Bachelor Thesis

Stockholm University

Degree Project in Marine Geology 15 hp

Dust record from Gällsereds Mosse ("Gällsered's Bog"), Halland, Southwestern Sweden

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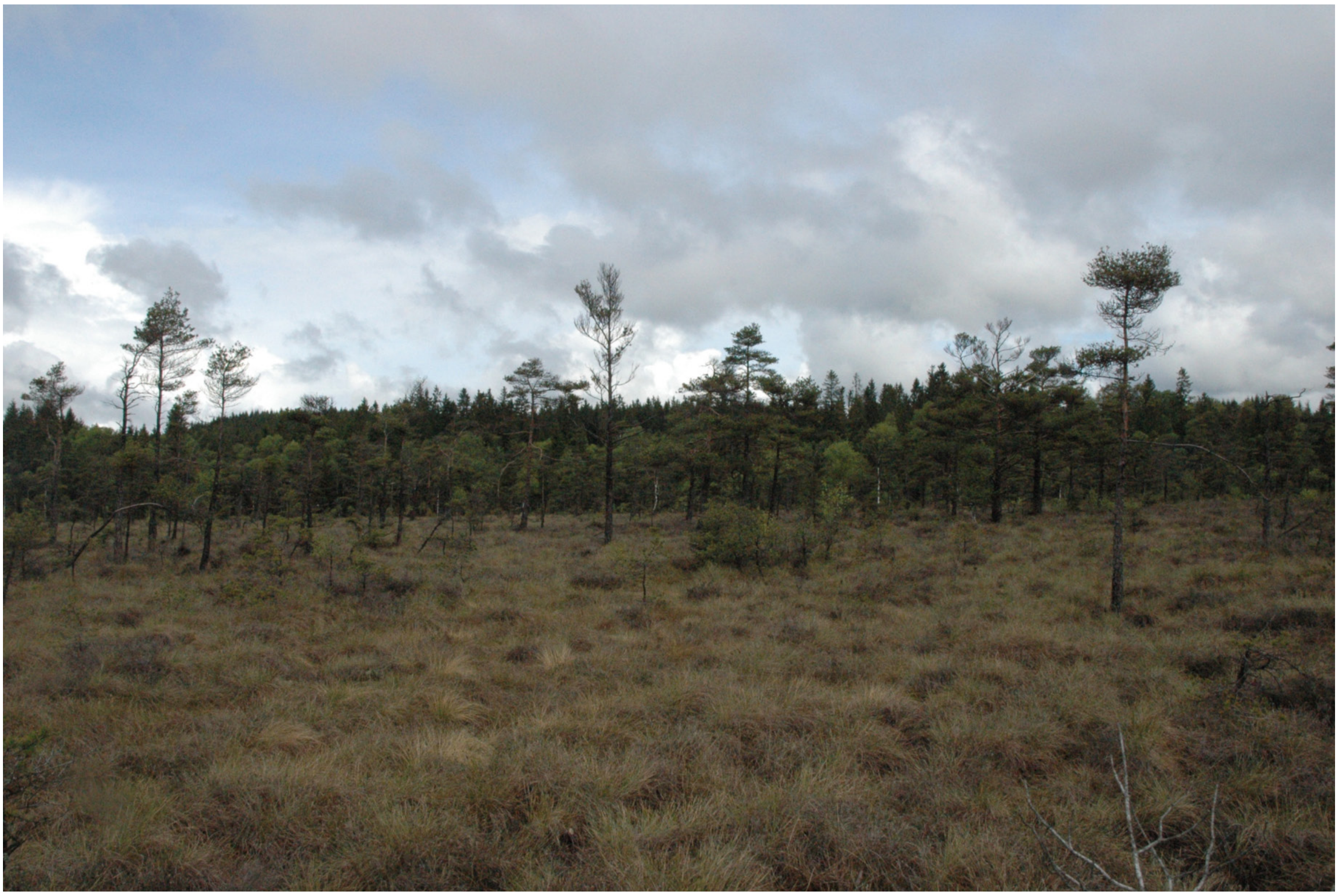

Stockholm 2020

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Abstract

Atmospheric dust is important not only as an acting force behind climate change, but also as an indicator of past climate. Dust records are valuable for understanding past climate but are not always readily available. Ombrotrophic peat bogs are an excellent source of dust records, due to the input being atmospheric alone, and the fact that the high organic content makes high resolution age-dating possible. By investigating a record from Gällsereds Mosse for elemental MAR for Al, Si and Ti, six dust events were established and correlated with re-interpreted data from three other ombrotrophic bogs (Davidsmosse, Draftinge Mosse and Gällsereds Mosse). This showed overlapping tendencies at several times, pointing to regional factors as driving force. Some of these increased values could be linked to previous studies on Holocene climate in Sweden. Investigations including more elemental MAR would possibly lead to more precise results and make it easier to determine a possible source material for the dust input.

Keywords

Atmospheric dust, paleodust records, ombrotrophic peat bogs, peatlands, Holocene, climate

Contents

Introduction

Atmospheric mineral dusts have a long history of piquing the interest of the scientific community, with the first records dating back to the 16th century (Marx et al., 2018) and they remain a widely researched subject still today. Increased atmospheric dust can be connected to climate in several ways. It can act as a driving factor when it comes to climate change, as atmospheric dust impacts incoming radiation through scattering, influences cloud formation and precipitation and can play part in atmospheric chemistry (Albani et al., 2015; Maher et al., 2010). Atmospheric dusts can also be a result of changing climate conditions, as research has shown that it has been much dustier during glacial periods, when the climate has been drier and the hydrological cycle has been operating on a smaller scale (Kylander et al., 2013; Maher et al., 2010).

Reconstructing past changes in deposition (dust deposition rates, source, mineralogy) can be achieved by looking at paleoenvironmental archives. Despite 75 % of dust being deposited on land (Shao et al., 2011), polar ice cores and marine sediments have been most extensively used (Kylander et al., 2016), leaving gaps in our understanding of terrestrial dust dynamics. In order for a given paleoenvironmental archive to provide a useful dust record, it is necessary for the dust signal to be trapped (i.e., not mobile) in the archive matrix. It is then of importance that it is possible to distinguish the paleodust from the matrix and that this signal can be put into a reliable chronological context, in order to get the timing of the changes in dust (Albani et al., 2015). This can be somewhat challenging when it comes to terrestrial dust deposits. Lake deposits are often influenced by additional sedimentary inputs, for example sedimentary loads brought into the lake fluvially; this poses a challenge when it comes to distinguishing the atmospheric dust input from the fluvial sedimentary input. Research has been carried out on loess deposits in several locations. Loess however, serve as both dust source and sink during windier periods and leaching within the profile can move materials around (Maher et al., 2010), which can mean that the records are not very straight forward when it comes to interpretation.

One terrestrial type of paleoenvironmental archive that has shown great potential for paleo dust research are ombrotrophic (rain fed) peat bogs. First of all, since all input comes from the atmosphere, the problem with separating atmospheric dust signals from the matrix is eliminated. The accumulated peat makes for a good matrix where the dust particles become entrapped and also makes it possible to perform carbon age-dating with high accuracy (Albani et al., 2015), making it possible to place the dust inputs chronologically. There is a lot of interest in northern peatlands for several reasons, one of them being that they host one third of the world's soil organic carbon, which make them invaluable both as a carbon sink and great candidates for paleoclimate research as carbon age-dating can be performed with high resolution (Kylander et al., 2018). The development of the northern peatlands is strongly influenced by the climate during Holocene. A variety of Swedish records show that there was a climate optimum occurring ca 7000 to 4000 BP, with climate being hotter and drier. After 4000 BP until present, there has been a gradual shift towards colder and wetter conditions (e.g., Almquist-Jacobson, 1995)

Due to the wet and cold conditions, Småland and Halland in south-central and south-western Sweden are home to many ombrotrophic peatbogs. Four bogs in the region have been sampled and studied for past changes in paleodust. Among the most well researched is Store Mosse (the "Great Bog"), Småland, which is the largest mire complex (77 km^2) in southern Sweden. Research on the development of the peatland system was undertaken by Svensson (1988), giving insight into the fen-bog transition conditions across the complex. Since then, several studies have been carried out, looking further into, amongst other things, the geochemistry of the dust input (e.g. Kylander et al., 2013). These have shown that elements such as Al, Si, K, Ti, Rb, Zr, U, Th, Sc, Y and the REE are hosted in conservative minerals within the peat matrix which do not move around in the profile, making them reliable indicators of dust events. Other elements such as Ca, Mn and Fe, however, are shown to be more mobile in the profile due to their redox sensitivity and their function as nutrients. Bulk density proved to be a good indicator of local hydrological conditions (wet/dry), as the plant detritus will be more decomposed during dry conditions, causing bulk density to increase (Kylander et al., 2013). Previous work at Store Mosse has identified three periods of increased dust deposition: 1) 6385 to 5300 BP, 2) 2380 to 2200 BP and 3) 1275 to 1080 BP (Kylander et al., 2016). These events were identified using Principal Component Analysis (PCA) so is based on the combined signal of some twenty elements associated with the first principal component. Draftinge Mosse (the "Draftinge Bog"), which is a smaller bog system ca 16 km to the southwest of Store Mosse, has also been researched with regards to atmospheric dust input and four dust events were identified: 1) 2800 to 2300 BP, 2) 2200 to 1600 BP, 3)1550 to 1100 BP and 4) 750 BP (Sjöström, 2018). Davidsmosse ("David's Bog") located further to the west and nearer the coast records six periods of increased dust influx: 1) 4400 to 4200 BP, 2) 3600 to 3300 BP, 3) 3200 to 3100 BP, 4) 2900 BP, 5) 2400 to 2200 BP, 6) 1500 to 1240 BP (Virolainen, 2016). Gällsereds Mosse ("Gällsered's Bog), which is located further to the west in relation to the three above-mentioned bogs has also been analysed but the data has not yet been interpreted. Importantly, no comparison between the four regionally relevant records have been made. A regional comparison would give more information about the climate changes at the time. If a dust change is mirrored at other sites, it is a stronger indicator of climate conditions than a record from a single location, as the latter would rather point to changes in local conditions, rather than climate.

Aims and objectives

The aim of this project is to compare and contrast changes in mineral dust deposition in Halland and Småland, using records from four sites, the oldest dating back 9000 years. This will be achieved by using previously collected, but not yet interpreted data, to reconstruct past mineral dust deposition at Gällsereds Mosse, focussing on conservative lithogenic elements (Al, Si and Ti) concentrations, peat accumulation rate (PAR) and bulk density data. Comparison will be made by re-interpretation of elemental MAR data from Store Mosse, Davidsmosse and Draftinge Mosse, and comparing the changes that occur above the fen-bog boundary at the four sites. The objectives are: (i) to compile a dust record for Gällsereds Mosse and defining periods of increased dust input; (ii) to establish periods of similarities and differences in elemental MAR across the four sites; (iii) to put the common trends in dust deposition across the four sites into context of previously proven Holocene climate fluctuations.

Methods and Materials

Gällsereds Mosse

The data used for this study was previously obtain through work and analysis by several different people (table 1).

Table 1. Table showing the previous work that had been done one the samples before this study and the people that performed each step.

Previous work performed on the cores	
Sampling and field work	Dr. Malin Kylander, Prof. Richard Bindler, Prof. Antonio Martínez Coritzas and Dr. Sophia Hansson
Subsampling and freeze drying	Dr. Sophia Hansson
XRF Analyses	Jenny Sjöström and Dr. Johan Rydberg
^{14}C-dating and age-depth modelling	Jenny Sjöström

Below follows a section detailing further the methods used to obtain the data from Gällsereds Mosse that were used in this study.

Site Description

Gällsereds Mosse (figure 1) is located in the South-Western part of Sweden, close to the coast in Halland. It is a rather small (approx. 300×400 m), dome shaped ombrotrophic peat bog located at around 101 meters above sea level. The average annual temperature is 7.5°C and the average annual precipitation is ca 1250 mm/year (SMHI, 2020). The underlying bedrock is gneiss (Lundqvist et al., 2008).

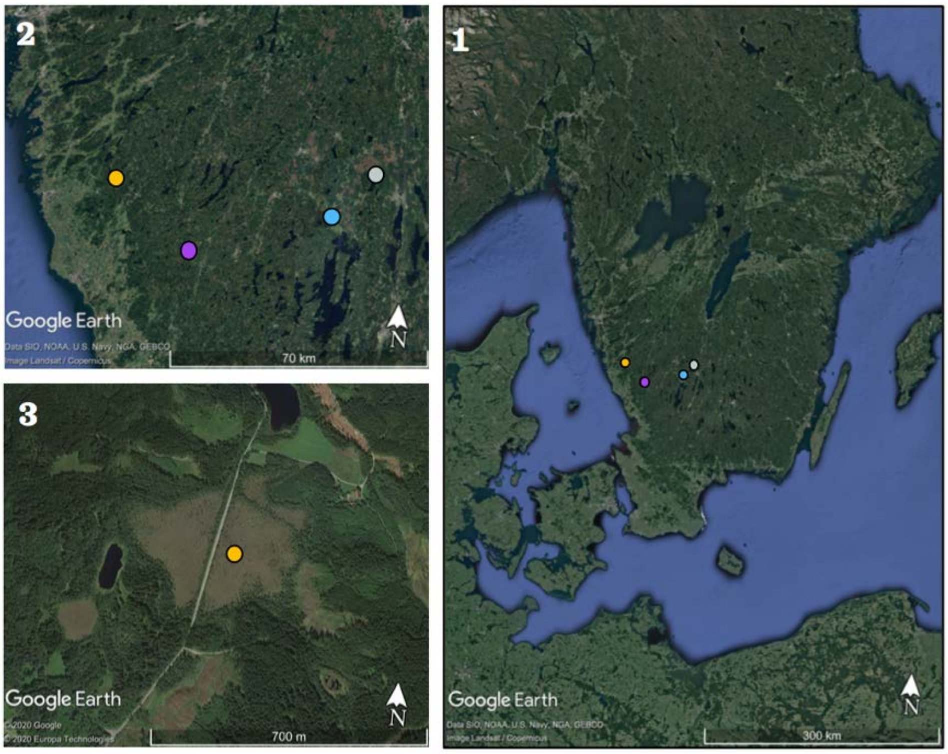

Figure 1. Image of Gällsereds Mosse in relation to the other three bogs examined in this report. The image to the right shows the four bogs in the context of Southern Sweden, image number two in the upper left corner shows a more zoomed in image of the bogs' locations in relation to one another. From left to right: Gällsereds Mosse (orange), Davidsmosse (purple), Draftinge Mosse (blue) and Store Mosse (grey). Image 3 in the bottom left corner show Gällsereds Mosse with approximate location for the coring site marked by the orange dot.

Sampling, Bulk Density and Core Alignment

The cores used for this study were recovered from the central dome of Gällsereds Mosse, 57º10'29"N, 12º35'51"E, in May 2014. A Russian corer with a 1 m long and 7.5 cm diameter barrel was used. Two adjacent parallel holes generated seven 1 m sections with 25 cm overlap. The cores were frozen and sub-sampled into contiguous 1 cm slices with a stainless-steel saw. The slices were then freeze-dried. By dividing the weight of each individual sample with its estimated volume, bulk density was calculated (g/cm^3). The overlapping cores were aligned using changes in bulk density for a composite sequence depth of 550 cm. A plant mill with Teflon vials and agate milling balls were used to mill samples where required.

Age Dating and PAR

Age dating using ^{14}C on plant macrofossils were performed at the Tandem Laboratory, Uppsala University (Ua) (table 2). A total of 4 dates where calculated. The CLAM program (v. 2.2) (Blaauw, 2010) was used to obtain the age-depth model. Calibration of the ^{14}C dates where included using IntCal13.14.C calibration curve (Reimer et al., 2013). There were no statistical outliers and the best fit was obtained using a smooth spline. Using bulk density (g/cm^3) and accumulation rate (yr/cm) data from the CLAM program, PAR ($g/m^2/yr$) were calculated.

Table 2. The sample depth, laboratory no., calculated ^{14}C yr and calibrated age range for the 4 dates calculated at the Tandem Laboratory, Uppsala University.

Sample Depth (cm)	*Laboratory no.*	*14C yr ± 1SD*	*Calibrated Age Range*
76	Ua-52051	1023 ± 31	905-984
295	Ua-52052	2543 ± 84	2361-2774
383	Ua-52053	3772 ± 60	3967-4300
546	Ua-52054	6655 ± 63	7430-7621

Elemental Concentrations

A Bruker S8-Tiger wavelength dispersive X-ray fluorescence spectrometer (WD-XRF) at the Department of Ecology and Environmental Sciences, Umeå University was used to analyse bulk peat samples for total elemental concentrations at 6-cm resolution. A calibration method (Rydberg, 2014) modified for peat and plant samples (Hansson et al., 2013) was used to measure elemental concentrations on 500 mg dried and milled peat samples. Precision and accuracy were assessed using an internal low-ash peat standard (n=6). Expressed as the relative derivation from certified values, accuracy was 10% or better except for Si, which was at 14%. Precision, which was calculated as one relative standard deviation was generally 10% or better. To obtain the elemental MAR ($mg/m^2/yr$), the elemental concentrations were multiplied by the PAR and then divided by 1000.

Interpretation of Data

For Gällsereds Mosse, the mobile element Ca and bulk density were plotted against the age, in order to determine where the fen-bog boundary is. MAR data for Al, Si and Ti were also plotted against the age. With the five graphs next to each other, excursions from background MAR were identified visually and defined as dust events (DE). Since all parameters at Gällsereds Mosse increased sharply at the top of the profile, likely due to anthropogenic activity (i.e., drainage or road building), the top 500 years have not been considered in order to avoid skewing of the data (see Appendix A).

For information on the methods behind the data used from Store Mosse please see (Kylander et al., 2013). Unfortunately for Store Mosse only Al MAR data was available. Silica was lost during sample preparation and the analytical quality of Ti was simply too poor to use (Kylander et al., 2013). For details on data collection from Draftinge Mosse, please see Sjöström (2018) and for previous work and descriptions of methods for Davidsmosse, please see Virolainen (2016) for further information. At both sited Al, Si and Ti Mar data was available and graphs were produced and interpreted in a similar manner as for Gällsereds Mosse. The top 500 years were excluded from all the graphs in order to make comparison possible.

Results

For Gällsereds Mosse, the bulk density and Ca (indicating fen-bog boundary), and elemental MAR are described for the first time and all interpretations are derived from this study alone. For Davidsmosse, Draftinge Mosse and Store Mosse, the fen-bog boundary will be assumed as suggested by previous studies, and focus will be put on the elemental MAR. For all bogs, fluctuations in MAR will only be considered when above the fen-bog boundary.

Gällsereds Mosse

The bulk density at the bottom of the section is around 0.15 g/cm^3, gradually decreasing down to 6500 BP (to ca 0.1 g/cm^3). An increase follows to 0.15 g/cm^3 until ca 5770 BP when there is a sharp drop down to ca 0.8 g/cm^3. The sharp drop is followed by an increase, peaking at ca 0.15 g/cm^3 at ca 5500 BP. A gradual decline follows down to ca 0.05 g/cm^3 around 5000 BP. Bulk density is then increasing again with peaking values above 0.15 g/cm^3 ca 4250 BP. A steep decline to ca 0.05 g/cm^3 occurs around 4000 BP, followed by a gradual increase culminating at ca 0.12 g/cm^3 around 3000-2500 BP. The decline after this is gradual down to ca 1750 BP where the levels reach ca 0.05 g/cm^3. After this point the average levels stay around 0.05 g/cm^3, except for peaks with values around 0.1 g/cm^3 around 1500 BP, and ca 0.14 g/cm^3 around 1200 BP.

Calcium MAR starts at ca 300 mg/m^2/yr about 7500 BP, going down and reaching levels of ca 150 mg/m^2/yr around 7000 BP. This level remains with minor fluctuations until ca 5770 BP where the level drops from around 150 mg/m^2/yr down to ca 90 mg/m^2/yr. This level is then maintained with some fluctuations at ca: 5500 BP, 4500 BP, 3750 BP, 2750-2000 BP, 1500 BP and 1000 BP, where levels are elevated to about 150 mg/m^2/yr.

Starting from ca 5770 BP, Al MAR is maintained at around 10 mg/m^2/yr until ca 5500 BP when levels increase to ca 25 mg/m^2/yr, declining again around 5240 BP back to ca 10 mg/m^2/yr. A change occurs around 4530 BP, when levels increase to ca 25 mg/m^2/yr. The next change is at ca 3255 BP, when the Al MAR goes back to ca 10 mg/m^2/yr. Around 2805 BP the levels go up to ca 50 mg/m^2/yr and goes down to ca 25 mg/m^2/yr around 3502 BP. Ca 2709 BP, the levels go up to about 110 mg/m^2/yr, declining gradually until a sharp drop from ca 60 mg/m^2/yr to ca 25 mg/m^2/yr around 2234 BP. A sharp increase up to ca 90 mg/m^2/yr around 1513 BP is followed by a gradual decline down to ca 60 mg/m^2/yr some 250 yrs later and levels eventually drop around 1239 BP to ca 25 mg/m^2/yr. Around 1022 BP an increase up about 90 mg/m^2/yr occurs before dropping down to ca 25 mg/m^2/yr at about 945 BP.

For Si MAR, the level stays around 40 mg/m^2/yr until ca 5500 BP when it increases to around 60 mg/m^2/yr. It declines again at ca 5240 BP back to about 40 mg/m^2/yr. A change occurs at ca 4530 BP when levels increase to approx. 60 mg/m^2/yr. The next change is around 3255 BP, when the Si MAR goes back to ca 40 mg/m^2/yr. At ca 2805 BP the levels go up to ca 100 mg/m^2/yr, and goes down to ca 60 mg/m^2/yr around 3502 BP. At ca 2709 BP, the levels go up about 250 mg/m^2/yr, increasing to ca 270 mg/m^2/yr some 200 yrs later, followed by a decline to ca 100 mg/m^2/yr another 200 years later, before dropping to ca 60 mg/m^2/yr, around 2234 BP. A sharp increase up to ca 180 mg/m^2/yr, around 1513 BP, is followed by a gradual decline to ca 120 mg/m^2/yr some 200 yrs later, and at ca 1239 BP a decline brings values down to around 60 mg/m^2/yr. At ca 1022 BP an increase up to about 300 mg/m^2/yr occurs before a drop down to ca 25 mg/m^2/yr around 945 BP.

Titanium MAR starts around 1 mg/m^2/yr ca 5770 BP, increasing to ca 2 mg/m^2/yr about 5500 BP. A decline again around 5240 BP takes levels back to ca 1 mg/m^2/yr. A change occurs at ca 4530 BP when levels increase to approx. 2.5 mg/m^2/yr. The next change is around 3255 BP, when the Ti MAR goes back to ca 1 mg/m^2/yr. About 2805 BP the levels go up to ca 4.5 mg/m^2/yr. Around 250 years later the signal goes up to ca 5 mg/m^2/yr, followed by a decline down to ca 2 mg/m^2/yr around 3502 BP. At ca 2709 BP, the levels go up to around 9 mg/m^2/yr, declining to ca 5 mg/m^2/yr about 400 yrs later, and goes down to ca 2 mg/m^2/yr about 2234 BP. A sharp increase up to ca 8 mg/m^2/yr around 1513 BP is followed by a gradual decline down to ca 5 mg/m^2/yr some 250 yrs later and eventually drops at ca 1239 BP to ca 2 mg/m^2/yr. At ca 1022 BP an increase up to about 10 mg/m^2/yr occurs before a drop down to ca 2 mg/m^2/yr around 945 BP.

The levels of all elements very much follow the same pattern when it comes to where the increases and decreases in MAR occur (*figure 2*). The PAR (not pictured) has an average of 62 g/m^2/yr follows a very similar pattern to the bulk density.

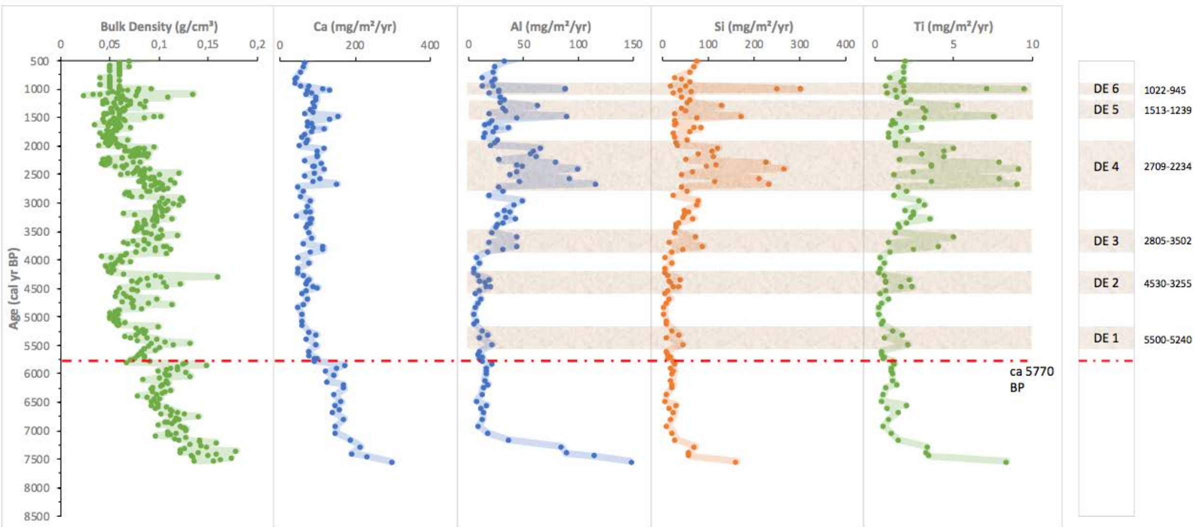

Figure 2. Figure showing the changes in bulk density, Ca, Al, Si and Ti MAR between 8500 and 500 BP. The periods with increased rates are marked out and specified in the column furthest to the right. The fen-bog boundary is marked by the red dotted line at about 5770 BP.

Davidsmosse

At Davidsmosse increase in the elemental MAR can be observed during 6 time periods *(figure 3)*. The first elevation starts ca 3815 BP and is made up by a sharp but not very large increase, followed by a quick decline. A gradual increase then follows with an equally gradual decrease around 3391 BP. Around 3309 BP an increase occurs, going up to higher values before gradually declining back to baseline levels ca 3125 BP. Increasing values are observed again ca 2971 BP until ca 2799 BP. Between ca 2239 BP and 2132 BP, levels are increased again. A sharp increase is seen at ca 992 BP and a decline follows ca 695 BP. The highest levels are seen ca 650 BP to 542 BP.

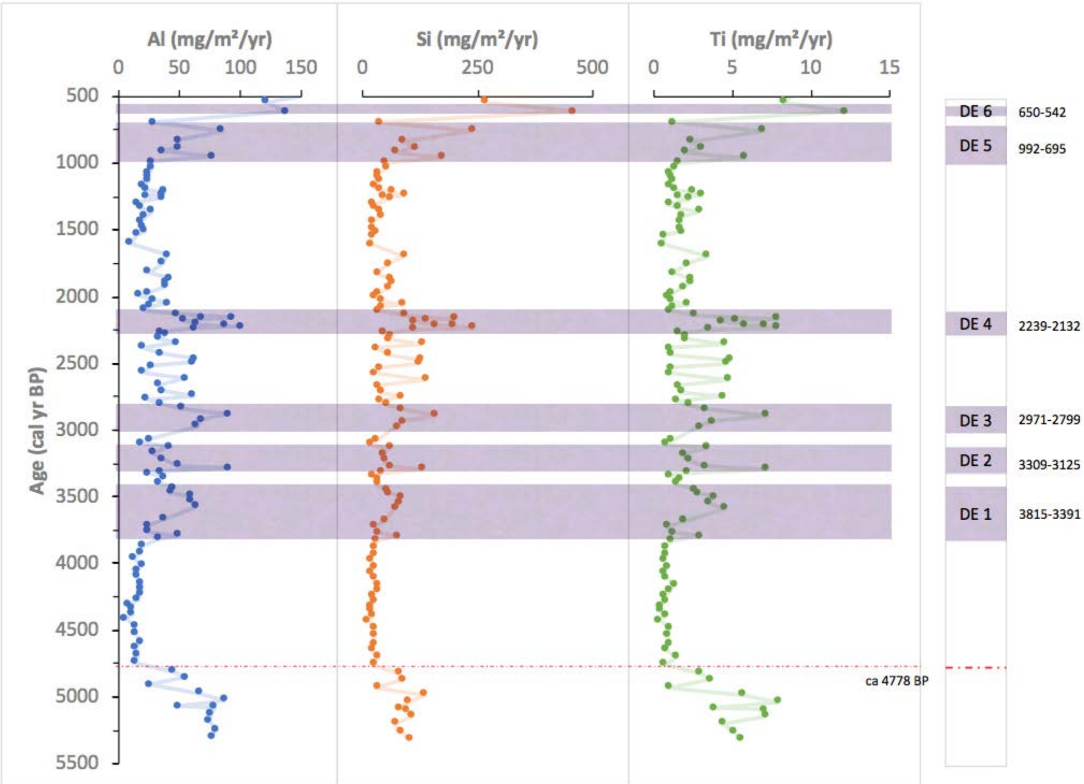

Figure 3. Graphs displaying Al, Si and Ti MAR changes between 5500 BP and 500 BP. The periods of increased elemental MAR are marked out and specified in the box furthest to the right. The fen-bog boundary is marked by the red dotted line at approximately 4778 BP.

Draftinge Mosse

Three periods of increase of elemental MAR are seen at Draftinge Mosse *(figure 4).* The first occurs at ca 2590-1637 BP and consists of a not very large but yet apparent increase in signals for all three elements. The second, at ca 1490 to 1118 BP, consists of a large increase over most of the duration of the event followed by a sharp drop. The third occurs at ca 795 to 504 BP and is started off with a sharp increase followed by a gradual decline. There is a hiatus in the record between 4500-3000 BP.

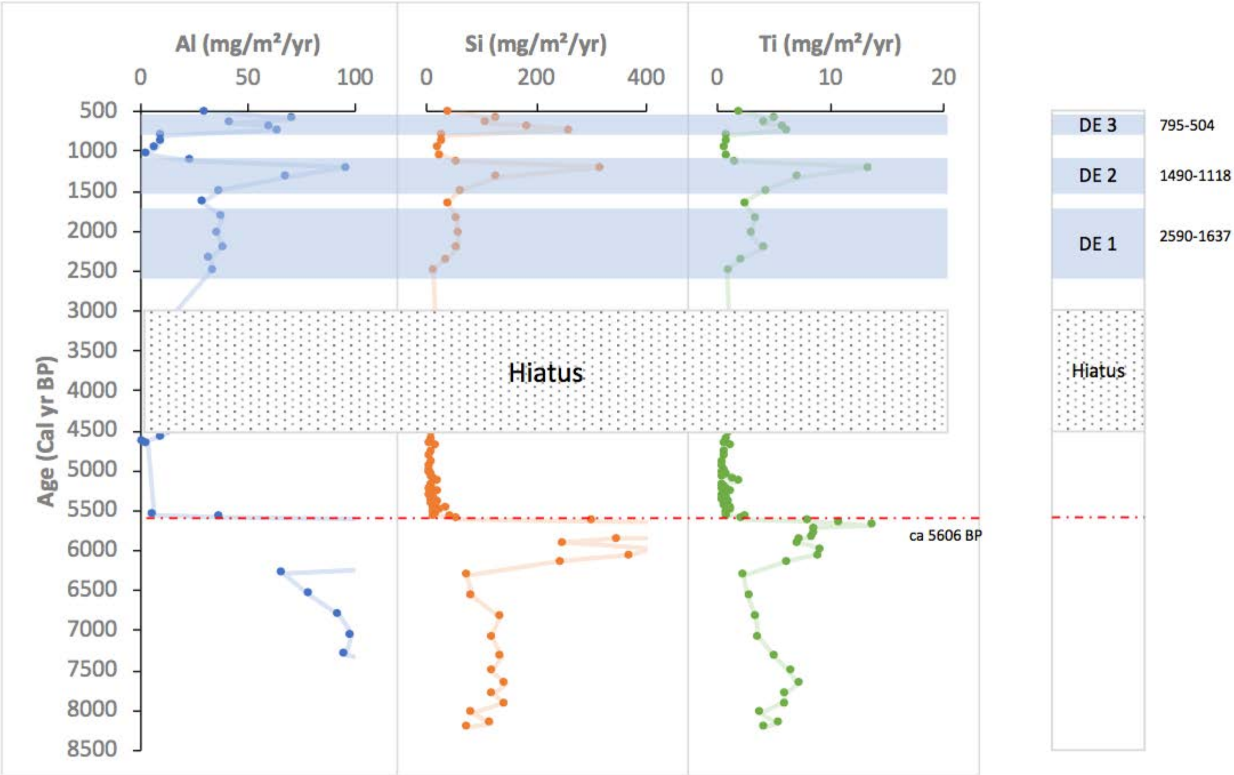

Figure 4. Graphs displaying Al, Si and Ti MAR between 8500 BP and 500 BP. The observed periods of increased dust are marked out and specified in the box furthest to the right. The fen-bog boundary is marked at approximately 5606 BP by the dashed red line. The hiatus, which is due to low PAR and thus less data points, is visible between 4500 and 3000 BP.

Store Mosse

Five periods of increased elemental MAR are seen at Store Mosse *(figure 5)*. The first one occurs from ca 5023 BP until ca 4650 BP. There are varying values in the data points, with some being at base values while others are showing increased values. The second increase is seen at ca 4250 BP followed by decline at ca 4134 BP. The third period of increased levels occurs ca 3560 BP until ca 2990 BP. The fourth period starts around 2653 BP with a gradual increase followed by alternating high and low values until 1946 BP, where the levels are again declining. The fifth change takes place around 1367 BP until approximately 717 BP. During this period the values alternate between high and moderate levels.

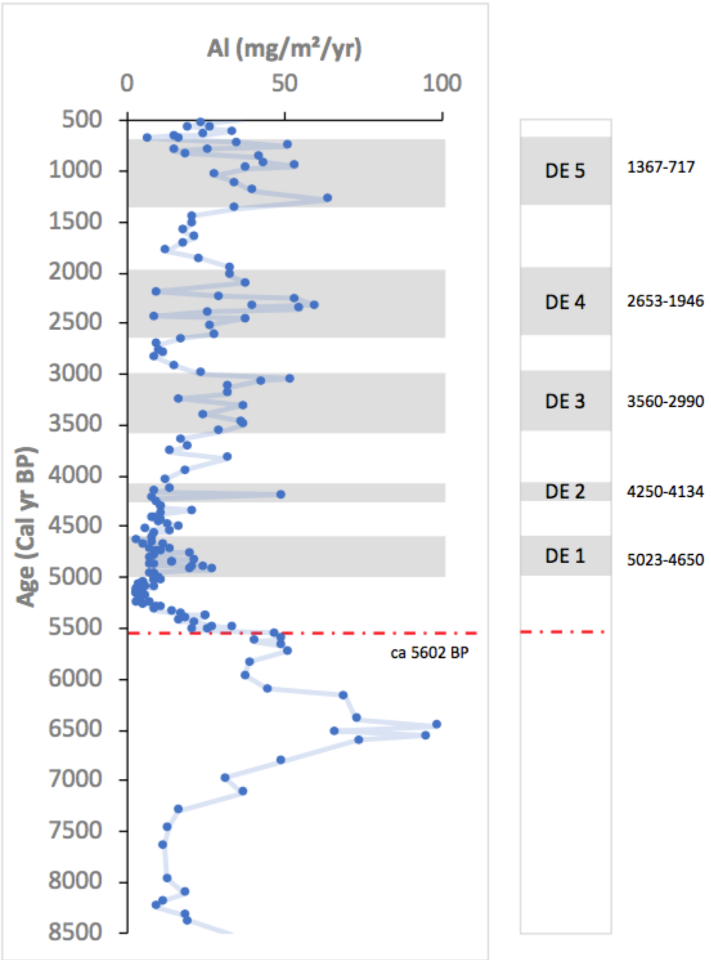

Figure 5. Graph showing the Al MAR between 8500 BP to 500 BP. The five periods of increased Al MAR are specified in the box furthest to the right. The fen-bog boundary has been previously defined and is marked out by the red dashed line at 5602 BP.

Discussion

Gällsereds Mosse

At Gällsereds Mosse, there is a synchronous drop in Ca and bulk density ca 5770 BP, which indicates the fen-bog transition, where the contact with the groundwater table was lost. Because of the lost connection with the groundwater, all input above the fen-bog boundary is atmospheric.
The variations in bulk density give indications to when the conditions were wet and when they were dry. Higher bulk density usually points to drier and warmer conditions. The bulk density curve at Store Mosse somewhat follows the general climate trend showed by previous studies (e.g., Antonsson & Seppä, 2007) with gradually declining values after the fen-bog transition. There are some exceptions, however. The trend after the HTM (ending ca 4000 BP (Antonsson & Seppä, 2007b)) is rising, indicating drier conditions. This contradicts previous research which suggest a pretty much continuous cooling trend with increasingly wet climate after 4000 BP until present. It is likely that the bulk density has been affected by other bog conditions during this time apart from wetness. There are several short-lived peaks in bulk density that do not follow the overall trend. These seem to occur simultaneously as elemental MAR peaks, possibly indicating shorter periods of drier conditions.

The elemental MAR rates experience elevated values simultaneously during six periods in the record, after the fen-bog transition. Since the increases are above the fen-bog boundary, it means that these must be due solely to atmospheric input and can therefore be considered dust events (DE). The fact that elemental MAR for Al, Si and Ti increase in parallel which points to a common process. When the combined increase of all three clearly exceed the baseline values, this is considered a dust event. The periods of increase are defined as: DE1 (5500-5240 BP), DE 2 (4530-3255 BP), DE3 (2805-3502 BP), DE 4 (2709-2234 BP), DE 5 (1513-1239 BP) and DE 6 (1022-945 BP).

Comparison of sites

Since the methods for interpretation are the same for the four bogs, it is possible to compare the dust events caused by Al, Si and Ti rich source material *(figure 6)*. In some cases, there are clear overlaps of the elemental MAR increases across the four sites. In other cases, there is correlation between two or three of the sites. There are also three seemingly local events, where the increase in dust input is not matched at the other bogs and can probably be linked to local conditions at the time. The local events are: Gällsereds Mosse DE 1, Store Mosse DE 1 and Davidsmosse DE 3. The hiatus in the Draftinge Mosse records is treated similarly to a dust event in the comparison, since it was most likely caused by drier conditions that produced gaps in the PAR record.

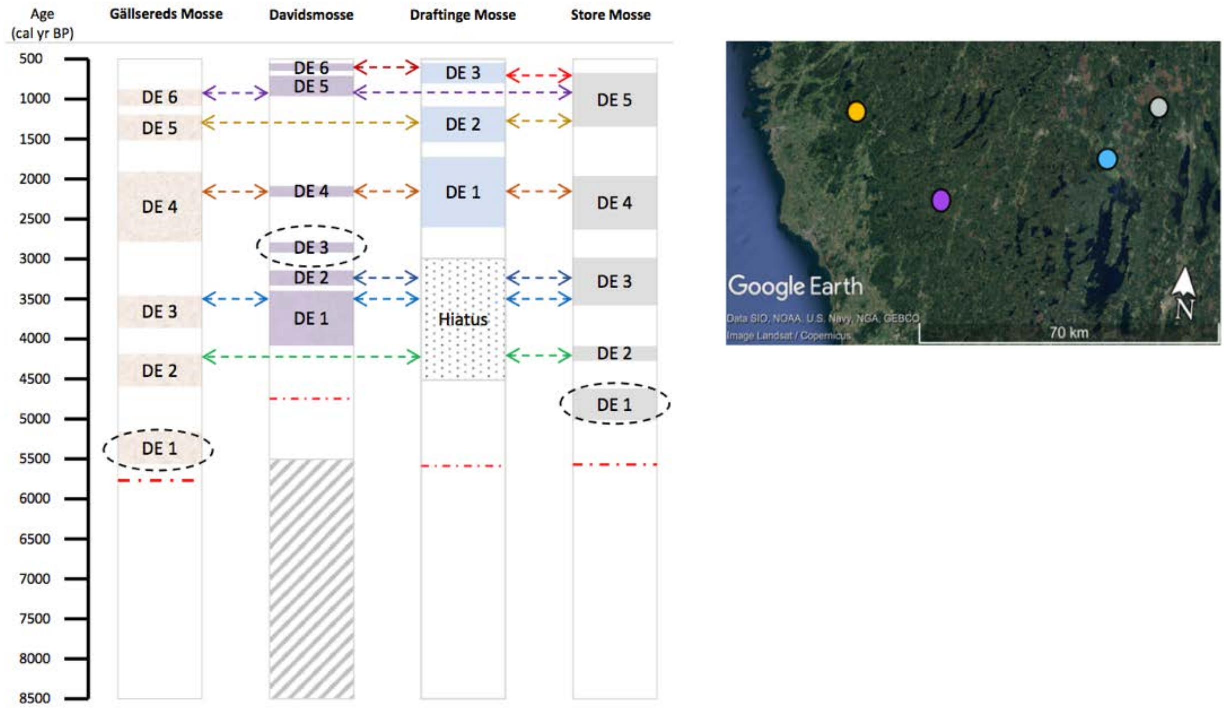

Figure 6. The dust events from the Gällsereds Mosse, Davidsmosse, Draftinge Mosse and Store Mosse in relation to each other along with an overview map of the locations of the 4 sites. The fen-bog boundaries are marked by the red dotted lines. The local events are circled, and the synchronous events are pointed to by the coloured arrows (different colours for different overlaps). Since the record from Davidsmosse doesn't go as far back in time, there is no data from before 5500 BP in that column. Map specification: Orange-Gällsereds Mosse, Purple-Davidsmosse, Blue-Draftinge Mosse and Grey-Store Mosse.

The time periods of overlapping dust input into the bogs are labelled synchronous dust events (SDE) Eight SDEs could be determined (*table 3*). Starting from the bottom of the profiles going up, they are: **SDE 1**: Gällsereds Mosse DE 2, Draftinge Mosse hiatus, Store Mosse DE 2, **SDE 2:** Gällsereds Mosse DE 3, Davidsmosse DE 1, Draftinge Mosse hiatus, Store Mosse DE 3, **SDE 3:** Davidsmosse DE 2, Draftinge Mosse hiatus, Store Mosse DE 3, **SDE 4:** Gällsereds Mosse DE 4, Davidsmosse DE 4, Draftinge Mosse DE1, Store Mosse DE4, **SDE 5:** Gällsereds Mosse DE 5, Draftinge Mosse DE 2, Store Mosse DE 5, **SDE 6:** Gällsereds Mosse DE 6, Davidsmosse DE 5, Store Mosse DE 5 **SDE 7:** Draftinge Mosse DE 3, Store Mosse DE 5, **SDE 8:** Davidsmosse DE 6, Draftinge Mosse DE 4, Store Mosse DE 5. Out of the eight defined SDEs there are two that include all four sites, SDE 2 and SDE 4.

At the time of SDE 2 the conditions were probably dry, since more dust is in circulation during times with dry climate. The hiatus in the record from Draftinge Mosse further enforces this theory. PAR is usually reduced during dry periods, because the lower water table allows plant material to decompose further. This is likely what caused the hiatus at that point. The reason that the hiatus is not visible in the record from the other three bogs could be due to different factors. Gällsereds Mosse and Davidsmosse are oceanic bogs (located closer to the coast). This ensures a more constant level of humidity at these two sites, making the PAR rather consistent even during drier periods. Store Mosse, although being located even further inland than Draftinge Mosse, does not show a hiatus. This is likely purely due to the massive size of this peatland which probably created a sort of buffering effect during the drier periods, leading to the PAR being somewhat consistent. There are also previous studies showing that water levels in southern Sweden lakes were low between 5000 BP and 3000 BP (Almquist-Jacobson, 1995), which further points to dry conditions during SDE 2. The other event covering all four sites, SDE 4, suggests a longer period of dry conditions. Gällsereds Mosse and

Draftinge Mosse experience their longest period of elevated dust input during this time, while Store Mosse is experiencing its second longest. Even though there is correlation with Davidsmosse, the event in that record is much shorter. SDE 4 is difficult to support by existing climate data as, during this time, research points to the climate experiencing a gradual transition towards wet and cold conditions from 4000 BP to present (Antonsson & Seppä, 2007). It is still likely that a regional climatic factor generated more dust during this time, since levels are increased at all four sites. For SDE 1 and SDE 5, all sites overlap except for Davidsmosse. SDE 1 falls within the time of the Holocene Climate Optimum, which would explain this event as the climate was generally warmer and drier during this time, making dust events more likely to occur. For SDE 5, the same problems arise as for SDE 4 when it comes to explaining the increased levels with existing knowledge of climate conditions. However, the increase at the three different sights, despite of Gällsereds Mosse being so much further to the coast, points to a regional event at this time.

Table 3. Compilation of the SDEs across the dataset. In total 9 SDEs where defined. The timing (yr BP) next to the event number is meant to point to the time where the overlap was most apparent, without saying that the SDE did not happen for a longer time period than that. The SDEs that include all four sites are in bold.

Synchronous Dust Event (SDE):	Bogs involved:			
	Gällsereds Mosse	Davidsmosse	Draftinge Mosse	Store Mosse
1 (ca 4250 BP)	DE 2	-	Hiatus	DE 2
2 (ca 3500 BP)	**DE 3**	**DE 1**	**Hiatus**	**DE 3**
3 (ca 3250 BP)	-	DE 2	Hiatus	DE 3
4 (ca 2200 BP)	**DE 4**	**DE 4**	**DE 1**	**DE 4**
5 (ca 1250 BP)	DE 5	-	DE 2	DE 5
6 (ca 900 BP)	DE 6	DE 5	-	DE 5
7 (ca 700 BP)	-	-	DE 3	DE 5
8 (ca 600 BP)	-	DE 6	DE 3	-

Interpretation of data

When interpreting the data in this study, only the shapes of the curves and the overall impression of increases versus decreases in values were considered. In several cases, it was not very straight forward which periods should be considered dust events and which should not. One example of this is DE 3 and DE 4 Gällsereds Mosse. The levels for Al and Si MAR are not significantly higher during DE 3 than during the period in between DE 3 and DE 4. However, since Ti MAR shows a rather large increase during DE 3 and a decrease before DE 4, it was decided that a change in dust deposition occurred. It was also difficult to determine what time frame would be appropriate to consider as the start and the end of each event. This means that the start and finish for the individual dust events should be looked at with a little caution.

The fact that the dust events at Davidsmosse seem shorter might be due to the fact that the record is shorter than for the other sites, leading to the vertical resolution being higher when visually interpreting data. This meant that increases that occurred close in time (e.g. DE 5 and DE 6) where interpreted as two separate events, while it might have been interpreted as one single event if the record had reached as far back in time as for the other three sites.

Previous research at Store Mosse (Kylander et al., 2016) has shown that periods with lower signals of a given conservative element does not necessarily mean that the dust input is decreased, but rather that the source material may have changed. It is therefore somewhat problematic to only analyse such few components as in this study. Research including the MAR of more elements would be more detailed on varying dust sources. Since Si and Ti data was not available for Store Mosse, the interpretation of dust input is more uncertain for Store Mosse than for the other three bogs.

Dust sources

While it can be a challenge to quantitively isolate local and remote sources in the dust record (Albani et al., 2015) it is one that is worth taking. The ability to fingerprint dust sources would have great benefit when reconstructing paleoclimate conditions, as they would tell whether dust events are significant on a local, regional or global scale. If it was possible to tell exactly what sources exist for each dust event, it would be easier to determine what type of activity (e.g. natural vs anthropogenic) that caused the dust event to take place. There are some ways already in place in which to determine the source material for dust influx. Looking at abundance of certain elements at certain times (which is what has been done here) can be linked to host minerals and in extension to source rocks/sediments. This can be done mainly by looking at correlation between certain elements in the record. One example of when correlations are used in order to get an idea of the mineral host is Kylander et al., (2016). Aluminium, Si and Ti are all common crust elements and rather abundant in the gneiss and granite that make up a large portion of the bedrock in Sweden. Aluminium and Si are both building blocks of common minerals such as quartz, feldspar, plagioclase and micas. Titanium, although not as abundant as Si and Al is found in minerals like ilmenite which can occasionally be found in granite. It is not possible to determine whether the source is located locally, regionally or globally from the methods used in this study, even though the correlation during certain time periods across the four bogs would probably not suggest a local source. If a similar, but more advanced and in-depth approach were to be carried out in a study across all four bogs, including more elemental data being interpreted via more state-of-the-art statistical analysis, the likelihood of more significant results would increase.

Conclusion

Research on atmospheric dust records in ombrotrophic peat bogs can increase our understanding of past climate conditions. After investigating Al, Si and Ti MAR at Gällsereds Mosse six dust events are suggested: DE 1 (5500-4240 BP), DE 2 (4530-3255 BP), DE 3 (2805-3502 BP), DE 4 (2709-2234 BP), DE 5 (1513-1239 BP) and DE 6 (1022-945 BP). Correlation between Gällsereds Mosse and Davidsmosse, Draftinge Mosse and Store Mosse point to eight synchronous dust events: SDE 1 (ca 4250 BP), SDE 2 (ca 3500 BP), SDE 3 (ca 3250 BP), SDE 4 (ca 2200 BP), SDE 5 (ca 1250 BP), SDE 6 (ca 900 BP), SDE 7 (ca 700 BP) and SDE 8 (ca 600 BP). SDE 1 and SDE 2 can largely be backed by previous research on climate conditions at the time, while other events, such as SDE 4 and SDE 5 are more difficult to correlate to existing literature. A multiproxy approach might help solving this problem just as research including more conservative elements would be valuable in order to establish potential dust sources.

Acknowledgements

First and foremost, I want to thank my supervisor Malin Kylander for her excellent and generous guidance and support during the making of this essay. I also want to thank Jenny Sjöström for valuable input. Lastly, I want to thank Felicia Sköllerfelt for all the moral support while learning about the secrets of ombrotrophic peat bogs together.

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Appendix A:

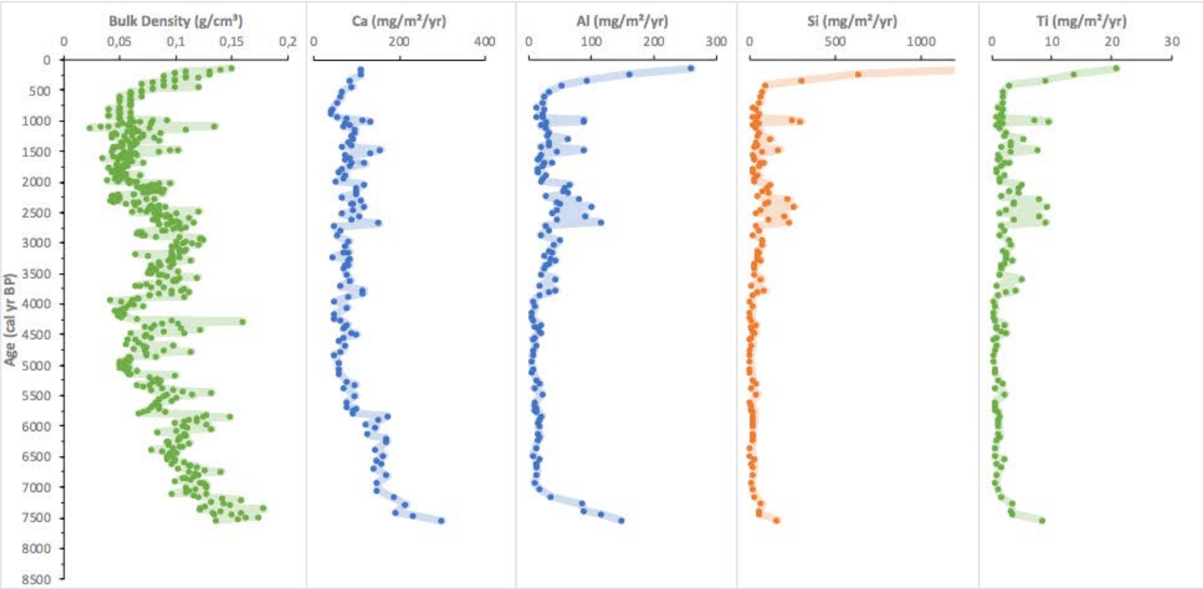

Figure A1. The original graphs from Gällsereds Mosse, before the top 500 years were removed.

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