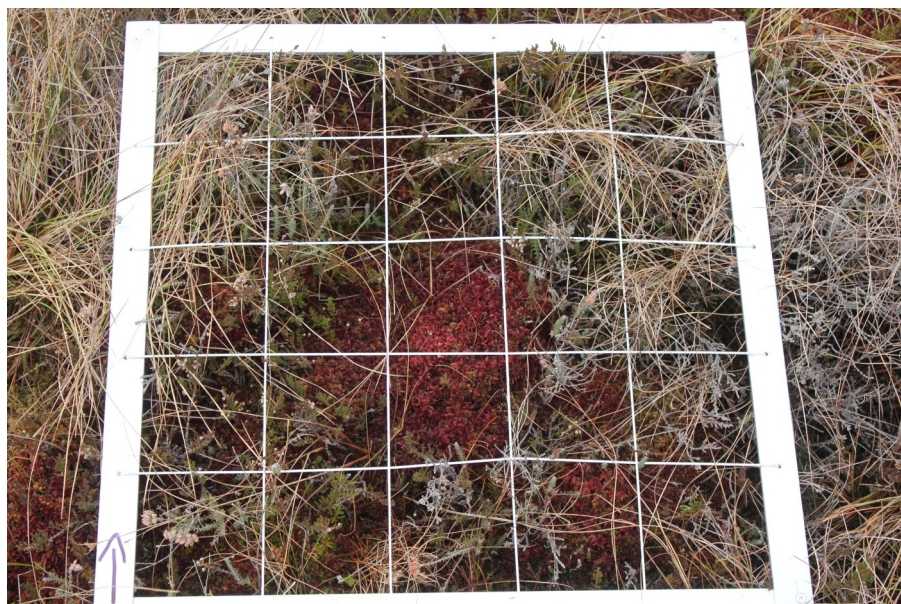


Is it possible to reconstruct local presence of pine on bogs during the Holocene based on pollen data? A study based on surface and stratigraphical samples from three bogs in southern Sweden

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Abstract: Horizons rich in subfossil stumps and roots of Scots pine (*Pinus sylvestris*) are frequently found in stratigraphies of northern European peatlands, providing clear evidence of Holocene periods with favourable conditions for bog-pine growth. The pines could only grow when bog-surface wetness was sufficiently low, and the presence of their remains is therefore a good indicator of past climatic conditions, mainly precipitation. Adamsson (2013) carried out a macrofossil study on Stass Mosse, a bog in central Scania, southern Sweden, and investigated peat-stratigraphical evidence of hydrological changes on the bog in the period 6000-3300 cal BP. The aim of the present thesis was to investigate if the presence of bog-pines at Stass Mosse, as reflected by subfossil stumps and macrofossils, can also be detected by pollen analysis of the same peat samples as analysed by Adamsson (2013). To facilitate interpretation of the stratigraphical pollen data, a complementary pollen study was made of surface samples from Fäjemyr in north central Scania. Samples were taken along a transect from the dense *Pinus* forest at the edge of the bog to the centre of the bog where pine trees were scarce and low in stature. The data from the site were analysed to identify any relationships between vegetation cover and pollen percentages and influx values. In addition, a surface sample from Store Mosse, a large bog in Småland further north within southern Sweden and without local presence of bog-pines, was included to further help interpretation of the pollen record from Stass Mosse. The results from Stass Mosse show that the pollen percentages and influx values generally increase at the same levels as the increases in macrofossils. Stass Mosse had generally low pine pollen percentages and influx values compared to Fäjemyr, and that might be caused by less favourable growing conditions on the bog, influencing pollen productivity. Fäjemyr did not have any consistent pattern between the number of local pines and pine pollen percentage or influx values in surface samples from the sites located at different distances from the dense pine forest at the edge of the bog. The reason is probably differences in moss growth at the different sites, and also there are dominantly regional pollen deposition at the sites. The results from the three peat lands show that it is not possible to identify the local presence of bog-pines only based on pollen data.

Keywords: pollen, *Pinus*, bog, vegetation cover, southern Sweden.

Supervisor(s): Mats Rundgren & Nathalie Van der Putten

Subject: Quaternary Geology

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Är det möjligt att rekonstruera lokal förekomst av tall på mossar under holocen baserat på pollendata? En studie baserad på yt- och stratigrafiska prover från tre mossar i södra Sverige

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Sammanfattning: Horisonter med subfossila stubbar och rötter av tall (*Pinus sylvestris*) är vanliga i stratigrafier från torvmarker i norra Europa. Dessa är tydliga indikationer på att det under holocen funnits perioder med tillräckligt gynnsamma förhållanden för tallar att växa på mossar. Tall kan endast växa på mossar när ytan är tillräckligt torr, och därför är rester av tallar på mossar goda indikationer på ett torrare klimat. Adamsson (2013) utförde en studie av makrofossil på Stass Mosse, centrala Skåne, och undersökte torvstratigrafin för att dokumentera förändringar i hydrologin på mossen under tidsperioden 6000-3300 cal BP. Syftet med det här examensarbetet är att undersöka om förekomsten av tallar på Stass Mosse, vilken påvisas av subfossila stubbar och makrofossil, även syns i pollendata från samma prover som analyserades av Adamsson (2013). För att underlätta tolkningen av stratigrafiska pollendata utfördes kompletterande pollenanalyser från ytprover från Fäjemyr, nordcentrala Skåne. Proverna togs utmed en transekt från den täta tallskogen vid kanten av mossen till de centrala delarna av mossen där tallarna var få och lågväxta. Pollendatan från lokalerna analyserades för att identifiera samband mellan vegetationsträckning, pollenprocentvärdet och influxvärden. Utöver detta gjordes en pollenanalys av ett ytprov från Store Mosse, en stor mosse i Småland, utan någon lokal förekomst av tallar. Pollenanalysen från Store Mosse inkluderades i undersökningen för att ytterligare underlätta tolkningen av pollendatan från Stass Mosse. Resultaten från Stass Mosse visar på att pollenprocentvärdena och influxvärdena generellt ökar på samma nivåer som det sker ökning av makrofossil. Stass Mosse har generellt sett lägre pollenprocentvärden och tallinfluxvärden än Fäjemyr, vilket kan vara orsakat av mindre gynnsamma växtförhållanden på mossen, som i sin tur påverkar pollenproduktiviteten. Fäjemyr hade inget konsekvent mönster mellan antalet lokala tallar och pollenprocentvärdet och influxvärdet på olika avstånd från tallskogen. Anledningen är förmodligen skillnader i mosstillväxt mellan de olika lokalerna, samt att pollendeponeringen främst är regional. Resultaten från de tre torvmarkerna visar att det inte är möjligt att identifiera den lokala närvaron av tall på mossar enbart baserat på pollendata.

Nyckelord: pollen, Pinus, mosse, vegetationstäckning, södra Sverige.

Handledare: Mats Rundgren & Nathalie Van der Putten

Ämnesinriktning: Kvartärgeologi

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1 Introduction

One of the largest challenges in our time is the ongoing climate change, already impacting global ecosystems. This trend towards generally warmer climate conditions will impact all ecosystems on Earth and the effects will become even larger in the future (IPCC 2007). One way of gaining knowledge about the present climate change is to study climate changes in the past. By doing this, one can try to assess whether the present climate change has natural causes, is man-induced, or a combination of both. This thesis can help to gain knowledge about past climate changes by studying changes in bog vegetation.

The climate on Earth is not constant and it changes both globally and locally. Most of these changes have natural causes and started long before humans entered the world. Some natural causes for large-scale climate change are variations in solar irradiance, aerosol and greenhouse gas content of the atmosphere and the Earth's orbit around the sun (Seppä et al 2009). The last 2.6 million years, called the Quaternary time period, is characterized by long (multi-millennial) glacial- and interglacial periods. Within these glacial and interglacials there are climatic changes of lower amplitude. The alternation of glacial and interglacial periods during the Quaternary is most likely caused by changes in the Earth's orbital parameters, the so-called Milankovitch-cycles. However, orbital changes alone would probably not create the glacial periods in the Quaternary, but they are reinforced by feedback mechanisms such as the ice-albedo feedback (a colder climate results in more ice cover reflecting the sunlight more efficiently than a land surface, and therefore making the global climate colder) (Roberts 1998). These feedback mechanisms are complex and are also interfering with each other.

The present interglacial period is called the Holocene (the last c. 11700 years). The Holocene climate archives are well-preserved and can be used to study climate changes in the past (Roberts 1998). There are different kinds of climate archives such as terrestrial ones like peat and lake deposits. But also marine sediments and ice cores are good climate archives. Climate archives are studied with proxy-methods, for example pollen, macrofossils or isotopes analyses.

Pollen analysis is the study of pollen of higher plants together with spores of ferns, mosses and club-mosses (Charman 2002) and it can be used as a long-term (10^2 - 10^3 years) technique for reconstructing vegetation. Since plant species have different demands,

pollen and spores can tell us about the environment and climate during the time the taxa grow at or near the site. Pollen analysis can show the sensitivity and response mechanisms of vegetation during climate changes (Seppä 2007). Looking over longer time scales one can reconstruct long-term climate changes. However, on shorter time-scales, a high-resolution pollen analysis allows to detect short-term vegetation changes. Pollen analysis can also inform us about humans interfering with the landscape and the vegetation and also about the spread of early agriculture (Seppä 2007). Pollen analysis is an old method, and one reason may be that pollen is almost always highly abundant, up to 10^3 - 10^5 grains cm^3 , in sediments (Seppä 2007).

Plants can liberate billions of pollen within one forest hectare and this pollen is transported and mixed, usually by wind. Most pollen is deposited 10^1 - 10^3 m from the source, providing local pollen. Some pollen gets brought by wind up into the atmosphere and can be transported theoretically indefinite distances (Seppä 2007). Therefore, in peat archives, it is almost impossible to distinguish between local pollen originating from trees in the near surroundings and pollen originating from long-distance transport (Seppä 2007).

Pollen data from lake sediments mainly reflect regional vegetation since few plants grow within the lake and pollen data from peat lands can reflect both regional and local vegetation. The proportion of local versus regional pollen on a bog is difficult to disentangle and it is also affected by the distance from the site to the edge of the bog. Even so, peat offers a good climate archive since it is present in most environments and is depending on the effective precipitation (precipitation minus evapotranspiration) (Charman 2002). If the climate gets warmer and/or drier, it can be seen in the peat itself as changes in the peat decomposition.

Since pollen are transported theoretically over indefinite distances, and are well-mixed in the "regional pollen cloud", pollen will give a regional as well as local vegetation signal. To get both the regional vegetation signal and the local signal from a site, it is good to also study plant macrofossils. By having pollen that give both the local and regional signal, and macrofossils that show the local vegetation, it is possible to separate the local and regional signal (Charman 2002). Macrofossils are larger parts, for example roots or bark, from the vegetation that has grown at the site. Macrofossils are rarely transported far from the growing site and that is why they show the local vegetation. By using a multi-proxy approach it is easier to make realistic interpretations of past vegetation (Charman

2002).

In a previous MSc project, Adamsson (2013) performed a plant macrofossil analysis of samples from the Stass Mosse bog, in Scania, southern Sweden. The aim of her thesis was to test if the establishment, growth and degeneration of bog-pines were connected to changes in bog-surface wetness, depending on effective precipitation. She also wanted to describe and date the Holocene occurrence of *Pinus sylvestris* on Stass Mosse and how that is related to local hydrological conditions and bog environment. Adamsson (2013) described the pine-bog horizon that can be seen today at the surface after abandonment of peat mining within the main part of the bog. Samples of selected macrofossils and bulk peat were radiocarbon dated and used to build an age model, one for each sequence. The time interval for the analysed intervals of the sequences is 3600-4200 cal years BP for the Tree Sequence (TS) and 3400-5800 cal years BP for the Complete Sequence (CS). TS was collected by Adamsson (2013) at an exposed *Pinus* stump near the edge of the excavated bog to correlate the *Pinus* horizon to the CS. CS was taken a few meters away, where the uncut peat surface was preserved. The sequence was taken to cover the interval of the *Pinus* stump horizon and to get the whole peat sequence to the present day.

This thesis builds on the MSc thesis by Adamsson (2013). Adamsson (2013) did the field work and collected cores from Stass Mosse that were correlated and described. Proxy methods applied to the peat sequences were bulk density, loss of ignition (LOI), humification and plant macrofossil analysis. The same peat sequences was studied with pollen analysis in this thesis, and these pollen data were compared with the results of Adamsson (2013).

1.1 Aim of the study

The aim of this study is to investigate if the local occurrence of pine (*Pinus*) at Stass Mosse during the Holocene, as evidenced by abundant pine stumps on the mined peat surface and by macrofossil data, can also be detected by pollen analysis. At Fäjemyr, another Scanian bog, the aim is to see if the pollen representation differs in surface samples depending on the distance to local *Pinus* populations using surface samples.

The pollen analysis focuses on the two sequences (CS and TS) and the same stratigraphic intervals as Adamsson (2013) investigated. The macrofossil data, ¹⁴C-dating and other material from Adamsson (2013) is used in this thesis. The macrofossil data show a large increase of *Pinus* at 320-310 cm in the CS. Within this interval pollen analyses were made every 1 centimetre to see more precisely when the

change occurred as well as to see how large the pollen variability could be on short (decadal) timescales. The 10 cm intervals over the whole sequence show the millennial scale trends. For Fäjemyr, surface samples at different densities of local *Pinus* population, from an open area to dense *Pinus* forest, were used to explore any patterns in *Pinus* pollen percentage and influx data. To assess if the pollen signal reflects the local taxa, a simple documentation of the vegetation was made at the sites.

This thesis will help to improve the knowledge, and thereby a more secure interpretation, of how the presence of *Pinus* on bogs has changed during the Holocene.

The specific questions that are addressed in this thesis are:

- Are there any clear variations in the presence of *Pinus* pollen from the Stass Mosse sequence that indicate changes in the local presence of *Pinus* at the bog surface during the Holocene?
- How does the *Pinus* pollen percentage and influx signal change over time in the Stass Mosse sequence?
- Are there increases in pine pollen at the same levels as there are increases in pine macrofossils?
- Does the presence of *Pinus* pollen differ depending on the amount of *Pinus* trees in the local vegetation when looking at surface samples from Fäjemyr?
- Does the presence of *Pinus* pollen differ when collecting surface samples from sites with the same density of *Pinus*, but with a different composition of the vegetation cover?
- Can one interpret the local presence of *Pinus* on bogs by analysing stratigraphical pollen data from a peat record?

1.2 Background

1.2.1 Peatlands

Peat, the material that peatlands consist of, is built up by plant remains that have not been completely decayed. To form a peatland, the accumulation of plants must be higher than the decay. Most of the production (accumulation) and decay occur in the top layer of the peat, the accumulation because of the plants fall down, and the decay because of higher oxygen levels (Charman 2002). Areas with high productivity (and therefore accumulation) are not always the places with most peatlands. The same areas usually have higher decay rates as well (Charman 2002) and the highest decay rates occur when the water table fluctuates. The

accumulation rate depends on, for example, the amount of nitrogen and phosphorous, pH, temperature, water content, oxygen supply and the plant material. Common accumulation rates for bogs in oceanic environments in Europe (UK) are around 1 mm/y, but the rate differs depending on climate. Colder climate conditions will change the bog-surface wetness towards wetter conditions. This is mainly because of less effective evapotranspiration. The bog-surface wetness records in the Baltic area are according to Seppä et al. (2009) a good proxy for changes in humidity when studying past climate changes. Colder climate, and therefore a wetter bog-surface, will give a low decomposition and warmer and drier a stronger decomposition. If the bog surface is dry, it is not unusual that a hiatus occurs in the sequence according to Jensen et al. (2002). A hiatus or very low accumulation rate can also cause a high pollen concentration in the record, giving an erroneous result in the pollen signal (Jensen et al. 2002). Peatlands are also important for the carbon cycle since bogs act as carbon “sinks” over longer time periods (centuries to millennia), unless drainage of peatlands occurs. This part of the carbon cycle is important for controlling some of the greenhouse gases, such as CO₂ and CH₄ (Charman 2002).

1.2.2 Bog- trees

Stumps and tree trunks are quite commonly found in peat bogs (Figure 1). *Pinus* is the most common species and can often be found in bog-tree horizons throughout the Holocene (Edvardsson 2013). These trees have grown on the bog when bog-surface wetness was low. This is known because trees need a certain distance between the roots and the water table. Since the water table is still close to the roots the trees usually grow close to their physical distribution limits. If the water table is lowering, trees can start to spread to new parts of the bog. Spreading of trees on a bog might be related to drier conditions, or local hydrological changes, for example a fen-bog transition (Eckstein et al. 2011). A study done by Edvardsson et al. (2012) from Viss Mosse in central Scania, Sweden, shows that during a bog-tree period, the bog surface wetness decreased, indicating a drier climate.

1.2.3 Fens and bogs

Fens and bogs are present in most parts of the world, and most bogs have been fens in the past. Fen-bog transitions are fairly common and can be seen in raised bog peat stratigraphies (Hughes & Barber 2003). Fens receive nutrients and water from the surroundings through run off/in wash and ground water, while bogs

get all of their water and nutrients from rainfall (Charman 2002). Because fens receive nutrients from the surroundings, the fens are more nutrient rich (eutrophic) and bogs generally nutrient poor (oligotrophic). Oligotrophic bogs are good archives for studying past climate change because the plants growing on a rain-fed bog are sensitive to changes in effective precipitation (precipitation minus evapotranspiration) and are in consequence directly reflecting atmospheric changes. The decay rates of *Sphagnum* mosses are low, and since bogs are characterized by *Sphagnum* species, bog peat usually has a lower decay rate, and therefore a higher accumulation rate, than fen peat (Charman 2002). Since the accumulation rate is mostly relatively high in a bog, it is possible to obtain high resolution records for the Holocene (Mauquoy et al. 2002). This makes bogs more sensitive archives for climate changes than fens (Langdon et al. 2003). The fen-bog transition mainly takes place during changes in effective precipitation. Hughes and Barber (2003) showed two ways for a fen-bog transition to take place. One way is through a shift to wetter climate conditions resulting in more effective precipitation. These conditions will benefit *Sphagnum* growth and a better preservation of the peat (low peat humification). In consequence, peat growth will increase significantly, as the decomposition is low. Another way of getting a fen-bog transition is through a lowering or fluctuating water table under drier and/or unstable climate conditions. This would cause separation between the ground water table and the bog surface providing aerobic conditions. The bog surface wetness will then decrease, creating increased decomposition. This peat is characterized by dry-tolerant species, such as *Calluna vulgaris* or dry-tolerant *Sphagnum* species. Later on, when the water table stabilizes, at or near the bog surface, the bog vegetation will change to a *Sphagnum* dominated ombrotrophic raised bog.



Figure 1. A bog-tree at Stass Mosse (Photograph: J. Edvardsson 2014).

1.2.4 Pollen analysis

Pollen analysis has mainly been carried out during the last hundred years, but pollen analysis as a method was already used about three centuries ago (Manten 1967). It is a very useful tool for studying past vegetation changes since pollen is found in all kinds of deposits and in high numbers (Charman 2002). The main reasons for applying pollen analysis in Quaternary sequences has been to correlate sediment sequences, to identify chronostratigraphic periods and to increase knowledge about past climate and vegetation (Seppä 2007). It is important to remember that pollen data from a single core do not show a complete ecosystem (Mauquoy et al. 2002) and that a larger basin has a higher amount of regional pollen than a smaller basin (Broström et al. 2004). Pollen is usually released from the plant during unstable atmospheric conditions on warm and sunny days with strong fluctuations in convective uplift and turbulence (Theuerkauf et al. 2012) and can be transported by wind, water or insects (Charman 2002). Pollen from different species show different morphologies and will be transported over different distances. *Pinus* pollen has air-sacks, so even if the *Pinus* pollen is larger than other pollen (and therefore generally heavier), *Pinus* pollen can be transported over large distances. But in general, heavier pollen is transported over a shorter distance and has a smaller source area, for example *Fagus* and *Picea* (Theuerkauf et al. 2012). The distance a pollen grain can be transported is determined by the fall speed of the grain in air, which is influenced by the shape and size of the pollen grain (Broström et al. 2004).

Only a small fraction of the pollen grains will fertilize a plant, and most of them will end up on land and start to decay. But some of the pollen will be deposited in anoxic conditions and will be preserved (for example in peatlands or lakes). During deposition, the hard and chemically resistant exine is the only part left, as the soft-bodied cell contents of the pollen are destroyed (Seppä 2007). In pollen studies it is assumed that all pollen grains are equally preserved in peat or lake sediments, but the preservation is affected by the thickness of the grain (Seppä 2007). Both lake and peat records have been important in historical as well as modern pollen analysis. Peat is present in most environments and most of the pollen in peat records is wind-transported, giving a dominantly regional pollen signal. A problem with peat records is that it might be difficult to know the influence of pollen from plants growing locally on the bog on the total assemblage (Charman 2002).

1.2.4.1 Pollen influx values

Pollen percentage values depend upon the abundance of all pollen taxa included in the pollen sum and are therefore uncertain for detecting local presence of specific taxa. The reason is because pollen percentages depend on pollen productivity, coverage and dispersal capabilities of the other taxa that are included in the pollen sum (Theuerkauf et al. 2012). Using pollen influx, which is the amount of pollen grains falling on a unit area of sediment in a given time, will provide more precise and useful data (Hicks & Hyvärinen 1999). In order to be statically relevant, pollen percentage and influx values should be based on a high number of counted pollen, the more the better. The determination of pollen influx values requires knowledge of the peat or sedimentation accumulation rate. The accumulation rate can differ markedly, both in time and across a bog (Mauquoy et al. 2002). Not knowing the accumulation rate is the main limitation of peat sequences when analysing pollen, but with relatively high resolution age models it is possible to get a secure result (Hicks & Hyvärinen 1999). Even so, peat is still better than lake sediments when analysing short-term variations in pollen, if the accumulation rate is known. The best peat deposits to use for pollen analysis is fast growing, uniformly humified peat composed of a single moss species (Hicks & Hyvärinen 1999). For the most secure result, annual resolution should not be used since it would show inter-annual variations in climate instead of the influx values characteristic of a specific vegetation composition (Hicks & Hyvärinen 1999). A peat study done by Hicks & Hyvärinen (1999) in Kevo, Finland, shows that the actual annual values for pollen influx are a bit lower than the data recorded from pollen traps, especially looking at the peak years, even if the influx values and the pollen traps show the same pattern (Hicks & Hyvärinen 1999). This is shown both for *Pinus* and *Betula* and it may create an uncertainty using pollen influx values, since the pollen traps have a more secure pollen amount.

Hicks and Hyvärinen (1999) studied how influx values varied for *Pinus* and *Betula* depending on the surrounding vegetation in Finland, as seen in Table 1. The higher the influx value, the more trees are present in the surroundings.

1.2.4.2 Pollen productivity

Pollen productivity estimates (PPEs) provide values of how much pollen are produced by different taxa. Direct measurements of pollen productivity are difficult to acquire and that is why PPEs are of great importance. PPE for a species can be obtained in an area by using surface samples and pollen depositional data

Table 1. Modified table from Hicks & Hyvärinen (1999). The influx values for *Betula* and *Pinus* based on pollen trap results from Kevo, Finland.

Presence of the relevant tree species with respect to the sampling site	<i>Betula</i>	<i>Pinus</i>
Not present within 10 km		<200
Not present within 1 km		200-500
Present at site but only sparsely	500-1000	500-1500
Open forest	1000-1500	1500-2000
Dense forest	>1500	>2000

from, for example, moss polsters (Theuerkauf et al. 2012). The PPEs are combined with distance weighted plant abundances from the vegetation in the surrounding area (Theuerkauf et al. 2012). Pollen productivity varies a lot amongst the most common wind pollinating plants (Seppä 2007) and results from pollen traps show that the pollen productivity changes markedly on an annual basis (Broström et al. 2008). Different taxa produce different amounts of pollen. Trees do for example produce generally more pollen than herbs. Therefore, herbs can be underestimated in the reconstructed vegetation studying fossil pollen records and in consequence there will be an underestimation of their presence in past open landscapes. At the same time other taxa with high pollen productivity, like trees, can be overrepresented in fossil pollen records (Broström et al. 2004). Even so, some herbs and shrubs like *Calluna vulgaris* for example are important pollen producers together with Juniper (*Juniperus*), buckthorn (*Plantago lanceolata*) and sorrel (*Rumex acetosa*). In a study by Broström et al. (2004) they found that most trees produced 6-8 times more pollen per unit area compared to *Poaceae*. However, some herbs show higher pollen productivity than some of the trees in the same study when looking at southern Sweden. Tree taxa with low pollen productivity are *Ulmus*, *Tilia*, *Salix* and *Fraxinus* (Broström et al. 2008). PPEs are influenced by the mean temperature in July and the precipitation. The mean July temperature of the previous year and PPEs for *Pinus*, *Picea* and *Betula* show a positive correlation in northern Finland and mountainous areas of Europe (Broström et al. 2008). Barnekow et al. (2007) suggest that summer temperatures in the years prior to efflorescence are

of great importance for controlling the amount of pollen produced. PPE can vary significantly even within one vegetation zone, as shown by Broström et al. (2008). These differences may be due to soil or more local climate conditions or methodological differences in the collection of vegetation data (Broström et al. 2008; Theuerkauf et al. 2012). The most important factor influencing PPEs seems to be climate and related factors such as growth forms and reproduction strategies (Broström et al. 2008). Even if the atmosphere normally is unstable, atmospheric instability does not primarily influence estimates of pollen productivity or the relevant source area of pollen (RSAP) (Broström et al. 2004). As stated by Seppä (2007), RSAP “refers to the size of the area around a given study site, which controls the individualistic features in the pollen assemblages of the site in relation to the uniform regional background pollen. The vegetation patterns within the RSAPs are therefore reflected in the lake-to-lake differences in pollen input in areas of the same regional vegetation”. Usually the RSAP is where 80 % of the pollen grains arrive (Theuerkauf et al. 2012).

1.2.4.3 Modelling of pollen deposition

The general way of interpreting pollen data is that a larger basin reflects a more regional pollen signal, while a small hollow reflects the local pollen signal (Seppä 2007). This straightforward model is however too simple for modern ecological analysis. One way of modelling pollen deposition is by using the Prentice-Sugita model. The principle behind the model is to quantify the pollen input from the vegetation surrounding

the sampling site. It can be done either by using the entire surface of the basin or by using only the centre of the basin (Seppä 2007). The input of pollen into the basin will be defined by three factors; (i) the pollen productivity of the plant species, (ii) a pollen deposition function (the proportion of airborne pollen at a certain distance from the source) and (iii) the mean plant abundance at a given distance from the centre of the basin (Seppä 2007). Distance-weighting must be applied since most of the pollen will be deposited near the source (Theuerkauf et al. 2012). The relevant source area of pollen (RSAP) is therefore an important part of the Prentice-Sugita model. As many other models, the Prentice-Sugita model uses idealistic assumptions, for example regarding local and regional vegetation patterns in the area, pollen transportation, deposition mechanisms and basin configuration (Seppä 2007). Although the model is constructed for lakes, it is also valid for bogs even if the result differs slightly (Mazier et al. 2012).

1.2.4.4 Holocene vegetation in southern Sweden and an historical overview over pollen studies

Brown et al. (2012) concludes that during the Holocene both precipitation and temperature have oscillated considerably in southern Scandinavia. Even so, the total energy budget has been quite stable during the last 7500 years according to Davis et al. (2003). The distribution of a forest type is determined by migration patterns, human activity and climatic changes. If all vegetation were natural, southern Sweden should be characterized by *Fagus* monocultures or a *Picea*-dominated boreal system (Björse et al. 1995). *Pinus* and *Fagus* are two of the most abundant taxa in southern Sweden today according to Björse et al. (1995), and the amounts and distribution patterns have varied significantly but systematically through time. The high amount of *Pinus* is mainly a result of planting during the last centuries (Mauquoy et al. 2002). *Pinus* pollen is transported far by wind, and Björse et al. (1995) state that *Pinus* pollen will be wind-transported even further in the open landscapes in the south-west of Sweden.

Malpighi and Grew started to describe and observe pollen three centuries ago, and they are seen as the co-founders of pollen grain morphology. They worked in Italy and England and borrowed each other's work freely (Manten 1967). Grew also established that pollen from different species has different shapes and sizes, but that the pollen from the same species looks the same (Manten 1967). The first time microscopes were good enough to see pollen was in 1836

and it was done by Göppert who studied Miocene material from Hessen, Germany (Manten 1967). Ehrenberg found *Pinus* pollen from Quaternary sediment from northern Sweden in 1837, and the year after he found *Pinus*-like pollen in Cretaceous flintstone (Manten 1967). Blytt from Norway could in 1876 distinguish some warmer, colder, wetter and drier periods based on the present distribution of the flora in Norway (Manten 1967). This methodology was later extended by the Swede Sernander who made it more generally applicable (Manten 1967). Another important person within palynology (the study of pollen and spores) is the Swede von Post. He held a lecture in 1918 about the forest-tree pollen found in peat deposits of south-Swedish, from Scania to Närke. He believed that the trees found rapidly invaded the area and that the pollen-analytical index levels were consequently to be considered as synchronous (Fries 1967). von Post gave the onset for the development of pollen analysis as we know it today. Studying fossil pollen records also opened up the amount of studies concerning modern pollen. During the mid 1900s until today, petroleum geology has increased the application of plant microfossil analysis (Manten 1967).

To quote von Post from his lecture in 1918; "I consider that this category of fossils, hitherto rather overlooked can indeed, through systematic treatment, considerably widen our knowledge of the Late Quaternary deposits and their history" (Fries 1967).

2 Study sites

Fäjemyr is a bog located in the north central part of Scania, Hässleholm municipality, southern Sweden (56°16'12" N, 13°33'11" E) (Figure 2), at an altitude of 135 m above sea level. The County Administrative Board of Scania describes Fäjemyr as an unexploited bog with large geological and biological values that should not be excavated (Länstyrelsen i Skåne 2014). There is a forested area at the edge of the bog that is dominated by *Pinus sylvestris*. On the bog *Pinus sylvestris* and *Betula pubescens* grow quite widespread but they are small, with more trees growing near the edge of the bog. The vegetation is dominated by *Calluna vulgaris*, *Erica tetralix* and *Eriophorum vaginatum* in the open parts of the bog, and in the denser forested area by *Eriophorum vaginatum*, *Erica tetralix* and *Vaccinium myrtillus*. *Sphagnum* grows over the whole bog. Figure 3 shows an overview picture of Fäjemyr.

Stass Mosse is located in central Scania, Hörby municipality, on the Linderödsåsen Ridge (55°54' N, 13°45' E). Figure 2 shows where Stass Mosse is located

ed within southern Sweden. The bog is approximately 0.3 km² and has been used in the past for peat cutting. In the 1960's, peat cutting reached down to a layer of larger *Pinus* stumps, remains of a long-gone *Pinus* forest that had been preserved in the bog (Figure 1). The amount of peat excavated is not known, but the excavated area covers at least a third of the bog (Adamsson 2013). Only a small area of the original bog remains undisturbed today (Liljegren & Björkman 2012). During the peat cutting, or before, the bog was drained and the drainage ditches can be seen in the southern part of the bog. Varying topography on the bog could be due to the drainage. Where the ground-water level has been lowered, peat deposits get more compressed and in consequence the surface has sinks. Today, the surroundings are dominated by a coniferous forest of *Pinus sylvestris* and *Picea abies*, together with some birch (*Betula pubescens*). The understory vegetation is dominated by *Calluna vulgaris*, *Erica tetralix*, *Vaccinium spp.* and brown mosses. On the mined peat surface, the vegetation is scarce, but some spots with *Eriophorum vaginatum*, *Carex spp.* and *Calluna vulgaris* occur.

2.1 Current climate

Örkelljunga municipality, close to Fäjemyr, has a mean annual temperature of 6.4 °C and a precipitation of 960 mm/year during 1961-1990. In Örkelljunga, the mean winter temperature in January is -2.3 °C and the mean July temperature is 15.4 °C. In northern Scania, where Fäjemyr is

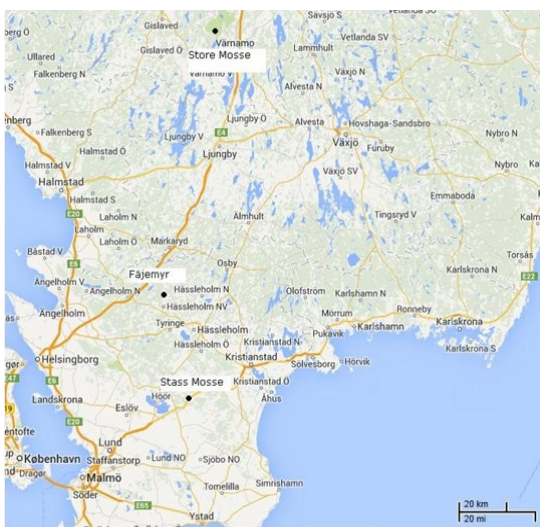


Figure 2. Map of southern Sweden. The investigated sites are marked with black dots. Map source: maps.google.se (2014).



Figure 3. Overview photo of Fäjemyr, taken from the centre (site 1) of the bog towards the denser forest (site 5) (Photograph: I. Timms Eliasson. 2014).

located, the number of days with temperature over 6 °C, a threshold temperature for vegetation growth, is around 220 days/year (Andersson & Johansson 1997).

Linderöd village, 4.5 km NE of Stass Mosse, has a mean annual temperature of 6.9 °C and a mean annual precipitation of 795 mm/year for the period between 1961-1991 (SMHI 2014).

2.2 Bedrock

As seen in the bedrock map from the Geological Survey of Sweden (SGU) (Figure 4), both the Tornqvist deformation zone and another perpendicular deformation zone are running close to Fäjemyr. The perpendicular deformation zone, called the protogin zone, has created a rift system and is approximately 1700 million years old, but has been active later on (Andersson & Johansson 1997). The Tornqvist deformation zone creates WNW-ESE oriented- diabase rift systems across Fäjemyr from perm-carbon and the bedrock consists of granitoid to syenitoid migmatitic gneiss that was created 1.7 billion years ago (Wikman & Sivhed 1993).

The Linderödsåsen Ridge, where Stass Mosse is located, is a bedrock horst formed by movements of the Tornqvist deformation zone, which is running NW-SE across Scania (Figure 5)(Wikman & Sivhed 1993). The deformation began in early Silurian (440-420 million years ago) when the continents Avalonia and Baltica collided (Ringberg 1986). The horsts in Scania were created later, about 200-300 million years ago (Andersson & Johansson 1997). The bedrock

in Stass Mosse consists of Precambrian gneiss (Ringberg 1986).

2.3 Quaternary deposits

The formation of most of the bogs in the Fåjemyr area is related to the closeness to the Småland highlands. Westerly winds and higher elevations result in higher precipitation in the area, creating water-logging (Andersson & Johansson 1997). Fåjemyr is a 3 km long peatland surrounded by till deposits in the west, as seen in the map from SGU (Figure 6). Further to the west and to the east and south glaciofluvial sediments are present and an esker that was deposited during the last glacial period.

Stass Mosse is situated on a large (almost 20 km²) glaciofluvial deposit running in NE-SW direction, as seen in Figure 7. South of the bog is an esker running NE-SW with a height of 3-10 m, and that correlates with the ice direction from NE, as can be seen from striae in the area (Ringberg 1986). The peat has formed on top of the glaciofluvial deposits and sands in the lower parts of the terrain that surrounds the esker. The glaciofluvial deposits on which the bog is situated, is characterized by broken-up and forked eskers with material ranging from boulders to silt.

When the ice retreated, around 14000-15000 cal years BP, dead ice was still lying in the area and sedimentation started between the dead-ice bodies. The landscape was quite flat, and the sedimentation probably took place in shallow water (between the dead-ice bodies). One of these dead-ice bodies was probably situated where Stass Mosse is located today. The sedimentation began around the ice, leaving a depression at the site when the ice melted away

(Ringberg 1986). This depression was later water-logged.

3 Material and Methods

3.1 Field work

3.1.1 Fåjemyr

The field work took place on the 26th of February 2014 at Fåjemyr. The objective was to collect surface samples for pollen analysis at different distances from the dense *Pinus* forest at the edge of the bog to the central part of the bog where pines are scarce and low in stature. Five sample sites were selected along a transect so that a range of pine densities was covered. Ten samples were taken, two at each site, one “open” and one “closed” sample. The *Sphagnum* at the closed sites was partly covered by dwarf shrubs, herbs and sedges and at the open sites, *Sphagnum* was exposed to the pollen rain. The closed sites were denoted “a” and the open sites “b”. The location of the sites can be seen in Figure 8.

The sites were located in the centre of the bog (away from larger trees) (site 1), near a small group of *Pinus* and *Betula* (site 2), inside a small group of *Pinus* (site 3), at the edge of the *Pinus* forest (site 4) and inside the *Pinus* forest (site 5). Surface samples for pollen analysis were systematically taken in *Sphagnum* patches. At each site, a grid with 25 squares (5×5 squares with a surface of 100 cm²) was placed on the vegetation so the sample spot was located in the centre of the grid. An estimation of the percentage cover of each species inside the grid was made. Figures 9a and 9b show the grid placed over a closed (1a) and an open (1b) site, respectively.



Figure 4. Bedrock map of the Fåjemyr area. The grey part is granitoid to syenitoid with diabas (purple) and amphibolite (green) (SGU 2014a).

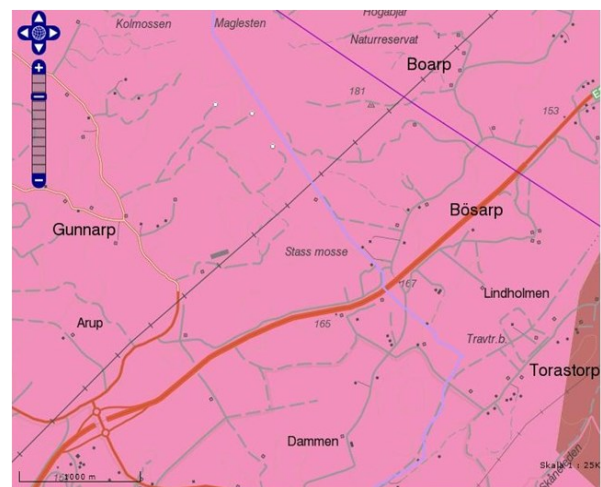


Figure 5. Bedrock map of the Stass Mosse area showing granitic orthogneiss (pink) (SGU 2014a).

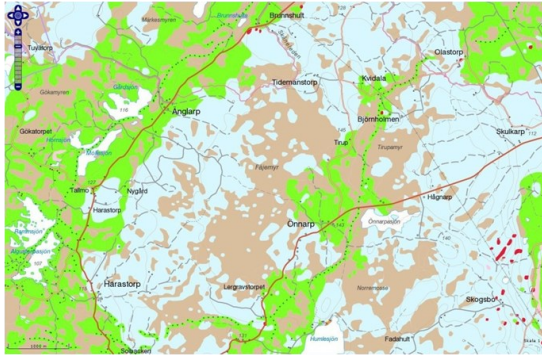


Figure 6. Map of Quaternary deposits in the Fäjemyr area, with glaciofluvial deposits (green), till deposits (blue) and peat deposits (brown) (SGU 2014b).

At each site, the *Pinus* and *Betula* trees within 10 and 50 meters radius were counted or estimated, and the height of the highest tree within 10 meter radius was noted. GPS points were taken at each site and the sites were photographed with the grid on top of the sample. The surface samples were taken by gently pressing down a plastic box in the *Sphagnum* moss and cut around and underneath so that the box was filled with moss. In this way the surface of the moss layer ended up in the bottom of the box. The boxes were carefully closed with a lid and transported to the Department of Geology, Lund University, where they were stored in a freezer overnight. The samples were deep-frozen because the volume of fibrous peat is difficult to determine. By freezing the sample, it is possible to get a more correct estimate of the volume by cutting out the volume needed (Faegri et al. 1989).



Figure 8. Map of Fäjemyr with the sampled sites marked out as coordinates, from site 1 in the centre of the bog towards site 5 at the edge of the bog. Map source: Google Earth 2014.

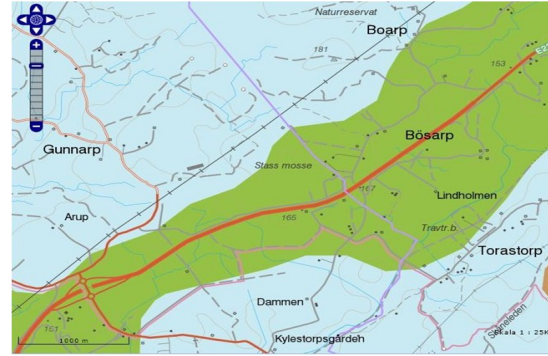


Figure 7. Map of Quaternary deposits in the Stass Mosse area. Glaciofluvial sediments (green) and till deposits (blue) (SGU) 2014.

3.1.2 Stass Mosse

The field work at Stass Mosse took place in September 2012, and was done by Adamsson (2013). The cores were taken by using a Russian sampler (1 meter length, 7.5 cm diameter). The coring sites are described above (in section 2). The cores were taken to Lund University and stored in the cold room and later correlated by Adamsson (2013).

On the 12th of March 2014 a visit was made to Stass Mosse to look at the coring sites of Adamsson (2013), the bog vegetation and the pine stumps that can be seen at the excavated bog surface. This was done to gain background knowledge about the site to facilitate interpretation of the pollen data.

3.2 Laboratory work

3.2.1 Fäjemyr and Store Mosse

After the surface *Sphagnum* samples had been in the freezer overnight, they were taken out and the sides of the frozen moss were cut off to limit contamination. Consequently cubes with a volume of 4 cm³ were cut from the top of each sample for pollen analysis. It was assumed that the top of the moss was covering the same time period at all the sites at Fäjemyr. About half of the sample was saved and stored in the freezer, in case something went wrong with the preparation. Ten cubes with a volume of 4 cm³ were put in test-tubes and stored in the cool room overnight. The frozen samples were weighed and the (wet) bulk density calculated. This provides a rough estimate of the *Sphagnum* growth rate and the peat decomposition rate, as well as the compression during sampling.



Figure 9a. The grid used for estimating the vegetation coverage in percentage at site 1a (Photograph Timms Eliasson 2014).

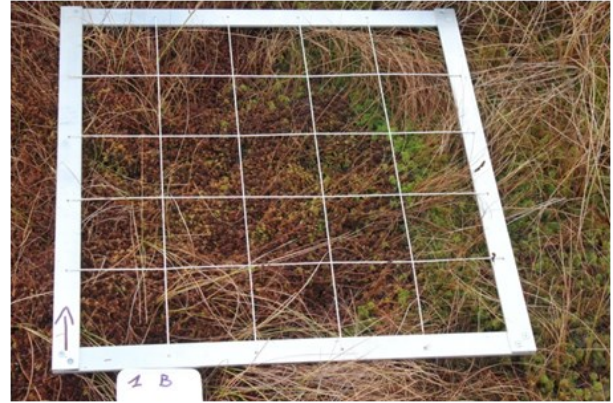


Figure 9b. The grid used for estimating the vegetation coverage in percentage at site 1b (Photograph Timms Eliasson 2014).

Store Mosse is an almost 100 km² large bog situated about 15 km NW of Värnamo in Småland, Sweden. The Store Mosse sample was added to assess what *Pinus* pollen percentage and influx values may be recorded in an extreme case where the distance to local pine populations is very large. Since the Store Mosse core (collected in 2008) was taken in the centre of a large bog without any trees in the near surroundings, the tree pollen signal should be regional. A sample of the topmost 4 cm was taken from the core and the volume was determined by water displacement. Based on an age-model by Rundgren (personal communication 2014) the top 4 cm were deposited during 9 years, resulting in an accumulation rate of 0.44 cm/year. The surface peat was more decomposed in Store Mosse than at the Fäjemyr sites.

3.2.2 Stass Mosse

The cores from Stass Mosse were subsampled in 1 cm slices by Adamsson (2013), and put in plastic bags in the cool room at Lund University. The samples were cut in approximately 1 cm³ and put in small glass jars and kept in the cool room until further processing. In the pollen lab, the volume of the samples was measured by water displacement in a test tube with 2 ml water.

3.3 Pollen laboratory

In the pollen laboratory *Lycopodium* spore tablets were added to the samples to estimate pollen influx values (Stockmarr 1971). Four tablets (one tablet containing approximately 20848 spores) were added to the samples from Fäjemyr and Store Mosse, and six tablets were used for the Stass Mosse samples. The tablets were dissolved in HCl to be dispersed within the sample. The added *Lycopodium* spores can easily be distinguished from the pollen. The main advantage of using exotic spores is that they are put into the sample

before any preparation process. Therefore, if some material is lost during for example filtering, it is assumed that the same amount of *Lycopodium* spores as other palynomorphs will be lost (Faegri et al. 1989). The amount of the *Lycopodium* spores added to a sample should be about the same amount as the pollen (Berglund & Ralska-Jasiewiczowa 1986) or not less than 20 % of the expected total fossil pollen (Faegri et al. 1989).

The samples were prepared in the pollen laboratory. After dissolving the *Lycopodium* tablets, the samples were filtered to remove coarse plant material. Most of the Stass Mosse samples had to be filtered twice because of coarse plant remains in the samples. The samples were boiled or warmed with different acids and bases (for example HCl and NaOH) to remove as much as possible of the plant remains, mainly as described by Birks & Birks (1980). The HF treatment was not necessary since the peat did not contain courser mineral grains (Faegri et al. 1989). The samples were mounted with glycerol, as described by Faegri et al. (1989) and Lowe & Walker (1997), and sealed with Permout.

Before counting the fossil pollen slides of Stass Mosse, the reference collection at the Department of Geology, Lund University, was used to get acquainted with the morphology of the most common pollen taxa. A microscope with 40× magnification was used for the pollen counting. For each sample from each site (Fäjemyr, Stass Mosse and Store Mosse), the goal was to count 500 pollen. The number of pollen counted should be high enough to maintain constant percentages in the pollen sum, usually around 300-500 pollen grains, depending on the problem being investigated (Birks & Birks 1980).

The pollen counts were put into Excel and percentages and influxes were calculated. The results were later put into the diagram program Tilia (Grimm

2007).

Influx values were calculated using the equation:

Fossil pollen concentration (grains/cm³) * sediment accumulation rate (cm/year) = Fossil pollen influx (grains/cm²·y) (Berglund & Ralska-Jasiewiczowa 1986).

The pollen concentrations were calculated using the equation:

(*Lycopodium* added/*Lycopodium* counted) * (Fossil pollen grains counted/Volume cm³) = Fossil pollen concentration (grains/cm³).

4 Results

4.1 Fäjemyr and Store Mosse

The results from Fäjemyr come from five sites with two surface samples from each site, with one closed (a-samples) and one open (b-samples). With closed samples (a-samples) is meant that the *Sphagnum* was partly covered by herbs, dwarf shrubs and sedges, for example *Calluna vulgaris* and *Euopium vaginatum*. At the open sites (b-samples) *Sphagnum* moss was exposed and not covered. The number of *Pinus* and *Betula* trees in the immediate surroundings of the sampled sites is shown in Table 2. Figure 10 with *Calluna vulgaris* shows a correspondence between vegetation cover and pollen data (percentage and influx values); more of the taxa in the vegetation gives higher percentage and influx values in the diagrams. Figure 11 with *Ericaceae undiff.* does not show a correspondence between vegetation cover and pollen data. The same data is shown for all pollen taxa as scatter plots in Appendix 1. The number of *Pinus* and *Betula* trees were counted or estimated, together with an estimate of the height of the highest tree within 10 m radius (Table 2). The

taxa found at the sites that were included in *Ericaceae undiff.* were *Erica tetralix*, *Vaccinium oxycoccus*, *Andromeda polifolia*, *Empetrum nigrum* and *Vaccinium myrtillus* (Table 3). *Calluna vulgaris* has a high R²-value in the diagrams shown in Appendix 1. For *Ericaceae undiff.*, vegetation coverage sometimes corresponds to the pollen amount, but without any consistent pattern and it has a fairly low R²-value. *Pinus* and *Betula* have low R²-values comparing influx, pollen percentage, highest tree and the amount of trees within 10 and 50 m radius. The highest tree was always *Pinus*, and therefore the highest tree is not taken into account with *Betula*. Pollen percentages are about the same (50-60 % for *Pinus* and 10-15 % for *Betula*) when the amounts of trees are zero, regardless if 10 or 50 meter radius is taken into account (Appendix 1). In general, the highest influx values were found in the relatively treeless sites (sites 1 and 2).

Site 1a

Site 1 is located in the centre of the bog as far away from surrounding trees as possible (Figure 8). The dominant vegetation covers at site 1a are *Sphagnum* and *Calluna vulgaris* (Table 3). The site has high influx values and high vegetation cover percentages of *Calluna vulgaris* as seen in Figure 10. No trees above 2 m were present within a 10 m radius, but 10 *Pinus* and 1 *Betula* were present within a 50 m radius. Site 1a had the highest pollen percentages and influx values of *Carpinus* in Fäjemyr, and the other taxa were close to the mean influx value, both with percentage and influx value (Figure 12). The bulk density was 0.75 g/cm³ (Figure 16).

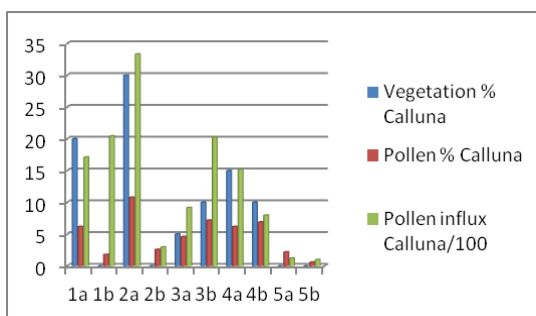


Figure 10. Vegetation cover (%), pollen percentage and pollen influx values for *Calluna vulgaris* at the Fäjemyr sites.

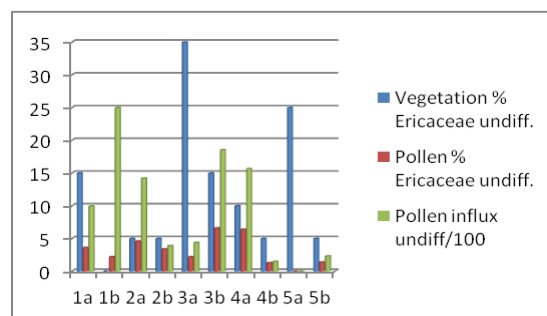


Figure 11. Vegetation cover (%), pollen percentage and pollen influx values for *Ericaceae undiff.* at the Fäjemyr sites.

Table 2. Number of *Pinus* and *Betula* trees within 10 and 50 m radius, and the height of the highest tree within 10 m radius for the Fäjemyr sites.

Sample/Site	Pine 10 m radius above 2 m	Pine 50 m radius above 2 m	Betula 10 m radius above 2 m	Betula 50 m radius above 2 m	Max tree height (pine) 10 m radius
1	0 (3 below 1 m high)	10	0	1	1 m
2	9	52	0	4	3 m
3	10	42	1	5	3 m
4	28	108	2	8	6 m
5	60	1500	6	150	12 m

Table 3. Estimated vegetation coverage at the different sites at Fäjemyr.

Site	Sphagnum spp %	Eriophorum vaginatum %	Calluna vulgaris %	Erica tetralix %	Vaccinium oxycoccus %	Andromeda polifolia %	Rynchospora alba %	Empetrum nigrum %	Vaccinium myrtillus %	Ericaceae undiff %
1a	35	30	20	15	Present	0	0	0	0	15
1b	80	20	0	0	0	0	0	0	0	0
2a	50	15	30	5	Present	Present	0	0	0	5
2b	80	0	0	5	0	Present	15	0	0	20
3a	35	25	5	0	Present	5	0	30	0	35
3b	40	35	10	5	Present	5	0	5	0	15
4a	60	15	15	10	0	Present	0	0	0	10
4b	40	0	10	5	0	Present	45	0	0	5
5a	45	30	0	10	5	0	0	0	10	25
5b	75	20	0	0	0	0	0	0	5	5

Site 1b

The underlying vegetation at site 1b consisted of *Sphagnum* and *Eriophorum vaginatum* (Table 3). Site 1b is the only site where *Calluna vulgaris* vegetation cover does not correspond to the influx values for *Calluna vulgaris*. *Calluna vulgaris* was not present in the grid, but the pollen influx value is high. In general, the pollen percentages in site 1b are high compared to the rest of the Fäjemyr sites, but for example *Betula* pollen percentage is lower than for the other sites. *Pinus* pollen percentage is higher than for most of the Fäjemyr sites. Site 1b shows the highest influx values for all taxa, except for *Carpinus*, and the *Picea* influx value which is close to the value in site 2a. Site 1b shows the highest *Pinus* influx value in Fäjemyr (Figure 12). The bulk density was 0.82 g/cm³, slightly higher compared to site 1a (Figure 16).

Site 2a

Site 2 was located beside a small group of trees that consisted mainly of *Pinus* in the centre of the bog (Figure 8.) *Calluna vulgaris* had 30 % of the vegetation coverage and high influx values and pollen percentages (Figure 10). No correlation was found between the vegetation cover percentage of *Ericaceae undiff* and the influx values in site 2a (Figure 11). Site 2 had a higher amount of trees than site 1 with 9 *Pinus* within the 10 m radius and 52 *Pinus* and 2 *Betula* within the 50 m radius (Table 2). The pollen percentage of *Pinus* is close to the mean value of all the sites in Fäjemyr (Figure 12). The pollen percentage of *Betula* was lower compared to site 1b. In general, site 2a did not have as high influx values as site 1 even taking into account that the sites were similar as they were both located in the centre of the bog. Site 2a still has high influx values compared to

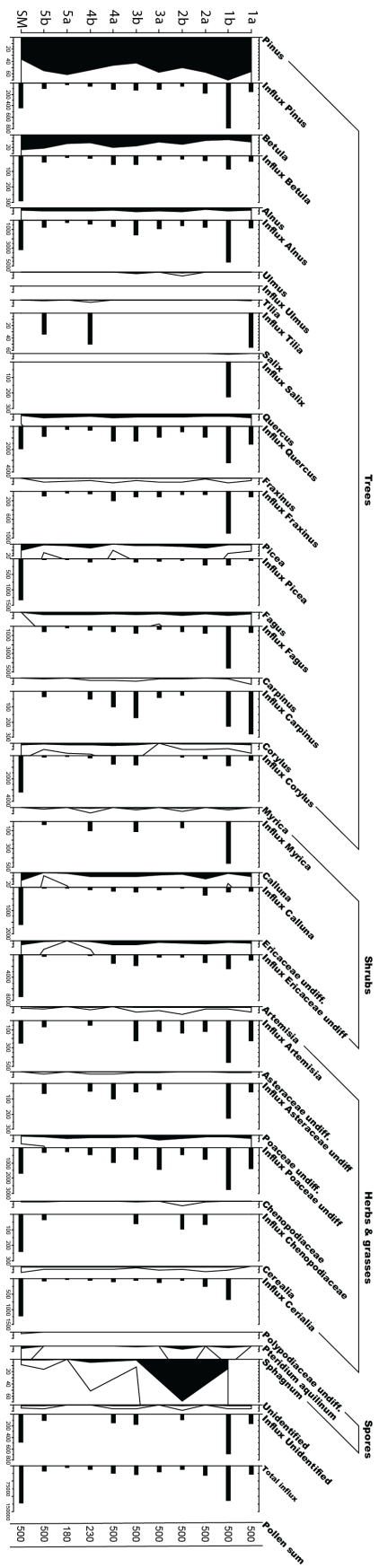


Figure 12. Pollen percentage and influx diagram for the surface-sample sites at Fågemyr (1-5) and Store Mosse (SM).

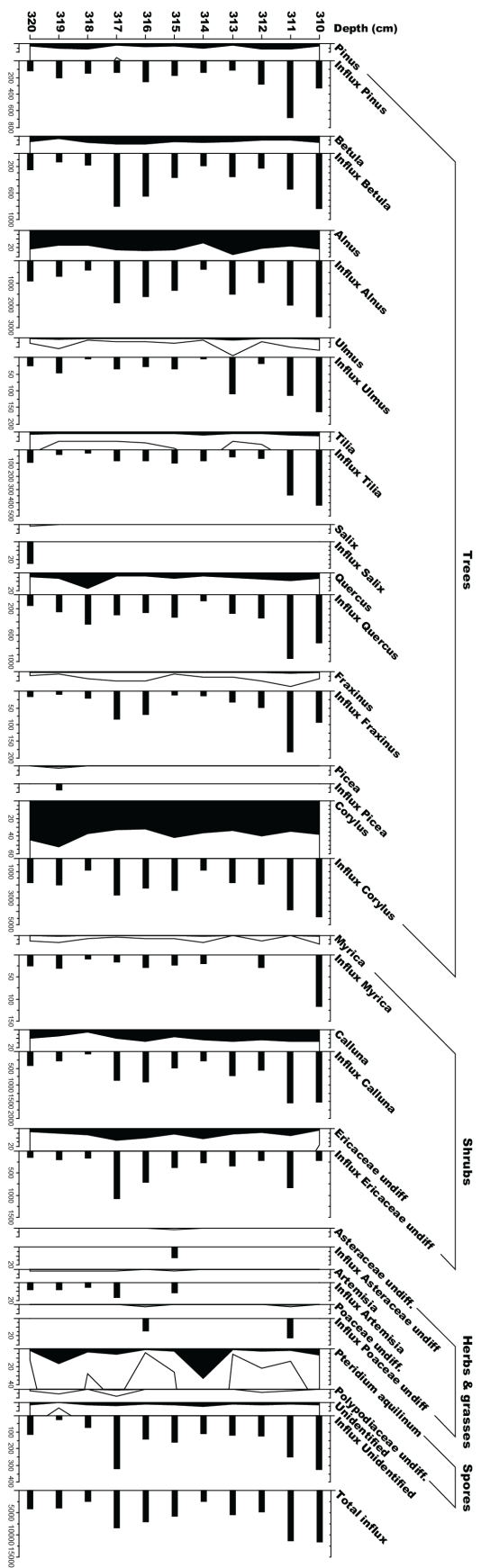


Figure 13. Pollen percentage and influx diagram for the high-resolution interval of the Stass Mosse complete sequence (CS).

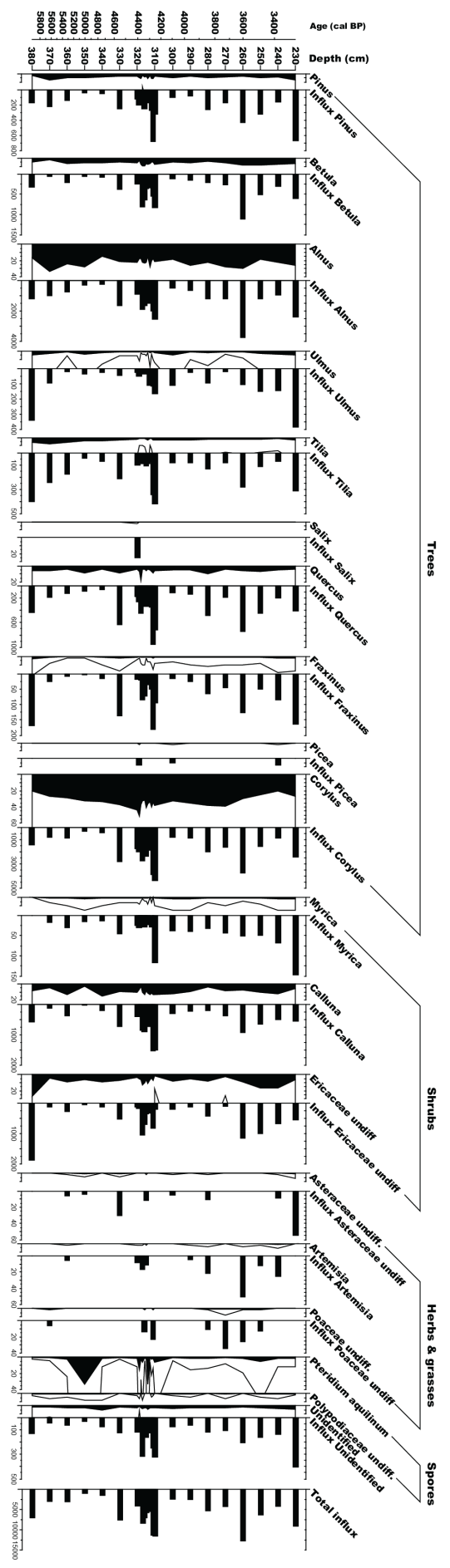


Figure 14. Pollen percentage and influx diagram for the Stass Mosse sequence (CS) including samples from the high-resolution interval.

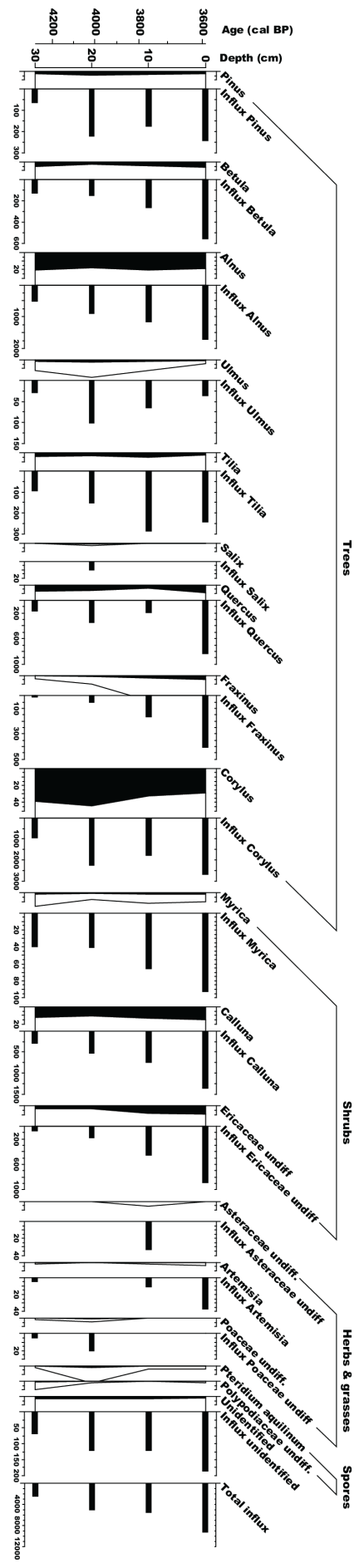


Figure 15. Pollen percentage and influx diagram for the Stass Mosse Tree sequence (TS).

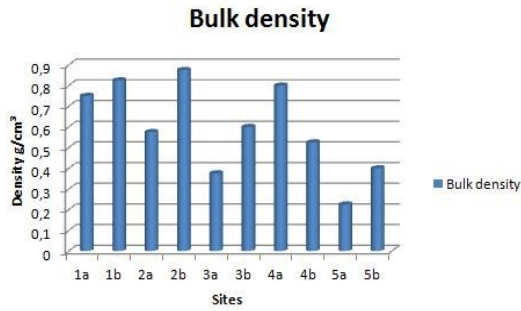


Figure 16. The bulk density for the different sites at Fäjemyr.

the rest of Fäjemyr. *Calluna vulgaris* had the highest influx values at site 2a compared to the rest of the Fäjemyr sites. The bulk density was 0.56 g/cm³, a quite much lower compared to site 1b (Figure 16).

Site 2b

Calluna vulgaris has low percentage cover and a lower influx value than site 2a (Figure 10).

Sphagnum has its highest percentage at site 2b and the site has lower *Pinus* pollen percentage than site 2a (Figure 12). *Betula* pollen percentage increases compared to site 2a. The influx values are generally lower in site 2b than in site 1 and 2a. *Pinus* influx is low, even compared to site 2a. Site 2b had the highest bulk density of Fäjemyr, 0.88 g/cm³ (Figure 16).

Site 3a

Site 3 was located within a small group of trees in a quite open area (Figure 8). *Calluna vulgaris* corresponds with influx value and vegetation coverage but *Ericaceae undiff* does not, see Figure 10 and 11. The site has close to the same amount of *Pinus* and *Betula* as site 2, as well as the same height of the highest tree. The *Pinus* pollen percentage in site 3a increases compared to site 2, and *Betula* pollen percentage decreases compared to site 2 (Figure 12). Sites 2 and 3 have generally similar influx values comparing *Pinus* and *Betula*. The bulk density for site 3a was the second lowest of all sites at Fäjemyr, 0.38 g/cm³ (Figure 16).

Site 3b

Calluna vulgaris influx value and vegetation coverage correspond (Figure 10). The *Pinus* pollen percentage decreases in site 3b compared to

site 3a and *Betula* pollen percentage increases compared to site 3a (Figure 12). The *Pinus* influx value is about the same for 3a and 3b. The influxes increases generally in 3b compared to 3a. Site 3b had a higher bulk density compared to site 3a with 0.6 g/cm³ (Figure 16).

Site 4a

Site 4 was taken near the edge of the bog (Figure 8) and *Calluna vulgaris* corresponds between influx value and vegetation percentage (Figure 10). There are higher *Pinus* and *Betula* trees compared to sites 1-3. The highest tree was about twice as high as in site 2 and 3 (6 m). The amount of *Pinus* and *Betula* increases (28 *Pinus* and 2 *Betula* within 10 m radius and 108 *Pinus* and 8 *Betula* within 50 m radius) (Table 2). The pollen percentage for *Pinus* is close to the same as in site 3b, and the pollen percentage for *Betula* is high compared to the rest of the sites at Fäjemyr (Figure 12). Site 4a has influx values comparable to the open sites (site 1-3) with a *Pinus* influx value close to sites 1a, 2a and 3ab, and generally higher influx values than site 4b. The bulk density at site 4a was one of the highest of Fäjemyr with 0.8 g/cm³ (Figure 16).

Site 4b

Because of very few pollen found in the sample, the counted pollen sum for site 4b was only 230 instead of 500. *Calluna vulgaris* percentage and vegetation cover correspond (Figure 10). As seen in Figure 12, the pollen percentages are higher in site 4b compared to site 4a looking at *Pinus* pollen, but *Betula* pollen percentage decreases compared to site 4a. Site 4b has the lowest influx values together with site 5a of all sites in Fäjemyr. Site 4a had a lower bulk density compared to site 4a, but not remarkably low compared to the rest of the sites at Fäjemyr (0.53 g/cm³) (Figure 16).

Site 5a

Site 5 was taken inside the *Pinus* forest at the edge of the bog (Figure 8). *Calluna vulgaris* was not present in vegetation coverage at site 5a, and cannot be seen in influx values. *Vaccinium oxycoccus* and *Vaccinium myrtillus* covered 15 % of the vegetation at the site, but *Ericaceae undiff* cannot be seen in the influx value (Figure 12). As

seen in Table 2, the numbers of *Pinus* and *Betula* trees inside the forest were much higher than for the rest of Fäjemyr (60 *Pinus* and 6 *Betula* within 10 m radius and 1500 *Pinus* and 150 *Betula* within 50 m radius). The highest tree was 12 m high (twice the height as in site 4). The pollen percentage of *Pinus* is high in 5a comparing to the rest of the sites in Fäjemyr, but not as high as in site 1 (centre of the bog) (Figure 12). *Betula* pollen percentage is slightly higher than for site 4b, but not as high as in site 5b. The site had the lowest counted pollen sum of all the Fäjemyr sites (180 pollen), and generally the lowest influx values of the sites in Fäjemyr. The bulk density at site 5a was the lowest of all sites in Fäjemyr with 0.23 g/cm³ (Figure 16).

Site 5b

Site 5b has some *Vaccinium myrtillus* (5 %) in vegetation coverage and an increase in *Ericaceae undiff.* influx compared to site 5a with *Ericaceae undiff.* vegetation coverage of 15 % (Figure 12). *Pinus* pollen percentage was generally high and *Betula* pollen percentage was also higher than at site 5a (Figure 12). The tree influx values at site 5b are comparable to sites 2 and 3, even if the amount of trees differs between the sites. Except for the tree influx values, site 5b has low influx values compared to the other sites. The bulk density was 0.4 g/cm³ (Figure 16) for site 5b.

Store Mosse

The Store Mosse sample was taken from the centre of the large bog. The peat was more decomposed than in Fäjemyr and had generally higher influx values (Figure 12). The *Pinus* pollen percentage was lower than some sites in Fäjemyr, but *Betula* had a higher pollen percentage value in Store Mosse than in Fäjemyr. The *Picea* influx value is much higher in Store Mosse compared to Fäjemyr. Herbs and grasses, *Calluna* and *Ericaceae undiff.* influx values are also higher compared to Fäjemyr. *Pinus* had a high influx value in Store Mosse, but not as high as site 1b, and *Betula* had a higher influx value in Store Mosse compared to Fäjemyr. The sample had clearly a higher decomposition than Fäjemyr, that could be seen just by looking at the sample.

The total influx value for Fäjemyr and Store Mosse show that the highest total influxes are at site 1b and Store Mosse, as seen in Figure 12. The lowest total influxes are at site 4b and 5a.

4.2 Stass Mosse

4.2.1 High resolution interval of the Complete Sequence (CS)

All taxa fluctuate through time and changes occur even on short time scales (Figure 13). *Pinus* influx values are fairly stable throughout the sequence until the peak at 311 cm. Thereafter the *Pinus* influx value decreases at 310 cm.

317-318 cm

As can be seen in Figure 13, *Pinus* and *Corylus* pollen percentages decrease at 317 cm compared to 318 cm. *Quercus* has a large pollen percentage increase at 318 cm (the highest percentage for *Quercus* in the high-resolution sequence), and decreases at 317 cm. *Alnus*, *Calluna vulgaris* and *Ericaceae undiff.* increase in pollen percentage from 318-317 cm. All taxa except *Pinus* and *Quercus* increase in influx value at 317 cm. *Pinus* shows a small decrease at 317 cm, but increase in influx value at 316 cm. The influx values are similar at 317-318 cm for *Pinus*. At 317 cm *Betula*, *Alnus*, *Calluna vulgaris* and *Ericaceae undiff.* show major increases in influx values.

At 318 cm *Quercus* is the only taxon showing increased influx value and it has also its maximum pollen percentage value (Figure 13). The shrubs have at 318 cm their minimum influx values within the whole sequence. *Betula*, *Alnus*, *Ulmus*, *Tilia* and *Fraxinus* all have the lowest or close to the lowest influx values in the high-resolution sequence at 318 cm.

314 cm

Pollen percentages are generally higher at 314 cm compared to 315 cm, except for *Alnus* that has one of the lowest pollen percentage values in the high resolution sequence (Figure 13). All taxa get lower influx values and *Quercus* has its minimum influx value. All taxa start to increase in influx values at 313 cm, right after the decrease at 314 cm.

310-311 cm

The pollen percentage values do not show the dramatic increase as seen in the influx values at this level (Figure 13). *Betula*, *Alnus* and *Corylus* have a slight increase in pollen percentage compared to below. *Pinus* and *Ericaceae undiff.* decrease, and *Quercus* and *Calluna vulgaris* have about the same pollen percentage values as below. *Betula*, *Alnus*, *Ulmus*, *Tilia* and *Myrica* have their highest influx values at 310 cm. At 311 cm *Pinus*, *Quercus* and *Fraxinus* have their highest influx values and *Ericaceae undiff.* increases dramatically compared to before. *Pinus*, *Quercus* and *Fraxinus* started to increase in influx values before the ones that had maximum influx values at 310 cm. The

increase did not always start one cm below but *Pinus* started to increase in influx value 1 cm below the start of the increasing influx for the taxa with influx maximum value at 310 cm. The increase in influx values can be seen in all taxa at 310-311 cm and these samples show the highest or second highest influx values in the whole high-resolution sequence. *Corylus* and *Calluna vulgaris* have almost the same influx value at 310-311 cm.

The total influx values for the high-resolution sequence are highest at 316 cm and 311-310 cm. The lowest total influx values are at 318 and 314 cm (Figure 13).

4.2.2 Complete sequence (CS) with high-resolution interval

The highest influx values in the CS are found at 230, 260, 310/311, 330 and 380 cm (Figure 14). The lowest influx values for all taxa are at 340-360/370 cm. *Pinus* has its highest influx value at 311 cm, and a peak in influx value at 230 cm. The pollen percentage at 380 cm is lower for *Pinus*, *Alnus* and *Corylus* compared to 370 cm. *Ericaceae undiff.* increases dramatically and *Betula* and *Calluna vulgaris* increase as well. At 340 cm, *Alnus* decreases dramatically in pollen percentage, and *Quercus* decreases as well. *Pinus* has about the same percentage as below, and *Corylus*, *Calluna vulgaris* and *Ericaceae undiff.* increase. *Pinus* and *Betula* have about the same pollen percentage as before at 330 cm. *Alnus*, *Corylus* and *Quercus* increases and *Calluna vulgaris* and *Ericaceae undiff.* decrease. The peak at 310/311 cm (in the high-resolution interval) begins already at 330 cm. All taxa start to increase at 330 cm. The high-resolution interval peak at 310/311 cm shows increased pollen percentage values for *Pinus*, *Alnus*, *Betula*, *Quercus* and *Calluna vulgaris*. *Corylus* and *Ericaceae undiff.* decrease in pollen percentage. At 260 cm, *Pinus* decreases together with *Corylus* and *Calluna vulgaris* in pollen percentage. *Alnus*, *Quercus* and *Ericaceae undiff.* increases. At the top of the core, at 230 cm, *Pinus*, *Alnus* and *Corylus* increase in pollen percentages. *Calluna vulgaris* and *Ericaceae undiff.* decrease in pollen percentage value.

Pollen of herbs and grasses are present within the entire CS, in small amounts, but they

increase further up the sequence (Figure 14). *Calluna vulgaris* and *Ericaceae undiff.* influx values fluctuate and are lower in the lower parts of the CS. Further up, after the peak at 310/311 cm, the influx values are quite stable until an increase in influx values at 260 cm. After the peak at 260 cm the influx values gradually decrease for *Calluna vulgaris* and *Ericaceae undiff.*

For some taxa, for example *Betula*, *Alnus* and *Corylus*, the influx values drop after the peak at 310/311 cm (Figure 14). The influx values increase slowly through time until a peak at 260 cm occurs. The same phenomenon occurs before the peak in influx values at 310/311 cm, except for *Alnus* that had a gradual decrease in influx values until the peak at 310/311 cm. *Quercus* shows the same peaks, but has a more gradual decrease after the peak at 260 cm, but a more dramatically decrease after the peak at 310/311 cm. In the lower part of the sequence the tree pollen influx values are decreasing more and more over time, until the peak at 310/311 cm occurs. After the peak at 310/311 cm influx values starts to increase more and more and then ends in a peak.

The total influx values for the CS with the high-resolution interval decrease from the bottom upwards to approximately the level of the high-resolution peak (Figure 14). Thereafter the total influx values generally increase. The decreases occur at the same time as there is lower accumulation rate, and higher total influxes occur when the accumulation rate is higher (see age scale in Figure 14).

4.2.3 Tree sequence (TS)

Pollen percentages in TS do not show dramatic changes over time (Figure 15). *Pinus* has a slight increase in pollen percentage at 20 cm, together with *Corylus*. At 20 cm, *Alnus* has a small decrease in pollen percentage. At 10 cm, *Quercus* has lower pollen percentage, and at 0 cm *Pinus* has a small decrease compared to 10 cm, and *Quercus* has higher pollen percentage compared to 10 cm. *Fraxinus* and *Ericaceae undiff.* show a general increase in pollen percentage values from the bottom of the core to the top.

Betula, *Alnus*, *Fraxinus*, *Myrica*, *Calluna vulgaris* and *Ericaceae undiff.* show general increases in influx values from 30-0 cm (Figure

15). At the same time, *Pinus*, *Ulmus*, *Tilia*, *Quercus* and *Corylus* have fluctuating influx values. All taxa (*Myrica* close to the same influx value as 20 cm) have an increase in influx values from 30-20 cm. *Tilia* and *Ulmus* are the only taxa that do not increase in influx values from 10-0 cm. The highest influx values are at 0 cm, except *Ulmus* (but *Ulmus* has low influx values), *Tilia* (about the same influx value as 10 cm) and *Corylus* (about the same influx value as 30 cm). *Pinus* show peaks in influx value at 0 and 20 cm.

The total influx increases from the bottom to the top in TS (Figure 15). The age model shows that the (long-term) accumulation rate has been about the same during the whole sequence, but a small increase in accumulation rate occurs over time.

5 Discussion

5.1 Fäjemyr

Vegetation percentage coverage and pollen data were compared for *Calluna vulgaris* and *Ericaceae undiff.* as seen in Figure 10 and 11. The high R²-value for *Calluna vulgaris* (Appendix 1), shows that *Calluna vulgaris* corresponded well between percentage coverage and percentage of pollen and influx value and has a consistent direction of relationship (more vegetation and more pollen). This indicates that the *Calluna vulgaris* pollen is predominantly local. *Ericaceae undiff.* did not show a high R²-value and no consistent direction of relationship (Appendix 1). The main reason for this is most likely that *Ericaceae undiff.* includes many different species with different pollen productivity, and the result is therefore that sometimes the influx value or pollen percentage corresponds to the vegetation percentage coverage, and sometimes it does not.

Pinus and *Betula* do not correspond between influx values or pollen percentage and vegetation cover (Appendix 1). This would indicate that the *Pinus* and *Betula* pollen are predominantly from a regional pollen source. The highest tree at the Fäjemyr sites did not either correspond between influx value or pollen percentage (Appendix 1). This does also strengthen the idea that at least the *Pinus* pollen (highest tree was always a *Pinus*) was regional pollen. When looking at the sites with a tree cover at zero percent, *Pinus* and *Betula* had a pollen percentage of 60 % for *Pinus* and 10-15 % for *Betula* (Appendix 1). This indicates that a large proportion of the pollen is regional and that the background pollen values are around 60 % for *Pinus* and 10-15 % for *Betula*.

If the pollen signal is predominantly regional for *Pinus* and *Betula*, the pollen percentage should be similar in the a and b sites since regional pollen is well-mixed in the atmosphere and fall down evenly on the

ground. Since this is not the case, something else is affecting the results. The most likely explanation is that the moss growth differs between the sites. The exact number of years in a moss polster is not known (Broström et al. 2004). Barnekow et al. (2007) studied peat surface samples in Kiruna, northern Sweden, using *Sphagnum* mosses, and concluded that the moss could be up to 5 years old in the top and that the age of the moss is site-specific, making it more difficult to distinguish the moss age at different sites. According to Broström et al. (2008) moss polsters typically trap 1-2 years of pollen. Using the green parts of the moss polsters should represent 1-2 year of deposition, as shown in a study in northern Finland (Broström et al. 2004). The general idea is that the age of moss polsters used for surface samples varies between 1 and 10 years depending on the species of the *Sphagnum* moss and what part of the moss that is used for the analyses (Broström et al. 2004). Therefore, if there are some sites at Fäjemyr where the moss grows more slowly, more pollen will be deposited in the top-most cm, and in consequence give higher influx values. In this study, the accumulation rate was assumed to be 1 cm/year for all of Fäjemyr sites and this is probably not a realistic assumption. The low bulk density in site 5a corresponds with low influx values, but the bulk density is not remarkably higher in site 1b, with high influx values, compared to the rest of the sites at Fäjemyr. The accumulation rate could be of importance at some sites, but may not be the only explanation. The differences in bulk density also reflect the compression during sampling, and that differs between different sampling sites. The low number of pollen present in the samples taken inside the *Pinus* forest (site 5) at Fäjemyr could be due to differences in moss growth. Moss growth differs depending on the *Sphagnum* species and the climate at the site. If the accumulation rate was higher than 1 cm/y, the amount of pollen would be less than for sites where accumulation rate is lower.

The generally low *Pinus* pollen percentages and influx values for site 5, which is situated within a dense pine forest, are at first hand unexpected but may be explained by specific pollen production and dispersal conditions. Most of the tree pollen at Fäjemyr is regional, as suggested by the data for *Pinus* and *Betula* (Appendix 1). The regional pollen falling into the forest could be trapped in the canopy preventing the pollen to fall down to the ground. Some of these could later fall down to the ground during rainfall, or alternatively, they could be taken by the wind once more and be transported away from the site. The tall trees inside the forest most likely produce a lot of pollen, but this pollen is probably mainly produced in the upper part

of the canopy and is therefore dispersed away from the forest by wind and become a part of the “regional pollen cloud”. How far away the pollen is transported depends on the wind velocity and fall speed. The fall speed differs between taxa, *Pinus* pollen falls with 0.031 m/s and *Betula* falls with 0.024 m/s (Theuerkauf et al. 2012). A low fall speed enables pollen grains to be transported further than pollen grains with higher fall speed which fall closer to the source. *Pinus* pollen have air-sacks making them more suitable to fly further with the wind, even if they are larger (and therefore heavier) than other pollen. The most common tree pollen found at Fäjemyr show different fall speeds of which the slowest one is *Alnus* (0.021 m/s) and the fastest one is *Fagus* (0.056 m/s) (Theuerkauf et al. 2012).

Another possible explanation for low pollen deposition inside the forest at Fäjemyr is that, when one accepts that most of the pollen from the taller pine trees dispersed away from the site by wind, the smaller trees inside the forest would be the ones providing pollen inside the forest. These smaller trees are growing in the shadow of the tall trees which might result in lower pollen productivity. The smaller trees inside the forest are about the same height as the *Pinus* and *Betula* trees out on the bog, but the trees growing on the more central (and wetter bog area) are likely to grow much slower or produce few pollen because of unsuitable growing conditions there. The *Pinus* and *Betula* growing within the forest have probably better growing conditions compared to the trees out on the open bog. *Pinus* and *Betula* inside the forest could therefore be younger than the trees out on the bog even if they are about the same height. Theuerkauf et al. (2012) suggest that *Pinus* starts to flower at an age of 30 years and *Betula* starts to flower after 20 years. It could therefore be that a large part of the small trees growing inside the forest are too young to flower. Moreover, according to Broström et al. (2008), it is well established that many species flower less inside a dense forest than in an open area.

According to Hicks and Hyvärinen (1999), at least for arboreal taxa, the pollen influx value is usually higher inside a small forest hollow than in the centre of an extensive mire.

The reason for this has to do with the distance from the source point of deposition, where pollen from an individual tree is deposited close to the source. This is not consistent with data for Fäjemyr or Store Mosse, which shows that pollen deposition can differ markedly between sites. According to Table 1 from Hicks and Hyvärinen (1999), all sites at Fäjemyr should be inside “dense forest”, both for *Pinus* and *Betula*. Our results strengthen the idea that conditions for pollen dispersal are very site specific, and that Fäjemyr has not the same growing conditions as the site in Finland (where Hicks & Hyvärinen carried out their study). It is also possible that samples from a small forest hollow are not comparable with data from a bog. A forest hollow probably forms a small opening in the forest, allowing pollen from nearby trees to disperse and be deposited there.

The highest influx values were found out on the bog (site 1 and 2, see Figure 8). In an open area, more well-mixed and wind-transported pollen is being deposited, and this regional wind-dispersed pollen might be more important in the pollen record than local pollen. Site 1b had the highest influx values of all Fäjemyr surface samples, and a probable suggestion might be that the moss sample had a lower accumulation rate. Therefore the pollen at site 1b had been deposited over a longer time span. Site 1b was the only site where *Calluna vulgaris* vegetation percentage coverage and influx value did not correspond. The influx values were anomalously high compared to the other sites relative to the vegetation percentage coverage, strengthening the hypothesis that the moss sample at site 1b collected pollen over a longer time span than the other sites. Store Mosse had a more decomposed surface peat than Fäjemyr and generally higher influx values (Figure 12). Since the core was taken from the centre of a large bog with no trees present locally, almost all of the tree pollen is regional. *Picea* has a higher influx value than in Fäjemyr and that may be explained by more *Picea* in the surrounding forest. Svensson (1988) also found a large contribution of *Picea* in the upper part of the core from Store Mosse with a pollen percentage of about 10 %. Store Mosse had a more reliable accumulation rate (0.44 cm/

y) than Fäjemyr (all sites assumed to be 1 cm/y). Since the accumulation rate was less accurate and most likely variable at Fäjemyr, it is not straightforward to use Store Mosse as a reference site to Fäjemyr. The *Pinus* influx value is higher in Store Mosse than in Fäjemyr, except for site 1b (probably because of the accumulation). Store Mosse shows that it is possible to get a very high *Pinus* pollen influx value from the regional pollen deposition only, since no *Pinus* grow in the centre of the bog. There are probably more *Pinus* trees in the surrounding area of Store Mosse than in Fäjemyr and that explains the higher influx values for *Pinus* in Store Mosse. Fäjemyr has a more open landscape in the surroundings.

Cyperaceae is a relatively common taxon found on bogs. Therefore *Cyperaceae* pollen should be quite common in the pollen records from the sites. Almost no *Cyperaceae* were found in surface samples or pollen sequences of Fäjemyr, Stass Mosse or Store Mosse, as seen in Figures 12-15. At Fäjemyr, one sample at a *Cyperaceae* plant was taken and analysed. Even then, the *Cyperaceae* pollen found were few and damaged, like the rest of the *Cyperaceae* pollen found from Stass Mosse and Fäjemyr. The most probable explanation is that the pollen production of *Cyperaceae* is low, for example for *Eriophorum vaginatum*. According to Broström et al. (2008), *Cyperaceae* has a quite low pollen productivity of 1.0 (the same as *Poaceae*). Gaillard (1984) did a pollen analysis on a large lake (Krageholmssjön) in southern Scania, and there the *Cyperaceae* pollen percentage was about 5 % in the top part of the sequence. The pollen percentage of *Cyperaceae* in the Store Mosse study by Svensson (1988) is around 5% in the top most part. This shows that *Cyperaceae* pollen does not need to be abundant in a peat sequence, even when *Cyperaceae* are known to grow at the site.

5.2 Stass Mosse

The *Pinus* pollen percentages show about the same pattern in Stass Mosse as in the pollen diagram from Krageholmssjön, southern Sweden (Gaillard 1984), even if the *Pinus* pollen percentages are slightly higher in the study by Gaillard (1984). *Alnus* is slightly higher in pollen percentages in Stass Mosse, and so is *Corylus*. The differences must be because of differences in the local environment. Krageholmssjön is a large lake receiving mainly regional pollen. Also the geology at Krageholmssjön is different, affecting the forest cover. *Pinus* pollen can be wind-transported quite far, especially in the open landscapes in the southwest of Scania according to Björse (1995). The regional *Pinus* pollen is therefore well-mixed and can originate far

away.

Corylus is typically not present on or near a bog. Even so, *Corylus* was almost constantly the most abundant taxon in the pollen record from Stass Mosse, sometimes up to 50 % of the pollen (Figures 13-15). *Corylus* is favoured by warm, light and dry conditions compared to most other tree species (Tinner & Lotter 2001). Theuerkauf et al. (2012) found a lot of *Corylus* pollen in their pollen analysis from Switzerland and southern Germany, but few *Corylus* trees in the area according to air photo analysis used to estimate the number of *Corylus* trees. Even if *Corylus* was less than 1 % of the coverage of the total forest area, the pollen percentage could be up to 12 %. This might be because *Corylus* is not an economic valuable tree, excluding it from the forest inventory. This is not the case here, but it shows that there can be a lot of *Corylus* pollen in a pollen record, even if the number of trees in vegetation is low. PPE in southern Sweden for *Corylus* is according to Broström et al. (2008) 1.4, which is quite low, for example compared to *Pinus* with a PPE of 5.7 in southern Sweden. Gaillard (1984) has done a pollen analysis at Krageholmssjön, southern Scania, and the percentage of *Corylus* pollen is about 20-30 % during the same time period as the one covered by this study at Stass Mosse (5800-3400 cal BP). Berglund et al. (2006) claim that during the period of 5800-3400 cal yr BP *Corylus* was a common tree species in Scania. *Corylus* was favoured by the openness of the forest with lighter conditions caused by human activities as humans started to cut the forest down to obtain grounds for agriculture (Berglund et al. 2006).

The highly variable pattern in pollen influx values in the high-resolution part of CS (Figure 13) indicates that pollen productivity does change even on short time scales. The macrofossil analysis done by Adamsson (2013) suggests that *Pinus* trees were present locally on the bog during the whole high-resolution interval (Figure 17), and probably before and after as well. These local pines could have contributed to increased *Pinus* pollen influx. Barnekow et al. (2007) suggest that a high-resolution pollen sequence will not reflect the vegetation composition, but rather temperature-related pollen productivity. Therefore, the fluctuations seen in the high-resolution interval are unlikely to reflect increases or decreases in vegetation composition, but changes in pollen productivity due to changes in climate. In addition, the pollen data may also be related to changes in peat decomposition (and therefore one cm in the peat sequence would not cover the same time period throughout the sequence), if all taxa vary together in influx values between samples.

The highest pollen influx peak of most taxa

within the high-resolution interval is seen at 310–311 cm (Figure 13). This could reflect more strongly decomposed peat, or a lower accumulation rate for peat resulting in more pollen per depth increment at this level. However, since all taxa show an increase in influx values, the reason for the increase is most likely that the peat decomposition has changed. Changes in peat decomposition would affect all taxa. Pollen productivity does not necessarily vary in the same way for all taxa in response to climate. It could also be a combination of higher pollen productivity and lower accumulation rate. The climate conditions could have become warmer, resulting in an increase in pollen productivity and at the same time promoting decomposition of peat as an effect of drier bog-surface conditions. The local taxa (*Calluna vulgaris* and *Ericaceae undiff.*) increase as well, so the increase in influx values partly depends upon higher peat decomposition. Interestingly, an increase of *Pinus* macrofossils occurs at the same level (Figure 17). This may reflect selective preservation of these tissues and further support relatively strong peat decomposition as the determining factor for the generally high pollen influx values at 310–311 cm.

All taxa except *Pinus* increase in influx values at 317 cm (Figure 13). Therefore increased decomposition is probably not a valid explanation here. On the other hand, if the climate got warmer and drier, it obviously favoured all tree species in the surroundings except *Pinus*. However, *Pinus* was also present on the bog during this time according to the macrofossil data (Adamsson 2013; Figure 17), and the pollen contribution of local *Pinus* pollen was therefore probably greater than at Fäjemyr (at present). This hypothesis is supported by the fact that the percentage and influx values of *Pinus* were much higher in Fäjemyr than in Stass Mosse. Much of the *Pinus* pollen at Fäjemyr was regional pollen and came from the surroundings, as suggested by the low R^2 -values for *Pinus* in Appendix 1. If Stass Mosse had the same amount of regional pollen as Fäjemyr, there should not be a major difference between Fäjemyr and Stass Mosse in *Pinus* pollen influx values and percentages. The reason is that most of the tree pollen at Fäjemyr

was regional and well-mixed in the atmosphere. Pollen influx values at Stass Mosse are therefore likely to have a larger contribution of local (on the bog) *Pinus* pollen. One thing that contradicts this hypothesis about the *Pinus* pollen increase at 317 cm is that local taxa (*Calluna vulgaris* and *Ericaceae undiff.*) increase in influx values dramatically at 317 cm. This would indicate an effect of the bog surface getting drier. The most probable explanation is that *Pinus* growing on the bog had its roots further down in the bog than surface vegetation. Therefore, a few drier years would not affect the *Pinus* growing on the bog, while it would affect shrubs or herbs such as *Calluna vulgaris* and *Ericaceae undiff.* as the bog surface experienced a drier environment. The strong increases in influx values for *Betula* and *Alnus* at 317 cm are probably because of changes in pollen productivity that can change a lot from one year to another.

The changes in the sequences in influx values could be due to temporary favoured or disfavoured changes in bog-surface wetness, caused by climate, making the bog surface drier or wetter. The bog-surface wetness does not change on an annual basis, but on a decal-millennial scale (Charman 2002). Because of changes in climate the decomposition rate and accumulation rate will change as well, making it harder to know how many years of pollen deposition there are in one cm of peat. The gradual changes in influx values present in the sequence are probable due to changes in pollen productivity or peat accumulation rate rather than due to the presence or absence of local trees. The trees are still locally present on the bog when the influx value decreases, but worse conditions in the environment (wetter or colder) makes the pollen production to go down or the decomposition rate to change.

The macrofossils show that *Pinus* were most likely present on Stass Mosse more or less the whole time represented by the CS (Adamsson 2013; Figure 17). However, based on the pollen influx data of Hicks & Hyvärinen (1999), Table 1, *Pinus* was present but only sparsely or not present at Stass Mosse. The same applies to *Betula*. The reason for this discrepancy is probably that the different sites cannot be directly com-

pared and Hicks & Hyvärinen did not collect samples from a bog. The increase in pollen influx values at 330 cm (Figure 14) probably represents the onset of the peak seen in the high resolution sequence, culminating at 310-311 cm (Figure 14). Since all the influx values increase compared to before it is likely that the decomposition increased.

The TS (0-30 cm) had *Pinus* macrofossils through the whole sequence (Figure 18). Roots grow down into the peat and therefore the peat surrounding the root is older than the root itself. The fact that a *Pinus* tree started to grow at this level indicates that it was dry enough (warm enough) for *Pinus* to grow on the bog. The increase in influx values at the surface (0 cm) (Figure 15) could be due to higher peat decomposition after the peat cutting that ended during the 1960's. Stronger decomposition would make the pollen influxes increase. Most taxa increase in influx values over the whole sequence, but some taxa have a decrease in influx values at 10 cm. It is mainly pollen from trees not growing on the bog that decreases, suggesting a pollen productivity signal related to regional

climate change. The local pollen have an increase in influx values over time, indicating a progressively drier bog surface and therefore higher pollen productivity for the local taxa or slower accumulation due to drier conditions. This supports that *Pinus* started to grow on the bog as a response to a gradual decrease in bog-surface wetness. When comparing the data in Table 1 to our pollen data, the influx values in Table 1 indicate that *Pinus* was not present within the close surroundings. That is disproved by the tree stumps so the pollen influx data of Hicks & Hyvärinen (1999) are clearly not directly applicable to the TS record. The Hicks & Hyvärinen (1999) influx data are not directly applicable for *Betula* either; according to Table 1 *Betula* should have been present within 1 km radius, but not in the close surroundings of the bog.

By combining macrofossil and pollen analyse, it is possible to distinguish between regional and local vegetation changes, as well as provide higher taxonomic precision than is possible with pollen data alone. Combining the two methods also makes it possible to detect taxa that were not found in one of the

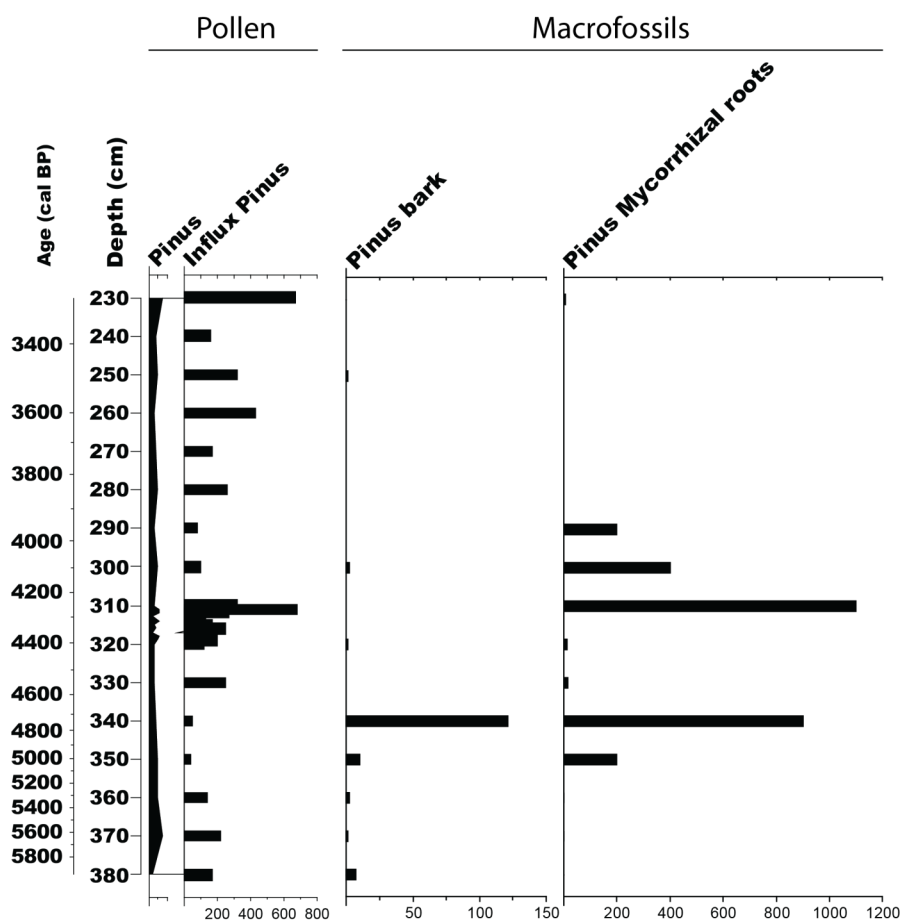


Figure 17. The *Pinus* macrofossils (bark and Mycorrhizal roots) for the CS from Stass Mosse combined with pollen percentage and influx for *Pinus*. Macrofossil data modified from Adamsson (2013).

analyse (Charman 2002). Adamsson (2013) got peaks in *Pinus* macrofossils at 290, 300, 310, 340 and 350 cm, with the largest peaks at 310 and 340 cm with *Pinus* periderm and *Pinus* Mycorrhizal roots (Figure 17). The peak at 310 cm in the pollen diagram is the largest peak in the high-resolution sequence, and the increase can be seen both in macrofossils and pollen. That strengthens that better growing conditions occurred at this time. At 340 cm, a high number of pine macrofossils were found by Adamsson (2013) but in the *Pinus* pollen record no increase in influx values is found. However, a small peak in influx values occurs at 330 cm. One possibility is that *Pinus* trees were present before the peak at 330 cm, and can therefore be found in the macrofossil record. But either it was too young trees to flower (Theuerkauf et al. 2012) until the peak at 330 cm, or the pollen productivity was lower at 340 cm because of less favourable climatic conditions. It could also be that the

roots are from a tree growing higher up or later, as discussed for the TS. Finding macrofossils before increases in the pollen record is a quite common phenomenon (Seppä 2007). Individuals of a species are then likely to have occurred at the site at the time of the recorded macrofossils during conditions limiting its population growth and pollen productivity, until external changes (for example climate) occurred (Seppä 2007).

In TS Adamsson (2013) found the largest number of *Pinus* Mycorrhizal roots at 20 cm, and *Pinus* periderm was most common at 30-20 cm in the macrofossil record. In the pollen record the highest influx value for *Pinus* was at 0 cm, and almost as high at 20 cm, with lower influx values at 10 and 30 cm. The lowest pollen influx value at 30 cm occurs at the same time as the largest peak in *Pinus* periderm, but for the rest of the records macrofossil and pollen data correspond fairly well. The reason for the observed differences is possibly that the macrofossils consist

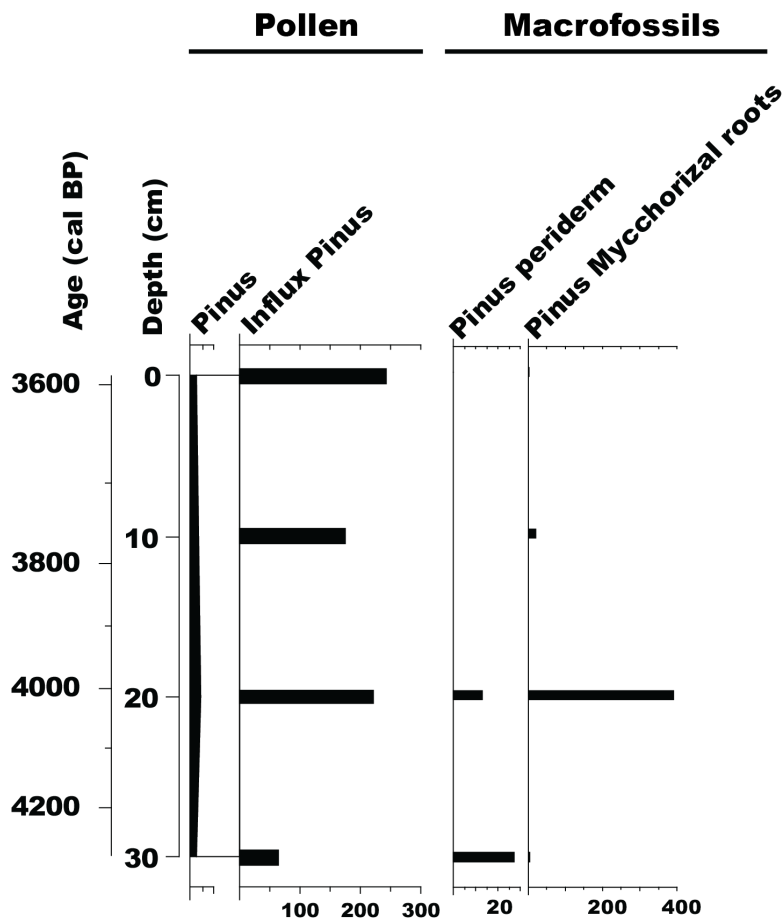


Figure 18. The *Pinus* macrofossils (bark and Mycorrhizal roots) for the TS from Stass Mosse combined with pollen percentage and influx for *Pinus*. Macrofossil data modified from Adamsson (2013).

mainly of root materials that are likely to become incorporated at some depth below the peat surface where the trees grow and the pollen are deposited.

5.3 Fäjemyr, Stass Mosse and Store Mosse combined

The total influx values seen in all three sites indicate changes in both accumulation rate and/or climate factors. For the CS with high resolution and TS (Figure 14-15) the increases in total influx values occur at the same time as the accumulation rate is high, as reflected by the age scales in the diagrams, and the opposite for low total influx values. The total influx values are also dependent on other things, for example pollen productivity.

The pollen data from Fäjemyr, Stass Mosse and Store Mosse all help to illustrate the changes in vegetation and changes in climate that affect pollen productivity that have occurred during the last 5800 years BP until present day. Comparing the pollen influx data from Stass Mosse and Fäjemyr is difficult since the accumulation rate of the *Sphagnum* moss samples from Fäjemyr is uncertain and the accumulation rates in Stass Mosse are based on an age-model with only a few radiocarbon dates. The uncertain accumulation rates will have effects on the pollen influx values, since the influx is calculated from the accumulation rate. Moreover, the low pollen influx values as found for the samples taken within the dense *Pinus* forest (site 5) at Fäjemyr may not be caused by the same processes as low influx values in parts of the Stass Mosse record. Even so, a large part of the changes in influx values are probably due to changes in pollen productivity caused by changing climate conditions. Colder or wetter climate may decrease the pollen productivity both at Fäjemyr and Stass Mosse. It is still difficult to know if the decline was caused by changes in climate or if it had other causes. For example the lower influx value of site 5 at Fäjemyr could be due to the pollen produced by higher trees and being wind-transported away from the site or that some of the regional pollen were trapped by the canopy. It is also shown that Stass Mosse had a higher amount of locally produced pollen (*Pinus*) than Fäjemyr, and the trees at the bogs do not grow high due to unfavourable growing conditions. The Store Mosse sample has a more certain accumulation rate but comes from a different region. The peatland is also very large compared to Stass Mosse and Fäjemyr and has a low amount of local tree pollen. The main contribution of the Store Mosse data in this thesis is to show that regional pollen deposition can be very dominant.

6 Conclusions

No consistent pattern could be observed between the number of local *Pinus* trees and *Pinus* pollen percentage or influx values in surface samples from sites located at different distances from the dense pine forest present at the edge of Fäjemyr. This is mainly because the tree pollen is dominantly regional and well-mixed in the atmosphere before falling to the ground. Different composition of the vegetation cover at the sites in Fäjemyr did not influence the *Pinus* pollen percentage or influx value. The differences in influx values between the a and b sites are probably due to differences in moss growth. The results show that it is not possible to interpret the local presence of *Pinus* on a bog only based on pollen data. At Stass Mosse, the *Pinus* trees were probably present on the bog within the CS or in the close surroundings, based both on the macrofossil data and pollen analysis. The pollen percentages and influx values change over time, and the changes are probably caused by changes in peat accumulation or pollen productivity (related to climate conditions). There are usually peaks in pollen percentage and influx values at the same levels as peaks in the macrofossils.

7 Acknowledgements

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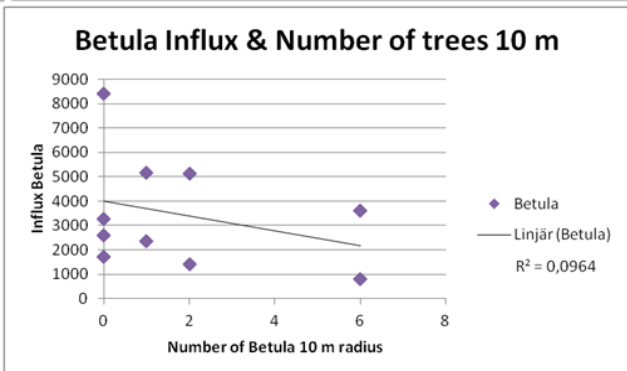
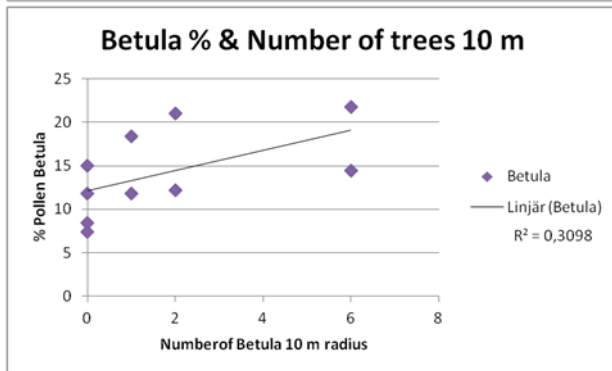
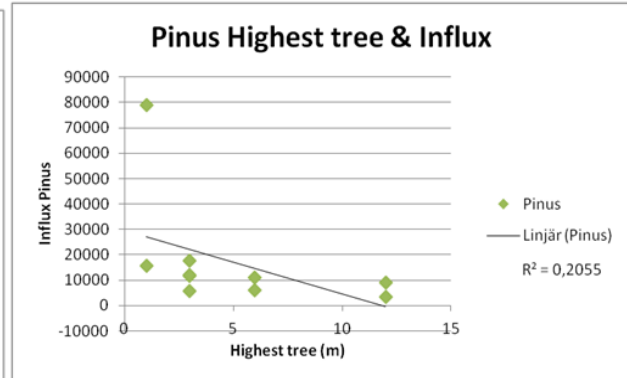
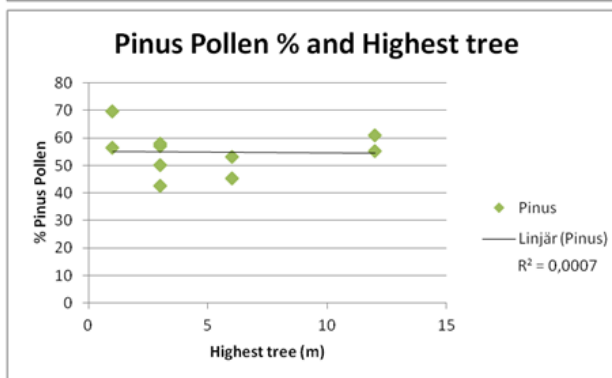
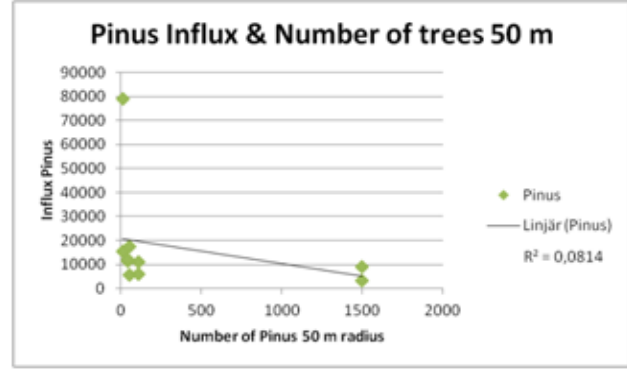
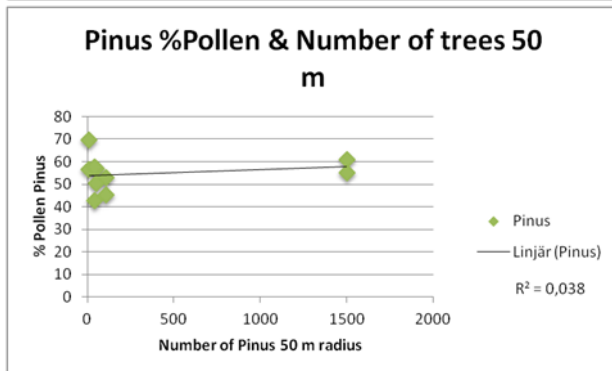
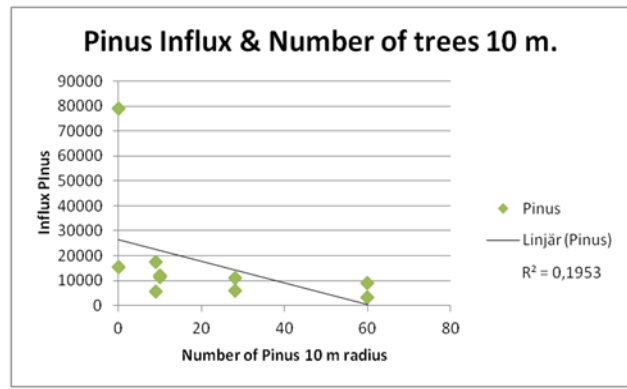
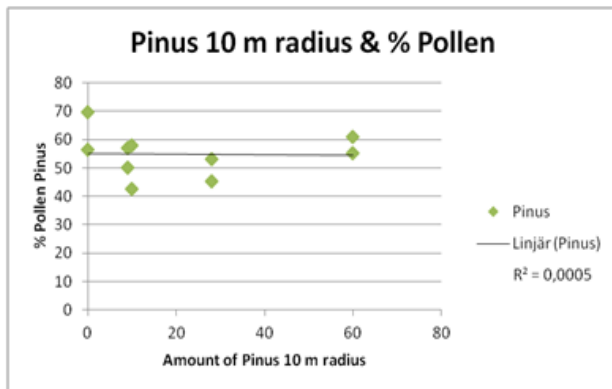
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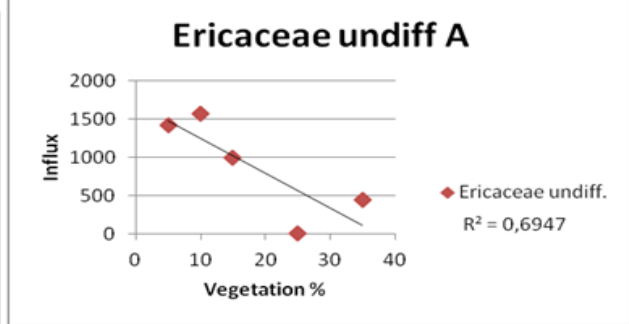
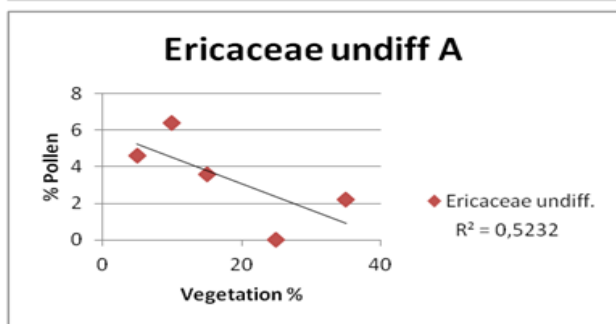
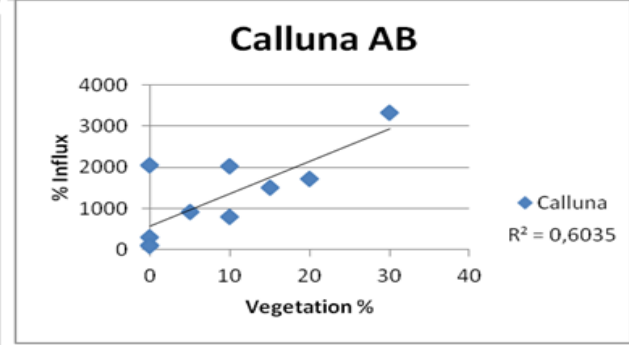
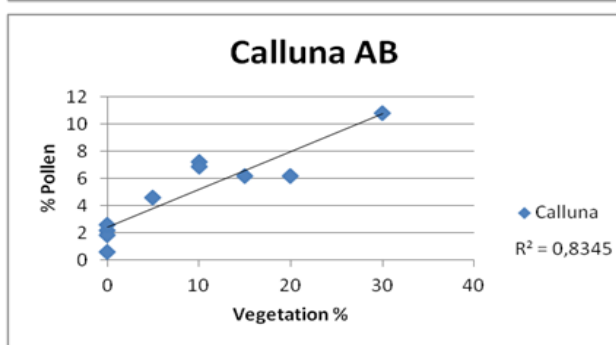
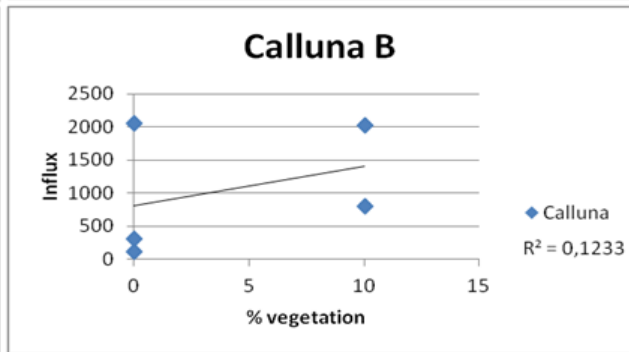
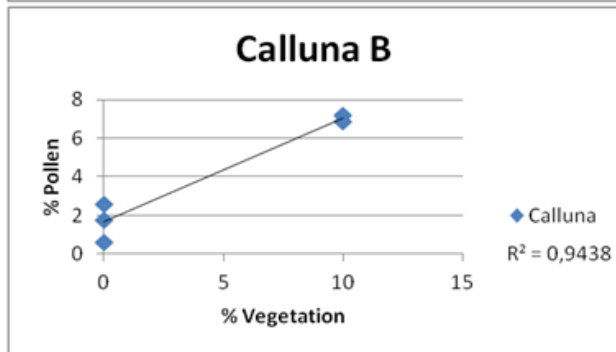
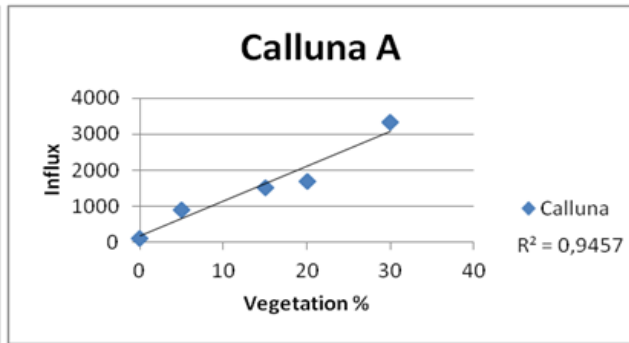
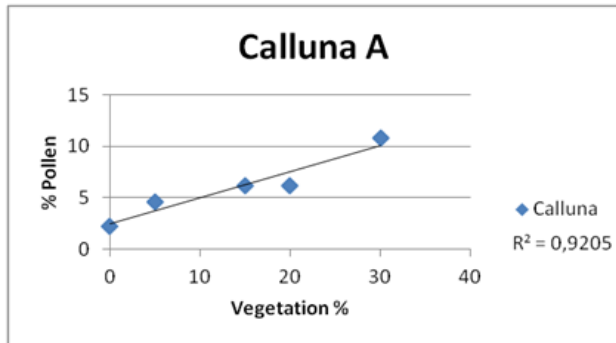
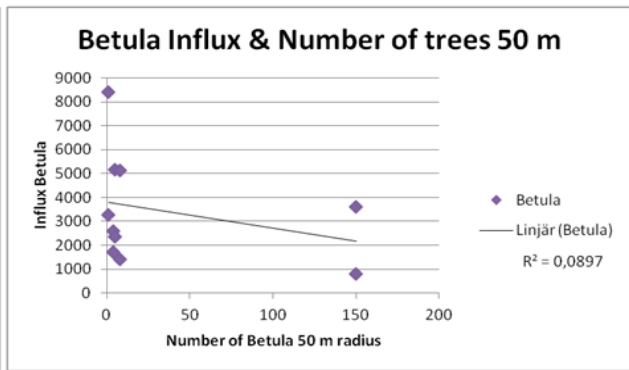
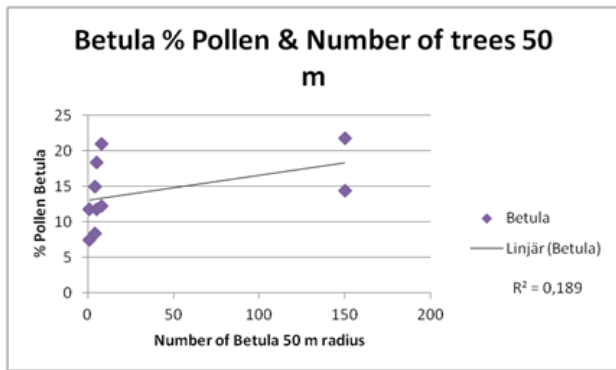
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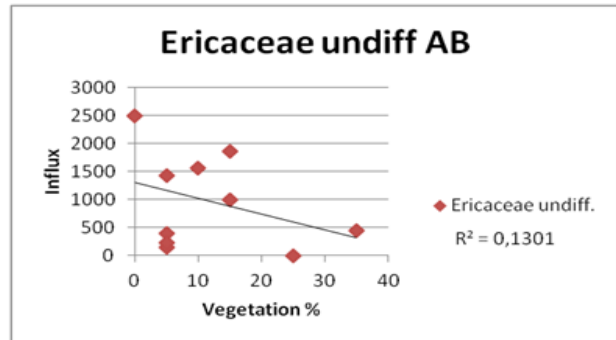
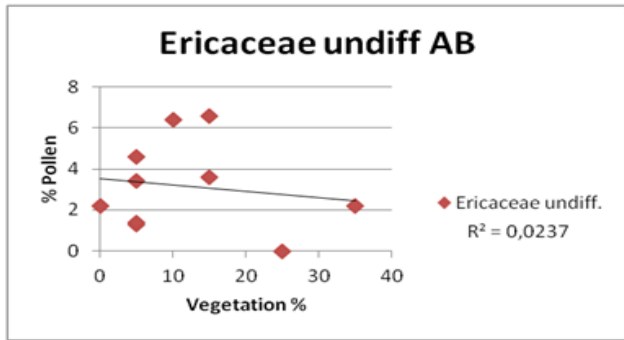
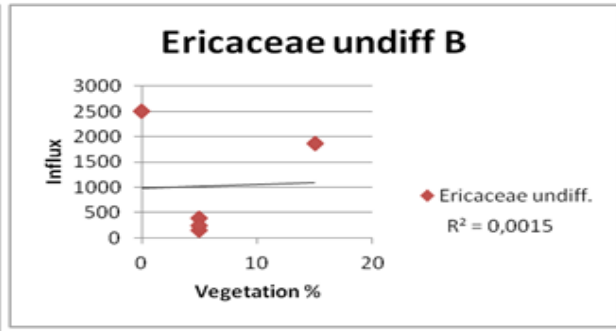
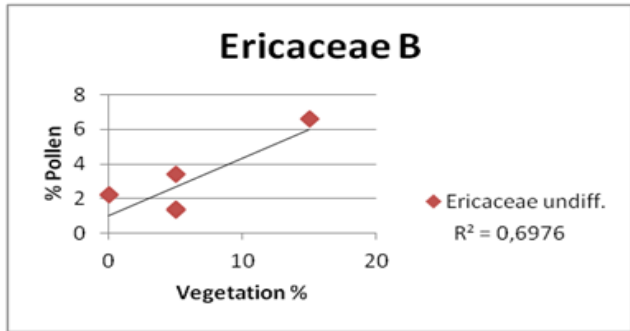
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