pollen in the 17th century (Campbell 1997).

in the beginning of period A. *Corylus* pollen then decreases to below 5 % in the middle part of period A. *Betula* increases from 15 % to almost 20 % whereas *Alnus* decreases from 10 % to 5 % during this period.

Juniperus pollen increases towards the middle part of period A to 5 % but decreases at the end to below 5 %. Poaceae pollen dominates the non-tree taxa group and increases to almost 4 % during period A. The highest value of *Artemisia* (mugwort, wormwood and sagebrush) pollen, 2 %, is found in the beginning of period A but the taxon decreases to 0.5 % towards the end. The same pattern applies to *Rumex acetosa* pollen as it increases to almost 1 % in the middle part of the period but decreases again towards the end. A few pollen grains of *Cerealia t.* and *Secale t.* have also been found in period A.

The two samples in period A shows high values of microscopic charcoal particles where 25-40 µm charcoal particles dominate. The algae taxa *Botryococcus* has high values during this period but shows signs of a decrease in the middle part of period A. The algae taxa *Pediastrum* has low values during period A and disappears in the latter part of the period.

5.2.1.2 Period B (710-695.5 cm)

This period is characterised by a decreasing trend of *Pinus* pollen to around 50 %, which is reversed towards the end of the period when *Pinus* again increases to 65 %. The period is also characterised by an increasing trend in the pollen percentage of deciduous trees, especially *Betula*, and minimum values for cereal pollen.

The *Betula* pollen percentage shows an increase to almost 25 % during period B, but decreases towards the end to about 15 %. *Alnus* and *Picea* have pollen percentage values around 5 % whereas *Corylus* and *Quercus* have values around 3 %. *Juniperus* pollen decreases to below 3 % and Poaceae pollen show values around 4 % during this time period. Cyperaceae shows a slight increase in the beginning to 2 % but decreases to 0.5 % towards the end of the period. *Rumex acetosa* pollen show values around 0.6-0.8 %. *Plantago lanceolata* pollen disappears in this period but returns towards the end with 0.3 %. Two grains of *Cerealia t.* are found during period B.

Microscopic charcoal particles decreases in period B and remains low during the whole period. The algae taxon *Botryococcus* has high values during the early part of the period but decrease towards the end of period B. The algae taxon *Pediastrum* has low values during the early and latter part of the period but increases during the middle part of period B.

5.2.1.3 Period C (695.5-681.5 cm)

This period is generally characterised by a decreasing trend in tree pollen and an increase in shrubs, dwarf shurbs, herbs, grasses, sedges and cereals.

Pinus pollen increases during the early part of period C to 70 %, decreases in the later part to 50 % but increases again to between 60-70 % at the end of this period. *Betula* pollen fluctuates around 10-15 % during this time period with a distinct increase to almost 17 % at around 690 cm. *Alnus* pollen decreases from 7 % to 1 % in the beginning of period C but increases thereafter to 5.5 % at a depth of 690 cm. *Alnus* pollen fluctuates during the latter part of the period between 2-4 %. *Juniperus* has low values during the early part of period C but increases towards the middle and reaches its highest pollen percentage value, around 11 %, in the whole sequence. *Juniperus* decreases to very low pollen values during sub-period C4. Herbs, grasses, sedges and cereals have high pollen percentage values during

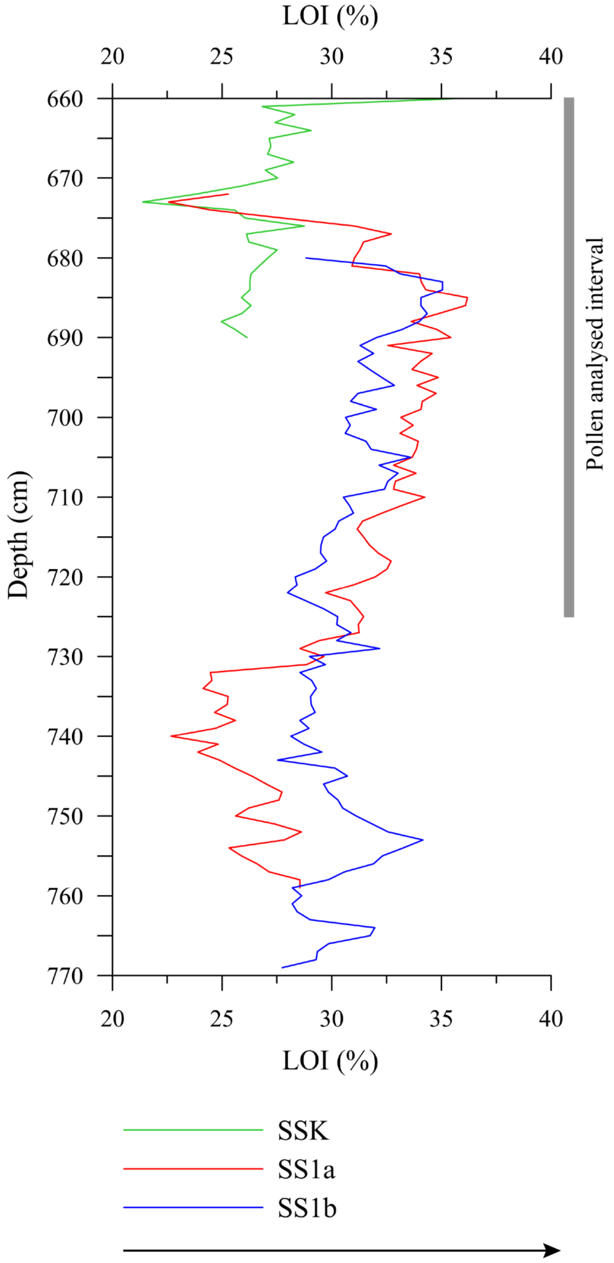


Figure 11. The loss on ignition in % for cores SSK, SS1a and SS1b. The pollen analysed interval for this study is illustrated by the grey line and an increase in the organic content is illustrated by the black arorow.

Lake Storsjön
57° 42' N, 16° 14' E
Pollen diagram

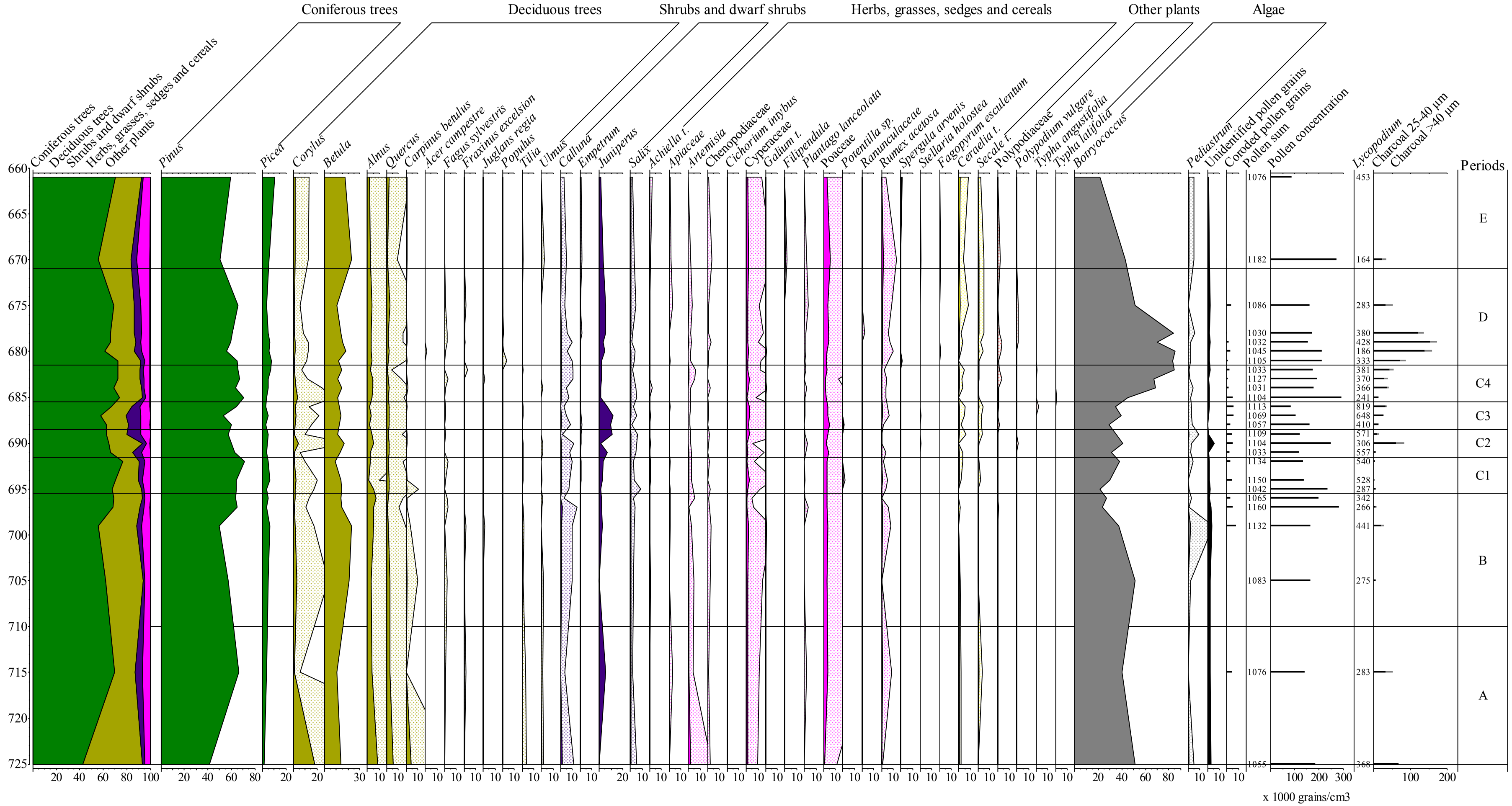


Figure 12. Pollen percentage diagram constructed from cores SSK and SS1a collected from Lake Storsjön using 26 samples and at least 1000 counted pollen grains for each sample. The samples are plotted on a depth scale and all taxa are presented as % of the pollen sum. Dotted graphs show data with 10x exaggeration. Counted *Lycopodium* spores for each sample was used to determine the pollen concentration. The diagram is divided into five periods (A-E) where period C is divided into four sub-periods (C1-C4). The periods and sub-periods are described in the text. The group *Cerealia t.* includes the cereal taxa *Triticum*, *Avena t.* and *Hordeum*.

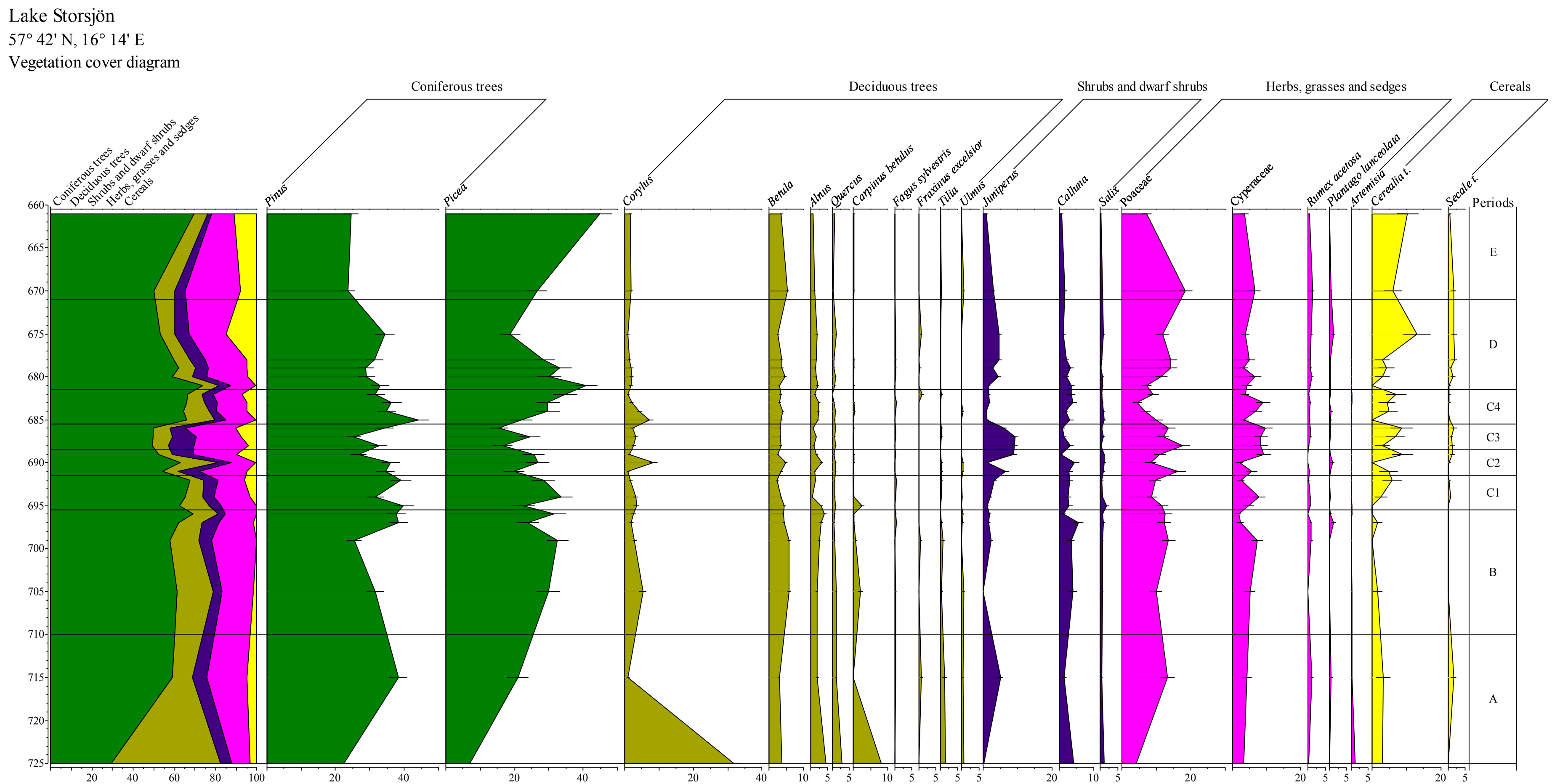


Figure 13. Vegetation cover diagram calculated by the REVEALS model and based on pollen counts from 21 selected taxa and 26 samples from cores SSK and SS1a delivered from Lake Storsjön. The samples are plotted on a depth scale and all taxa are presented as % and standard errors are shown by the black lines. The diagram is divided into five periods (A-E) where period C is divided into four sub-periods (C1-C4). The periods and sub-periods are described in the text. The group *Cerealia t.* includes the cereal taxa *Triticum*, *Avena t.* and *Hordeum*.

sub-period C1, reach minimum values at 690 cm during sub-period C2 but recovers in the sub-periods C3 and C4.

Sub-period C1 is characterised by low microscopic charcoal particle values, whereas a peak in microscopic charcoal particles at 690 cm characterises sub-period C2. Sub-period C3 shows a slight increase in microscopic charcoal particles which continues in sub-period C4. The algae taxon *Botryococcus* increases again in period C and is relatively stabled during sub-periods C1-C3. The taxon increases further during sub-period C4. The algae taxon *Pediastrum* has low values during period C but increases in the latter part of sub-period C2 and decreases again in the early part of sub-period C3.

5.2.1.4 Period D (681.5-671 cm)

This period is characterised by the highest values for cereals where *Cerealia t.* show pollen percentage values of 0.8 % and *Secale t.* 0.5 %. *Pinus* pollen increases from 55 % to 65 % but drops to 50 % at the end of period D. *Picea* show pollen values between 5.5-6.6 %. *Betula* pollen decreases from 18 % to 10 % towards the middle of period D but increases at the end to more than 22 %. *Juniperus* has stable values around 3-5 % and the same applies for Poaceae. *Rumex acetosa* pollen increases from 0.7 % to 1.3 %. One pollen grain of *Fagopyrum esculentum* has been found at 680 cm.

The highest values of microscopic charcoal particles characterises the beginning of period D. The charcoal particles decreases in the remaining part of the period but the value is still high. The algae taxon *Botryococcus* continues to have high values during the early and middle part of period D but decreases slightly in the latter part of the period. The algae taxon *Pediastrum* has low values during period D but show a small increase in the middle part of the period.

5.2.1.5 Period E (671-660 cm)

This period is characterised by high cereal pollen percentage values, increasing *Pinus* and *Picea* pollen percentage values and decreasing pollen values for shrubs, dwarf shrubs, herbs, grasses and sedges.

Pinus pollen increases from 50 % to 60 % whereas *Picea* pollen increases from 5.5 % to 10 % during this period. *Betula* pollen experiences a small decrease from 23 % to 17 % towards the end of the period. *Alnus* pollen decreases from 3 % to 1.5 % and *Juniperus* pollen decreases from 3.5 % to 1.5 %. Poaceae pollen decreases from 6 % to 2.5 %, Cyperaceae pollen decreases from 2 % to 1.3 % and *Rumex acetosa* pollen decreases from 1.3 % to 0.4 % during period E. *Cerealia t.* pollen increases from 0.4 % to 0.8 % whereas *Secale t.* pollen decreases from 0.5 % to 0.2 %. One pollen grain of *Fagopyrum esculentum* has been found at 670 cm.

Period E shows low values of microscopic charcoal particles, especially the top sample at 661 cm. The algae taxon *Botryococcus* has high values during this period but shows signs of a decreasing trend towards the top of the sediment sequence. The algae taxon *Pediastrum* has stable and relatively high values during period E.

5.2.2 REVEALS model

5.2.2.1 Period A (725-710 cm)

The REVEALS based reconstruction for period A is characterised by increasing percentage cover values for coniferous trees and decreasing values for deciduous trees. *Pinus* shows cover percentage values around 20 % in the beginning of this period that increases to almost 40 % in the middle part and decreases again to 35 % at the end of the period. Reconstructed *Picea* cover increases from 7 % to almost 30 % during period A. *Corylus* and *Carpinus betulus* cover have high values in the beginning of the period, 30 % and 8 % respectively, but they decrease towards the end to below 5 % and 2 %. *Betula*, *Alnus* and *Quercus* have percentage cover values around 5%.

Juniperus cover increases to 5 % in the middle part of period A but decreases at the end of the period. The reconstructed Poaceae cover increases from 4 % to over 10 % and Cyperaceae shows percentage cover values around 5 %. *Rumex acetosa* and *Plantago lanceolata* increase in the middle part of period A to 1 % and 0.6 % respectively, but decrease at the end of period A. The highest value of *Artemisia* cover, 1.5 %, is found in the beginning of period A, *Artemisia* then decreases to below 0.5 %. *Cerealia t.* shows cover percentage value of 3 % but decreases to 1.5 % at the end of the period. *Secale t.* is found in the middle part of the period and shows a cover percentage value around 1.5 %.

5.2.2.2 Period B (710-695.5 cm)

Period B is characterised by a decrease of *Pinus* cover from 32 % in the beginning to 28 % in the middle part that coincides with an increase in *Picea* cover from 30 % to 33 %. This pattern is reversed in the latter part of the period where *Pinus* increases to almost 40 % and *Picea* decreases to 24 %. *Betula* cover percentage values decrease from 6 % to 4 % and *Corylus* from 5 % to 2 % during period B.

Juniperus disappears in the middle part of this period but reaches cover percentage values of 2 % at the end. *Calluna* cover increases from 4 % to 6 %. Poaceae cover reaches almost 12.5 % during this time period. Cyperaceae reaches cover percentage values of 7 % in the middle part of period B but decreases towards the end of the period. *Rumex acetosa* disappears in the middle part of period B but re-establishes itself to 1 % at the end of the period. *Plantago lanceolata* also disappears in the middle part of the period but reaches cover percentage values above 1 % in the latter part of period B. *Cerealia t.* has cover percentage values around 0-2 % and no pollen grains of *Secale t.* are found in period B.

5.2.2.3 Period C (695.5-681.5 cm)

Period C is in the early and late part characterised by increasing cover percentage values of non-tree taxa with a distinct drop at 690 cm (sub-period C2). The drop coincides with increasing cover percentage values of tree taxa, especially *Picea*, *Corylus* and *Betula*. Herbs, grasses and sedges show cover percentage values of 15-23 % during sub-period C1, decreases to around 11 % in sub-period C2 and increases thereafter again to between 20-25 % in sub-periods C3 and C4. Cereal cover increases at 694 cm to 6 % but drops at 690 cm to minimum values and increases thereafter again to a maximum value around 10 % in sub-period C3 and C4. *Secale t.* almost disappears in sub-period C4.

Pinus shows cover percentage values around 40 % in the beginning of this period, but drops to 30 % at 694 cm and then fluctuates between 25-45 % in the remaining part of the period. *Picea* cover increases to over 30 % in the beginning of this period which coincides with a decrease in *Pinus* cover at 694 cm. *Picea* cover then shows a mainly decreasing pattern to around 20 % in sub-period C3, and increases in sub-period C4 to almost 40 %. *Corylus* shows cover percentage values around 1-3 % during this period but distinctly increases to 8.5 % in sub-period C2. The same pattern applies to *Betula* that shows cover percentage values between 2.5-4.5 % but increases to 5 % in sub-period C2. *Carpinus betulus* shows cover percentage values around 0.2 % during the entire period C except at 695 cm where a peak of 2.5 % is seen. *Juniperus* cover slowly increases in the beginning of this period to almost 7 %, drops at 690 cm to 1 % and thereafter reaches its highest cover percentage value of almost 9.5 % in sub-period C3. *Juniperus* then decreases to below 4 % in sub-period C4.

5.2.2.4 Period D (681.5-671 cm)

Period D is characterised by the highest cover percentage values for *Cerealia t.* and *Secale t.*, 13 % and 0.8 % respectively. *Pinus* cover increases to almost 35 % but decreases after 675 cm to 24 %. This coincides with a decrease in *Picea* cover where the taxon decreases to 19 % which after 675 cm changes to a cover percentage value of 26.5 %. *Betula* cover shows the same pattern where a decrease from 4.5 % to 2.5 % is followed by an increase to 5 %. *Corylus* and *Alnus* have cover percentage values around 1-2 %.

Juniperus cover increases during this period and reaches cover percentage values of 4.5 %, Poaceae cover increases to over 18 % at the end of period D and Cyperaceae cover increases to almost 7 %. *Rumex acetosa* and *Plantago lanceolata* cover also increases during this period to around 1 %.

5.2.2.5 Period E (671-660 cm)

Period E is characterised by increasing cover percentage values of *Picea* and *Cerealia t.*, and decreasing values of *Betula*, *Juniperus*, Poaceae, Cyperaceae, *Secale t.* and *Rumex acetosa*.

Picea cover increases drastically during this period from 24 % to 42 % and *Cerealia t.* cover increases from 6 % to 10 %. *Pinus* cover is stable during this period around 25 %. *Betula* cover shows a slight decrease from 5 % to 3 %, *Juniperus* cover decreases from 3 % to 1 %, Poaceae cover shows a major decrease from 18.5 % to 7 % and Cyperaceae cover decreases from 7 % to 3.5 %. *Secale t.* cover decreases from 2 % to 0.5 % and *Rumex acetosa* cover decreases from 1.5 % to 0.5 %.

5.3 Principal Component Analysis (PCA)

The position of pollen taxa, illustrated by arrows (Fig. 14), are determined by the variation of their abundance in the samples and the significance of that variation for the overall variation in the total pollen data (Broström et al. 1998). Pollen taxa with arrows pointing in the same direction have a positive correlation to each other and arrows pointing in the opposite direction have a negative correlation. The position of each sample is illustrated by white circles (Fig. 14).

The PCA of the pollen data clearly shows a change in the landscape through time (Fig. 14). The first two principal component axes (axes 1 and 2) explain 61 % of the variation in the pollen set, where the first axis represents 44 %. The other axes (axes 3, 4 and 5) explain 22 % of the variation together. The major variation in the pollen data are explained by *Juniperus*, *Corylus*, *Pinus*, *Picea*, *Quercus*, *Carpinus betulus* and *Alnus*. *Pinus* and *Picea* correlate positively to each other and the same applies to *Calluna* and *Betula*. *Juniperus*, Cyperaceae, *Cerealia t.*, *Secale t.* and Poaceae also have a positive correlation to each other. *Carpinus betulus* and *Alnus* have a negative correlation with *Juniperus* and Poaceae on axis 1. *Pinus* and *Picea* have a negative correlation with *Juniperus* and *Corylus* on axis 2.

6. Interpretation

6.1 Period A (AD 250-500)

How far back in time the investigated sequence reaches is unclear since the results from the ^{14}C-analysis are still pending, but correlations with other pollen diagrams (e.g. Göransson 1989 & 2010; Lagerås 1996a) suggest that period A represents the time interval between approximately AD 250 and AD 500. Further does the establishment of *Picea* at around 725 cm support this view since the establishment of *Picea* occurred at AD 250 according to the Mabo Mosse bog pollen diagram (Göransson 1989 & 2010).

Pinus dominated the vegetation during period A. *Picea* started to spread as a consequence of forest clearing and grazing along with the spreading of the taxon from north to south. Pollen spectra for this period indicate a landscape characterised by decreasing pollen values for *Corylus*, *Carpinus*

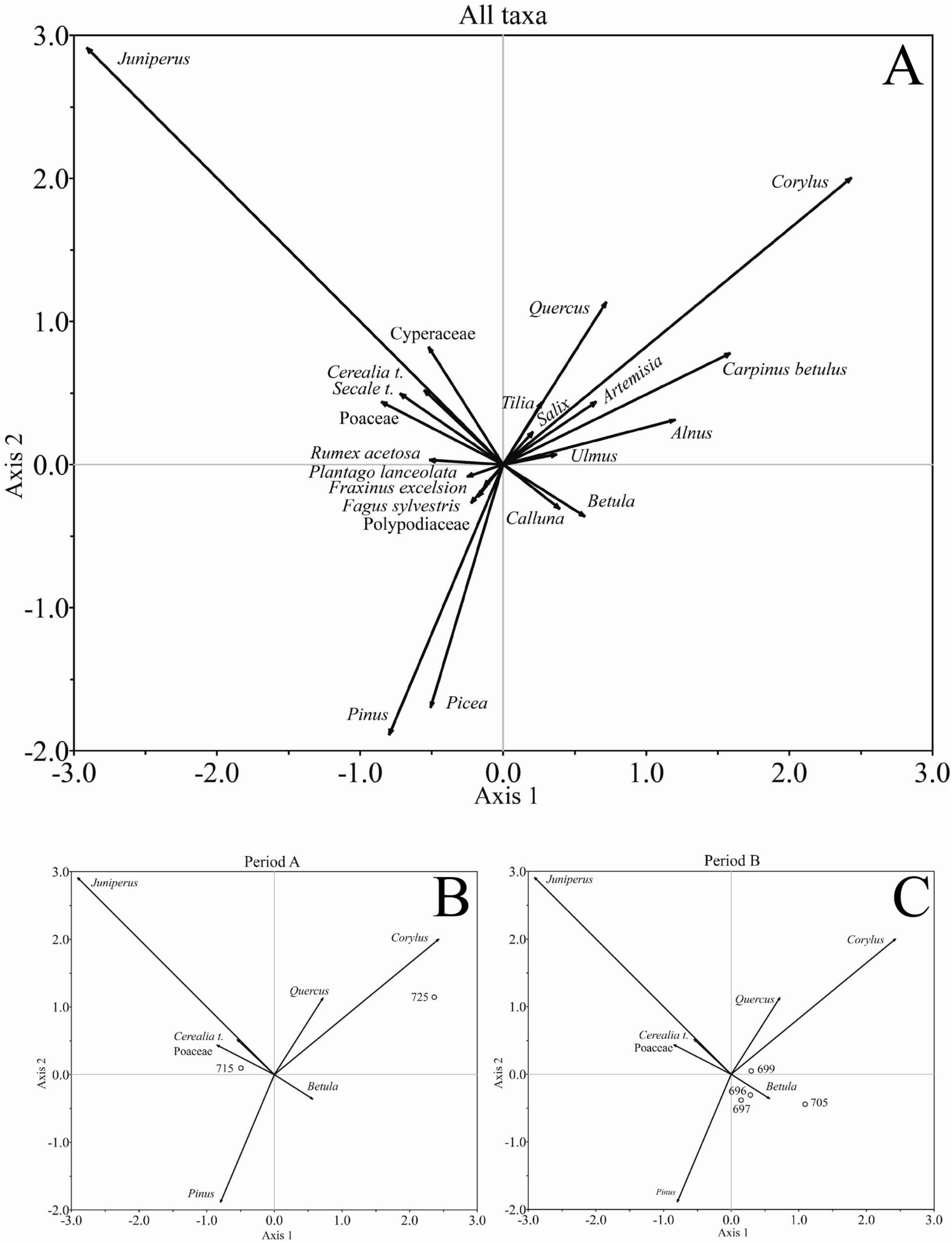
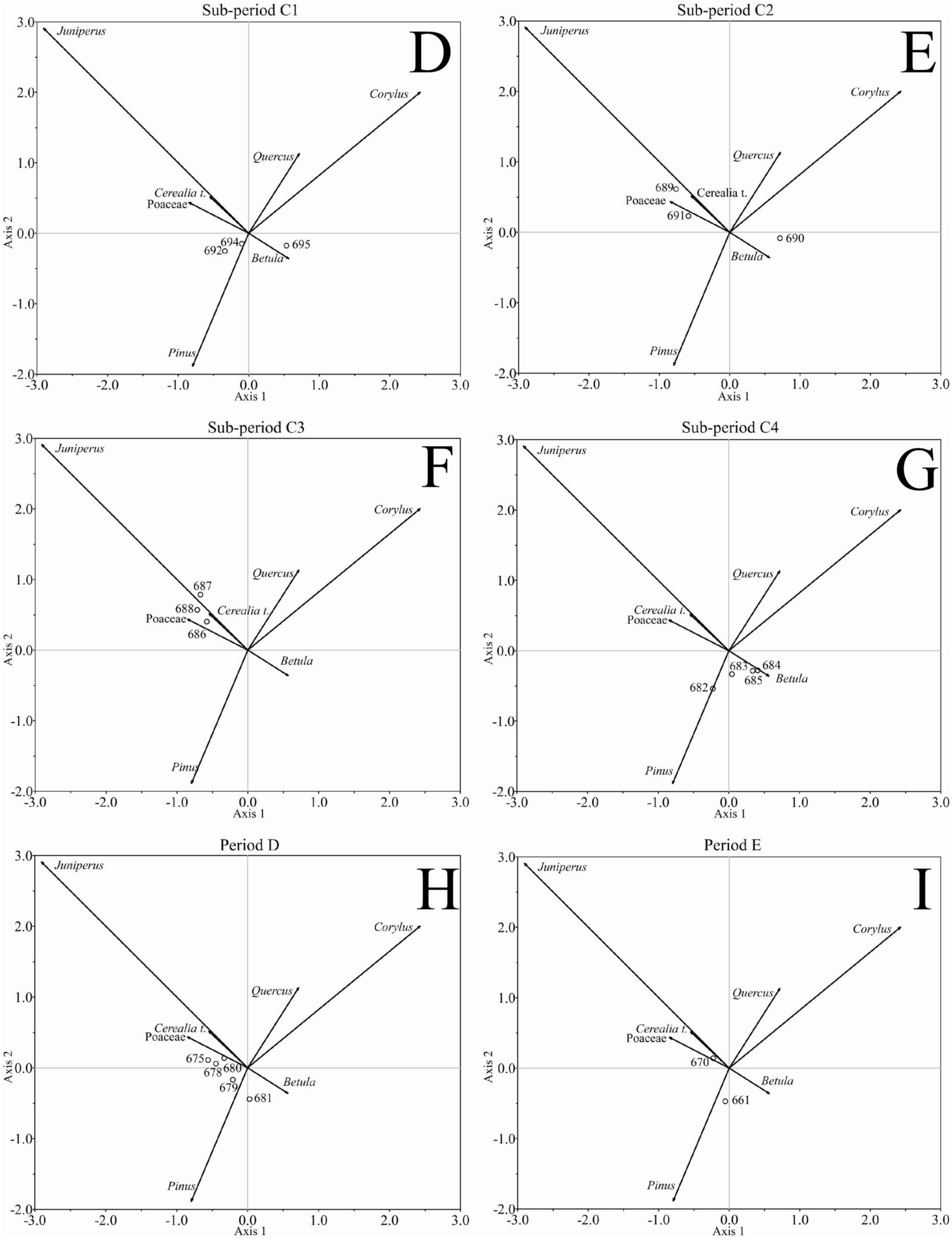


Figure 14. Plotted PCA data (axes 1 and 2) with (A) 22 taxa (black arrows) and (B-I) 26 pollen samples (white circles) divided into periods (A-E) and sub-periods (C1-C4). Seven taxa (*Betula*, *Cerealia t.*, *Corylus*, *Juniperus*, *Pinus*, Poaceae and *Quercus*) area also illustrated in B-I. The eigenvalues of axis 1 (λ_1=0.44) and 2 (λ_2=0.17) indicate that the axes account for 44 % and 17 %, respectively, of the total variation in the data set. The pollen samples are labeled with their depth in cm (Fig. 14 continues on page 27).


Sub-period C1
D
Juniperus
Corylus
Quercus
Cerealia t.
Poaceae
694
692
695
Betula
Pinus
Axis 1
Axis 2
Sub-period C2
E
Juniperus
Corylus
Quercus
689
Cerealia t.
Poaceae
691
690
Betula
Pinus
Axis 1
Axis 2
Sub-period C3
F
Juniperus
Corylus
Quercus
687
688
Cerealia t.
Poaceae
686
Betula
Pinus
Axis 1
Axis 2
Sub-period C4
G
Juniperus
Corylus
Quercus
Cerealia t.
Poaceae
683
684
685
Betula
682
Pinus
Axis 1
Axis 2
Period D
H
Juniperus
Corylus
Quercus
Cerealia t.
Poaceae
675
678
680
679
681
Betula
Pinus
Axis 1
Axis 2
Period E
I
Juniperus
Corylus
Quercus
Cerealia t.
Poaceae
670
Betula
661
Pinus
Axis 1
Axis 2

betulus, *Quercus* and *Alnus* along with increasing pollen values of human-activity indicators such as Poaceae and *Rumex acetosa*. This is supported by the PCA that shows a landscape change from a deciduous forest characterised by *Corylus*, *Quercus*, *Carpinus betulus* and *Alnus* into a semi-open forest dominated by *Juniperus*, Poaceae and Cyperaceae (Fig. 14A-B). The algae value during this period is high which suggest a high organic input to the lake that would favour the algae production. High and increasing pollen percentage values of *Juniperus*, Poaceae, *Rumex acetosa* and *Plantago lanceolata* suggest an expansion of open pasture lands and deforestation around 715 cm as a consequence of land clearance and increased grazing pressure. The pollen curve for *Cerealia t.* is continuous during the whole period and a similar pattern is visible in other pollen analytical studies from southern Sweden where the pollen curve for *Cerealia t.* becomes continuous around 350-300 BC (Göransson 1989; Lagerås 1996a). This suggests that the start of the investigated sequence represents the first strong indicator for continuous cultivation in the investigated area (Appendix A). *Secale t.* pollen is observed for the first time at 715 cm and the first findings of *Secale t.* occurred between AD 0-500 in the Småland Uplands and AD 350 in Östergötland (Göransson 1989; Lagerås 1996b). *Secale t.* was probably not cultivated during this period and only occurred as a weed among the other crops (Göransson 1989).

It is however difficult to discuss trends in this period since only two samples have been analysed.

6.2 Period B (AD 500-800/1000)

Low pollen values for cereals, *Plantago lanceolata* and *Juniperus* and a decrease in *Rumex acetosa* pollen suggest a time period characterised by abandonment of pastures and arable fields. This is supported by low values of microscopic charcoal particles and by the PCA (Fig. 14A & C). Despite this, continuously high pollen values for meadow and pasture indicators such as Poaceae, Cyperaceae, *Calluna*, *Salix* and *Artemisia* along with the presence of a few pollen grains of *Cerealia t.* propose that agricultural activity continued in the area, but possibly just at a small scale. *Betula*, *Corylus* and *Carpinus betulus* show great abundance in period B. The increase in the three tree species was probably a consequence of the decrease of pasture and meadow lands which gave *Betula*, *Corylus* and *Carpinus betulus* an opportunity to expand from their previous positions as shrubs and isolated trees in pasture fields. *Betula* reached its maximum pollen value during this period, and a major increase of *Picea* pollen and a decrease in *Pinus* cover is visible in the REVEALS reconstruction diagram. An increase of *Picea* is shown in studies from southern Sweden around AD 500-1000 and is interpreted as either a consequence of a climate shift towards increased snow fall conditions, which would favour the expansion of *Picea*, or an effect of local land-use changes (Lagerås 1996b). The decrease of deciduous trees after 705 cm suggests that *Picea* also began to dominate areas that earlier were dominated by deciduous trees. Minimum for cereals and the increase of deciduous trees are identified in other studies from southern Sweden and are explained by the abandonment of pastures and arable fields around AD 500-1000, which suggests that period B in this study should represent this time interval (Lagerås et al. 1995; Lagerås 1996a & 1996b).

The low values of *Cerealia t.* during this period could however also be explained differently; *Triticum*, *Hordeum* and *Avena sativa* are self-pollinated taxa and the spreading of pollen grains is dependent on the agricultural technique, for example harvesting and threshing (Göransson 1989; Lagerås & Sandgren 1994). The decrease in cereals could thus be caused by a change from a slash-and-burn cultivation to more permanent arable fields which is supported by the low values of microscopic charcoal particles seen in period B (Lagerås & Sandgren 1994). This, along with the high pollen values of other pasture indicators could be an explanation of the vegetation changes during this period.

The algae continues to have high values during the early and middle part of this period which should suggest a high organic input to the lake. The algae value does however decrease during the latter part of the period which suggest a decrease in the organic input and possible a decrease in the cultivation of the area.

6.3 Period C (AD 800/1000-1600)

The first part of the period (C1) is characterised by an expansion of grasslands, meadows, pastures and arable fields which strongly suggests that the period represents the Medieval expansion, AD 800-1300. The same features are present in other pollen analytical studies from southern Sweden (Göransson 1989; Lagerås et al. 1995; Lagerås 1996a & 1996b) and the PCA also shows a change from a semi-open landscape to a more open and cultivated landscape (Fig. 14A & D). The algae value increases again after the decrease in the latter part of period B which suggest an increase in the organic content and an increase in the cultivation of the area.

Cereals, pasture and meadow indicators such as Poaceae, Cyperaceae, *Rumex acetosa*, *Juniperus* and *Calluna* increase during this period. This represents an opening of the landscape. A decrease of the deciduous trees *Betula*, *Alnus*, *Carpinus betulus* and *Corylus* indicates forest clearance and cultivation of previously abandoned areas in period B. *Pinus* reaches its highest pollen value during the end of sub-period C1 which is an indicator of an open landscape that favours the production of *Pinus* pollen. The increase in *Pinus* pollen could also be a sign of a real increase in the *Pinus* cover, suggested by Fig 13. Common shrubs in the grasslands were *Calluna* and *Juniperus*. Some of the grasslands were probably used for hay production (Lagerås 1996b). The amount of *Cerealia t.* pollen grains indicates permanent arable fields that are supported by the high amount of *Juniperus* pollen; the shrub is poorly fitted for a mobile agricultural system where clearance is dependent on fire (Lagerås 1996a).

An abrupt decrease in cultivation indicator species notable at 690 cm (sub-period C2) could be a sign of an end of the cultivation in the area as well as signs of over-growth. This could represent the Medieval decline in the late 14th and early 15th centuries, linked to the Black Death, which was characterised by farm abandonment and over-growth (Lagerås 2007). The shift is also notable in the PCA that shows semi-open to a deciduous forest with the establishment of pioneer tree species like *Betula* and *Calluna* (Fig. 14A & E). No pollen grains of *Cerealia t.* were found and *Rumex acetosa*, Chenopodiaceae, *Artemisia* and *Juniperus* drastically decrease. The farm abandonment allowed the deciduous trees *Betula*, *Corylus*, *Carpinus betulus*, *Quercus* and *Alnus* and the shrub *Salix* to increase. Poaceae and Cyperaceae also decrease but the pollen values for the two taxa remain relatively high and along with an increase of *Plantago lanceolata* pollen they indicate that grasslands were still present in the study area. The grasslands could have been used by distant farms and the increase in *Calluna* and the decrease in Poaceae, suggest that some of the grasslands were turned into poor heathlands (Lagerås 2007).

The low values of *Cerealia t.* during sub-period C2 could however, as suggested for period B, also be explained by other reasons, such as the agricultural technique and the spreading of the pollen grains. This explanation is also supported by the value of algae during this sub-period, which remains as high as in sub-period C1.

Sub-period C2 is followed by a re-expansion of arable fields and higher cereal values than previously noted in the area in sub-period C3 and C4. The PCA indicates an open and cultivated land in sub-period C3 and a semi-open land in sub-period C4 (Fig. 14A, F & G). The increase of Poaceae and Cyperaceae suggests an expansion of grasslands, pastures and meadow fields. *Rumex acetosa* responds slower to landscape changes but the taxon drastically increases in the middle part of sub-period C3 and C4. Deforestation is shown by the decrease in tree pollen and the decrease in *Calluna* shows that the grasslands that were turned into heathlands once again were cleared. The agricultural production started to increase and abandoned farms were re-occupied. This is supported by the value of algae production in the lake during these sub-periods, the value starts to increase during sub-period C3 and drastically increases during sub-period C4. This suggest an increase in the cultivation of the area resulting in an increase of the organic input to the lake.

The replacement from a one-course cropping system to a three-course cropping system occurred in the 16th century and could be seen in sub-period C4. *Juniperus* drastically decreases during this sub-period which could be a consequence of the replacement of grazing in permanent pastures in the outfields to grazing on cultivated land in the infields. This led to a decrease in *Juniperus*, since the shrub was not able to grow on cultivated land (Lagerås 1996a). The decrease in *Juniperus* could however also be explained by an increase in fire clearance and that is supported by an increase in microscopic charcoals particles. Either way, the increase in microscopic charcoal particles suggests that clearance by fire did occur in the area.

6.4 Period D (17th-19th centuries)

The introduction of *Fagopyrum esculentum* and the highest value of cereals in the middle part of this period suggest that it represents the vegetation and land-use during the 17th to 19th centuries. *Fagopyrum esculentum* was established in Europe during the 17th century and the agriculture experienced an expansion during the 17th and 18th centuries which reached a peak in the 19th century (Campbell 1997; Lagerås 2007). The PCA shows a cultivated landscape (Fig. 14A & H). The highest value of algae production is notable during this period which indicate that this period should represent the 17th to 19th centuries. The algae value decreases in the latter part of the period but still have high values.

High pollen values of Poaceae, *Rumex acetosa*, *Artemisia*, *Plantago lanceolata* and *Juniperus* show an increase in open land and an expansion of pastures and meadows. The high values of cereals suggest cultivation of new arable fields and the same features are visible in other studies from southern Sweden (Lagerås et al. 1995; Lagerås 1996b). Semi-open landscape indicators like *Betula* and *Corylus* decreased during this period which indicates a transformation of the landscape and it became more strictly divided into forest and open land areas (Lagerås 1996b). This could be an effect of the reform "*Storskiftet*" in the beginning of the 19th century. The expansion of open land is further supported by the decrease in *Picea*. The increase in *Juniperus* suggests an expansion of pastures on soils that earlier were covered by *Picea* (Lagerås et al. 1995). *Juniperus* was probably also common in meadows.

6.5 Period E (19th-20th centuries)

This period represents the late 19th to the 20th centuries and is characterised by reforestation, shifts in land-use and decline in species diversity. This is also notable in the PCA where the samples scores change from a cultivation signal to a coniferous forest signal (Fig. 14A & I). High pollen values of *Cerealia t.* and *Secale t.* illustrate that the arable lands were not affected by the reforestation and that the open land decline was limited to the outfield areas. It also marks the probable introduction of more efficient agricultural techniques and fertilizers (Lagerås et al. 1995; Olsson & Lemdahl 2009). The value of algae is relatively stable during this period which indicates a stable organic input to the lake. Pollen values of the pasture indicators Poaceae, Cyperaceae, *Rumex acetosa*, *Plantago lanceolata*, *Artemisia*, *Juniperus* and *Calluna* as well as the increase in *Picea* show a change in land-use. Species related to meadow and pasture land areas were more common in the traditional land-use period, for example during the 16th to 18th centuries and the decline in species diversity is characteristic for the modern land-use transition period (Fredh et al. 2012). During the second half of the 19th century, the outfield areas became more economically important for forestry which led to the replacement of pastures and meadows with plantations of *Picea*. This resulted in a decline in species diversity and decreasing pollen values for grasses, sedges and herbs (Olsson & Lemdahl 2009). The decrease in species diversity further led to an increased dominance in vegetation coverage of fewer taxa throughout the 20th century (Fredh et al. 2012).

Microscopic charcoal particles was only found in the lower part of the period which suggests that the occurrence of fire was very limited during this period.

A general staff map over the area from 1885 shows an area dominated by coniferous and deciduous forest along with patches of open areas. The map does not show what type of vegetation that dominated the open areas but the areas are probably cultivated or outfield areas. The area has not been through any drastical changes since the late 19th century and the landscape surrounding the lake today is dominated by forestry, mainly coniferous trees, with patches of clear-felled areas and cultivated areas (Fig. 5).

7. Discussion

7.1 Chronology and relation to other studies in Småland and Östergötland

This study was not able to present an absolute chronology for the sediments sequence since the results from the ^{14}C and ^{210}Pb datings are still pending. The established chronology is thus based on correlation with other pollen analytical studies and known vegetation events, such as species establishments and major changes, in the pollen data from Lake Storsjön. One of the reasons the drainage area of Botorpsströmmen River was selected as an investigation area for this study was because no other pollen analytical studies have been performed in the area. Due to this, the study could not be correlated with other studies in adjacent areas. The pollen analytical studies that were used to establish the chronology were therefore situated in Östergötland and the Småland Uplands.

The Lake Storsjön area has a mean annual temperature of 6.0-6.5 °C, an annual precipitation of 556.5-559.5 mm/year and is situated 90-100 m above sea level. The locality Dags mosse bog in Östergötland investigated by Göransson (1989) has a climate that is similar to Lake Storsjön with a mean annual temperature of 6.2 °C, an annual precipitation of 486.8 mm/year (1961-1990, the meteorological station Visingsö was used to provide the meteorological data from the Swedish Meteorological Institute) and is situated 96 m above sea level (Göransson 1989). The Småland Uplands is a marginal region that is unfavourable for agriculture due to the relatively high altitude, between 280-320 m above sea level, which results in a lower mean annual temperature of 5 °C and an annual precipitation of 690 mm/year (Lagerås et al. 1995).

It is important to understand that there is a climate difference between the pollen analytical sites in the Småland Uplands when comparing them to the region of Lake Storsjön, which is situated in the Småland Lowlands. Still, the different areas can be correlated with each other, especially since the area surrounding Lake Storsjön also can be referred to as a marginal region due to the geological setting of the region. The western parts of the region are dominated by thin, discontinuous till, wave eroded sediments and peat (Svantesson 1999a; Lindén 2010a & 2010b). The eastern part, closest to the coastline, is dominated by exposed bedrock. Harsh conditions and crises in the society are most likely to be recorded in marginal areas since they were the first ones to be abandoned for more agriculturally productive areas. There is a high chance that the observed periods suggesting farm abandonment and reforestation in the pollen data from the marginal areas of the Småland Uplands also are recorded in the pollen data from Lake Storsjön.

The establishment of different plant species during the Holocene can be used to construct a relative chronology. The low resolution pollen diagram based on cores SSK, SS1a, SS2, SS3 and SS4 covers almost the entire Holocene and has been used to correlate the studied sediments with vegetation events during the Early and Middle Holocene (Appendix A). Pollen samples with an interval of 10 cm were analysed and a minimum of 200 pollen grains were counted for each sample. The number of pollen grains used in a pollen analysis usually has a range from 200 to over 1000 counted pollen grains and the accuracy generally improves with increasing numbers of counted pollen grains. For rare taxa especially, higher pollen counts are required. The number of pollen grains counted in this low resolution pollen diagram is in the lower part of this interval but it should however be accurate enough to imply the general patterns of the vegetation and also the establishment, increase and decline of different common taxa.

Because the sample interval and the pollen sum between the two pollen analytical studies differ, the vegetation and land-use changes that are notable in the high resolution pollen diagram from Lake Storsjön do not necessarily have to be notable in the low resolution pollen diagram covering almost the entire Holocene from Lake Storsjön. Reforestation patterns or increases in land-use have thereby a higher chance to be recorded in the high resolution diagram than the low resolution diagram since the sample interval is closer. For example, in some parts of the high resolution diagram the pollen samples have an interval of 1 cm.

Three major vegetation events notable in the high resolution pollen diagram from Lake Storsjön are the establishment of *Picea* at 725 cm, the first appearance of *Secale t.* at 715 cm and the finding of *Fagopyrum esculentum* at 680 cm and 670 cm. The start of the establishment of *Picea* in the Late Holocene is indicated in the pollen diagram by a "long tail" that is notable in the low resolution pollen diagram at 760 cm to 725 cm. The establishment of *Picea* in the area is thereby placed at 725 cm where the frequency of *Picea* pollen has increased to almost 3 %, which should represent the real establishment of the tree taxon.

The relative chronology provided by the correlation with other pollen analytical studies along with known vegetation events give a suggestion of the chronology of the sediments from Lake Storsjön, which hopefully will be verified by the pending dating results.

7.2 Alternative interpretations of the pollen and vegetation cover data from Lake Storsjön

The interpretation of the pollen data has not been validated by independent dating results, and alterative interpretations of the vegetation and land-use history of the drainage area of Gåsfjärden are thereby possible.

Since it has been reported from other localities in both Sweden and Europe that the Medieval decline is not always visible in pollen diagrams there is a risk that the event is not recorded in the studied sediments. Lagerås (2007) has performed a study on four study area and only two, Grisavad and Värsjö Utmark, indicate farm abandonment during the 14th century whereas the other two sites, Östra Ringarp and Bjärabygget, show no signs of the Medieval decline. Lagerås (2007) explains the difference in land-use between the sites with character differences, such as different soil characters and altitude.

Östra Ringarp is located on a sandy till and sandy glaciofluvial deposit and the area had an early farm establishment. During the 17th century the area had a large amount of farms and had a more central character than the other localities. Further, Östra Ringarp is the only site that today still has an existing farm. The Grisavad study site is located at the same altitude as Östra Ringarp but the area is dominated by glaciofluvial deposits and peatlands which give the area a poor character. This difference between the geological setting of Östra Ringarp and Grisavad could thus explain the recorded farm abandonment at Grisavad and the continuality of the agriculture at Östra Ringarp during the 14th century. The locality Värsjö Utmark has a marginal character due to its high altitude, 120 m above sea level, which could explain the abandonment during the 14th century. The fourth study site, Bjärabygget, is however also located in a marginal area and still shows signs of a continuity of the agriculture during the 14th century. This indicates that there does not have to be a relationship between marginal areas and farm abandonment. The study of Lagerås (2007) does, however, suggest that marginal areas record farm abandonment and reforestation at a higher extent than central areas.

The pollen record from Lake Storsjön shows signs of overgrowth and farm abandonment in both period B and sub-period C2. It could be argued that sub-period C4 and period D also show signs of overgrowth and farm abandonment but the absence of cereals alone should not be treated as a sign of overgrowth. Different characteristic features of farm abandonment and reforestation should be linked together; for example, a decline of cereals along with a decrease in pasture and meadow indicator taxa and an increase in tree taxa could indicate that a reforestation and farm abandonment occurred in the area. The decrease of cereals in the early part of sub-period C4 and period D do not however coincide with any significant decrease in other pasture and meadow indicators or with an increase in tree taxa and should thus not be treated as another possible interpretation of the position of the Medieval decline. The finding of *Fagopyrum esculentum* at 680 cm further supports this view, since sub-period C4 and period D thereby should be too young to represent the 14th century. It should also be mentioned that when performing high resolution pollen analysis the curves for the different species often get a jagged appearance, which further advices a correlation between different species before establishing an interpretation of the sequence.

Period B shows signs of overgrowth and farm abandonment over a longer period than sub-period C2. The signs of overgrowth could indicate that this period represents the Medieval decline but could also, as suggested earlier, indicate that the period represents the reforestation during the 6th century. The establishment of *Picea* at 725 cm is incompatible with the interpretation that period B would represent the Medieval decline. This, since it has been reported from the Mabo Mosse bog that the establishment of *Picea* in southern Sweden occurred at circa AD 250 (Göransson 1989 & 2010). The first appearance of *Secale t.* at 715 cm further suggests that period B should represent the reforestation during the 6th century since it has been reported from both Östergötland and the Småland Uplands that the first appearance of *Secale t.* occurred around AD 0-500 (Göransson 1989; Lagerås 1996b).

The lack of dating results further stresses the importance of correlation with other pollen analytical studies in order to interpret vegetation and land-use changes.

7.3 Palaeoecological interpretation of pollen data and REVEALS model input

It is generally known that biases exist in pollen analysis and that the production of pollen grains and transportation method varies between taxa. For the representation of different taxa in pollen diagrams both these factors play a very important role and the REVEALS model can be used to establish a more reliable landscape distribution of different taxa.

Different taxa use different strategies for the dispersal of pollen grains. Frequently overrepresented taxa in pollen analyses are tree species, especially *Pinus* and *Betula* since the two taxa disperse large quantities of pollen grains to the atmosphere. *Picea* on the other hand, does not produce as much pollen as *Pinus* and is often underrepresented in pollen diagrams. *Picea* pollen grains are also very large and heavy, and therefore disperse less well by wind. Other vegetation groups that are underrepresented in pollen diagrams are herbs and cereals. Herbs often use insects or other animals for the spreading of their pollen grains and are thereby less likely to be deposited in lakes, mires or bogs. On the other hand, grasses and sedges are often very well represented in pollen analyses since the pollen grains are dispersed by wind. Grasses and sedges are for that reason probably the taxa that are best represented among the non-tree types. Sedges may also be over-represented because they grow along lake shores. Cereals, with the exception of *Secale t.*, are self-pollinated taxa and the dispersal of pollen grains for those taxa depends on the agricultural technique. Pollen grains from self-pollinated cereals are only released during harvesting and threshing, where large amounts of pollen grains are dispersed to the atmosphere (Göransson 1989).

Pollen productivity estimates of modern pollen assemblages and the fall speed of pollen grains are used by the REVEALS model to reconstruct the extent of the vegetation cover of every analysed taxon and by doing so, calculates the distribution of different vegetation types and the openness of the landscape. For example, the model takes into account that the pollen productivity and the pollen representation of *Picea* in pollen data underestimate the actual representation of the taxon in the landscape. After a performed REVEALS modelling, *Picea* thereby has a higher representation in the cover percentage diagram than in the pollen diagram. The same applies for herbs and cereals, and this is why the landscape illustrated by a cover percentage diagram often shows a more open landscape than a pollen diagram. On the other hand, an overrepresented taxon like *Pinus* shows a lower representation after the REVEALS model, which is a better representation of the actual extent of *Pinus* in the landscape (Hellman et al. 2008).

Like other models, the REVEALS model uses some basic assumptions in order to simplify the reality. The model assumes that pollen grains are transported by wind above the canopy, that the wind direction is equal over the entire basin, that the sedimentary basin is a circular opening in the canopy, that no source plants exist in the basin and that the atmospheric conditions are equal through time (Sugita 2007a). Applying the model requires estimates of pollen productivity and fall speed, and due to this, the REVEALS model cannot use all discovered taxa in a pollen data set and thereby the model, to some extent, also underrepresents the openness of the landscape since this usually affects insect pollinated taxa and also alter the representation of different taxa.

The study site must be carefully selected in order to get as accurate results as possible. This is due to the different assumptions of the model, such as the size, shape and the type of site (lake or bog). The model assumes that the pollen count of each analysed sample exceeds 1000, and it is thus very important that the counted pollen grains are at least 1000 pollen grains. Ideally, several pollen data sets from different study sites should be used in order to further eliminate the biases of the model but if this is not possible, it should at least be considered when interpreting the results. This study only uses one site, Lake Storsjön, which could affect the results and influence the interpretations. The pollen diagram and the vegetation cover diagram are thereby used together when interpreting the results to reduce this bias.

The REVEALS model is a powerful tool and a great complement to pollen analysis. Even though the simplicity can be used as an argument against the REVEALS model, it is also the strength of the model since it makes it possible to calculate the different landscape components and the extent of the representation of different taxa in a landscape more accurately. Still, the REVEALS model is only a model that uses different values and assumptions in order to calculate the results but it is valuable in order to improve the accurate representation of the openness of a landscape.

7.4 Relations to conditions in the Baltic Sea

Periods of hypoxia have occurred in the Baltic Sea for over 8000 years and hypoxic conditions during the last century can be linked to human activities such as land-use, deforestation and nutrient input along with climate variability such as increases in temperature and precipitation (e.g. Andrén et al. 2000; Österblom et al. 2007; Voss et al. 2011). In the scientific world there is an ongoing discussion whether the periods of hypoxia in the past are a consequence of natural events or if the hypoxic conditions in the Baltic Sea during a longer time-scale could have been influenced by anthropogenic impacts (e.g. Andrén et al. 2000; Bianchi et al. 2000; Conley et al. 2009; Zillén & Conley 2010).

Laminated sediments that indicate hypoxic conditions have occurred in the Baltic Proper during three major periods, between ca. 8000-4000 cal. year BP, between 2000-800 cal. year BP and after AD 1900 (Zillén & Conley 2010). These periods of hypoxia have been suggested to be natural events by Bianchi et al. (2000) but recent investigations by Conley et al. (2009) and Zillén & Conley (2010) correlate hypoxic conditions in the Baltic Sea during the last 2000 years with human activities.

Hypoxic conditions between 8000-4000 cal. year BP can be explained by relatively high salinity in the Baltic Sea (Zillén & Conley 2010). This resulted in a strong salinity stratification of the water column that limited the oxygen circulation to the deepest parts of the basin causing hypoxic conditions in bottom waters. A relation between variations in salinity and hypoxia does not however exist for the last 2000 years, which suggests that hypoxic conditions during the last two millennia were not caused by natural events. The periods of hypoxic conditions can instead be linked to anthropogenic impacts such as population increase, deforestation, technological development and increase in land-use (Zillén et al. 2008; Zillén & Conley 2010).

The period of hypoxia between 2000-800 cal. year BP is associated with the Medieval expansion, AD 800-1300, where the population increase triggered an intensification of land-use (Zillén & Conley 2010). The hypoxic conditions in the Baltic Sea during the Medieval expansion were followed by more oxic conditions during the Medieval decline which can be correlated with stagnation in land-use, population decrease and farm abandonment. The period of hypoxic conditions after AD 1900 can be linked with the Industrial Revolution where an intensification of land-use and use of fertilizers, population increase and the planting of *Picea* occurred.

Climate anomalies like the Medieval Warm Period, the Little Ice Age and the warming trend for most of the 20th century can also be correlated with variations in hypoxia during the last 2000 years (Andrén et al. 2000) but the correlation between temperature and hypoxia is not supported by the global hypoxia trend (Diaz & Rosenberg 2008; Zillén & Conley 2010). The global trend in hypoxia can however be linked to human activities which further proposes that the hypoxic conditions during the last 2000 years are a consequence of human impacts (Diaz & Rosenberg 2008). The investigation by Zillén & Conley (2010) suggests that human impact and variation in this impact severely influence and control the development of hypoxic bottom waters in the Baltic Sea and that conditions in the Baltic Sea during the last 2000 years can be linked to land-use development. Land-use development in the drainage area of the Botorpsströmmen River, Småland are, at least, likely to have influenced the conditions in Gåsfjärden.

8. Summary

- A sediment sequence (SS1a, SS1b and SSK) from Lake Storsjön in Småland, Sweden was collected and subsampled for pollen analysis, loss on ignition, ^{210}Pb dating and ^{14}C dating. The dating results are still pending.
- A relative chronology was established based on correlation to other pollen analytical studies in Småland and Östergötland and the occurrence of well-established vegetation events in the sediment sequence from Lake Storsjön. The sequence was divided into five periods (A-E) where period C was further divided into four sub-periods (C1-C4).
- Period A most probably represents the time interval between approximately AD 250 and AD 500 based on the establishment of *Picea* at around 725 cm, the first finding of *Secale t.* at 715 cm and the first appearance of a continuous cereal pollen curve.
- Period B is interpreted as a reforestation period characterised by farm abandonment. The period probably represents the reforestation event during the 6th century. The presence of a few pollen grains of *Cerealia t.* suggests that agricultural activity continued at a small scale in the area.
- Sub-period C1 is characterised by an expansion of grasslands, meadows, pastures and arable fields which suggest that the period represents the Medieval expansion around AD 800-1300.
- Signs of over-growth and farm abandonment suggest that sub-period C2 represents the Medieval decline during the 14th century. The sub-period is characterised by a drop in pasture, meadow and arable field taxa.
- The reforestation and farm abandonment in sub-period C2 is followed by a re-expansion of arable, pasture and meadow fields in sub-periods C3 and C4. This suggests that the two sub-periods represent the re-expansion of agriculture during the 16th century.
- The introduction of *Fagopyrum esculentum* at 680 cm and the highest value of cereals in period D suggest that period D represents the vegetation and land-use during the 17th to 19th centuries. The introduction of *Fagopyrum esculentum* occurred during the 17th century in Europe and the agriculture experienced an expansion during the 17th and 18th centuries which reached a peak in the 19th century.
- Period E most likely represents the late 19th to the 20th centuries and is characterised by reforestation of *Pinus* and *Picea*, high values of cereals and a decline in species diversity.

- Periods of hypoxia in the Baltic Sea during the last 2000 years have been related with the land-use changes notable from Lake Storsjön as well as in other pollen records. The correlation shows that hypoxic conditions in the Baltic Sea can be related to periods characterised by intense agriculture and that more oxic conditions in the Baltic Sea can be related to periods characterised by reforestation and farm abandonment.
- This study gives an insight into the vegetation and land-use changes in a lowland area of Småland that has not been the subject of other studies. The study further indicates that the agriculture during the last 2000 years have been characterised by periods of intensified agriculture and periods of agricultural decline that can be linked to larger national events such as the Medieval expansion, Medieval decline and the Industrial Revolution.

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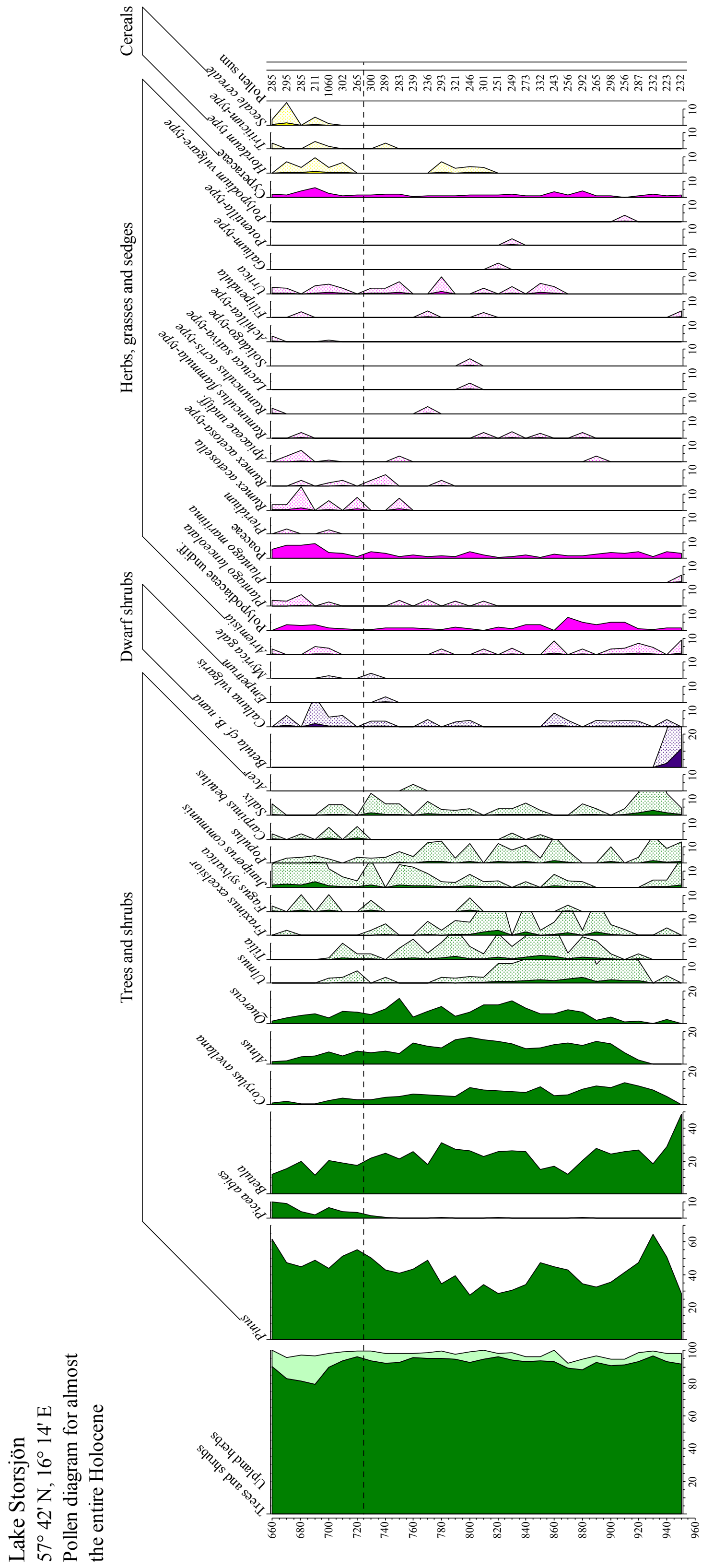
Appendix A

Pollen diagram (analysed by Anne Birgitte Nielsen) constructed from cores SSK, SS1a, SS2, SS3 and SS4 collected from Lake Storsjön using 30 samples, a selection of species and at least 200 counted pollen grains for each sample. The samples are plotted on a depth scale and all taxa are presented as % of the pollen sum, dotted graphs show 10x exaggeration. The dashed line at 725 cm marks the end of the high resolution pollen diagram and the vegetation cover diagram (Fig. 12 & 13).



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