Degree Project in Physical Geography and Quaternary Geology

Stockholms universitet

# Lateglacial and Holocene vegetational change in northern Halland, southwestern Sweden

Ylva Palmgren

Master's level 45 HE credits, autumn 2023

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Ylva Palmgren

Department of Physical Geography
GE9010 Degree Project in Physical Geography and Quaternary Geology 45 HE credits
NKA362
Polar Landscapes and Quaternary Climate (120 HE credits)
Fall term 2023
Supervisor: Martina Hättestrand
Examiner: Peter Kuhry
Assessor: Qiong Zhang

Cover: Ylva Palmgren

Stockholms universitet

# Abstract

The archaeological site at Skatmossen in coastal northern Halland, southwestern Sweden, is among the oldest evidence of human presence in Sweden, possibly dating back to more than 15,000 cal yr BP. To understand the environment in which the early visitors of Sweden were living, a palynological study on a sediment core retrieved from a nearby fen, Käringmossen, was conducted to reconstruct past vegetational, environmental and climatic changes in coastal northern Halland. The reconstruction spans from the time shortly after the last deglaciation of Halland, 15,300 cal yr BP, until the present, but focuses on the Lateglacial period and early to mid-Holocene. In the Käringmossen pollen record, from the early to mid-Lateglacial period, a general development from sparse steppe-tundra vegetation during the Oldest Dryas to *Betula* woodlands and Ericaceae heaths during Allerød can be inferred. This is followed by a cooling phase in the early Younger Dryas, between 12,800–12,400 cal yr BP, when biological productivity decreased, heaths disappeared, woodlands were suppressed, and steppe-tundra related taxa expanded. After this short cooling phase, biological productivity however increased again and tree-birch re-expanded. In the Holocene, with start in the Preboreal period, around 11,500 cal yr BP, a general pattern of immigration of new tree taxa to increasingly dense forests can be discerned. This trend reaches its culmination in the Atlantic period, during the Holocene Thermal Maximum (8,000–5,000 cal yr BP), when *Betula* dominated broad-leaved forests with *Quercetum mixtum* elements developed. Towards the late Holocene, human influence increased in the Käringmossen landscape. This is seen as increased vegetation openness in the Subboreal period, possibly as early as 5,400 cal yr BP, indicating forest clearance for cultivation and pasture. Later, around 2,000 cal yr BP, rye pollen grains are further indications of agriculture, while high percentages of coniferous pollen in the 21$^{st}$ century reflect a change in land use from agriculture to modern commercial forestry.



## Keywords

Lateglacial; Holocene; pollen; palynology; vegetational change; palaeoenvironment; climate change; Skatmossen; Halland; southwestern Sweden

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# 1 Introduction

Ever since the deglaciation of the last Fennoscandian Ice Sheet (FIS), humans have been living in Sweden. The first people to set their foot in southern Sweden, around 15,000 cal yr BP, arrived in an arctic environment with sparse vegetation cover and underdeveloped soils (Berglund, 1966; Liedberg Jönsson, 1988; Price, 2015). As time progressed and climate and environment changed, humans continued to occupy and settle in Sweden (Price, 2015). A fundamental aspect to understanding Swedish human history and prehistory is therefore to have knowledge about past environmental and climatic change and how humans responded to these changes. In a time of anthropogenically caused global warming (Cook *et al.*, 2013), this knowledge may also help provide a framework for understanding future climate change and its potential consequences (e.g., Brooks, Grist and Brown, 2009; Zhang *et al.*, 2011; Hansen and Sato, 2012).

One way of studying past climatic and environmental change is to look at past vegetational changes. This is often done through pollen analysis, a method originally developed by Swedish geologist Lennart von Post (1916, 1918). The basis of pollen analysis is to use fossil pollen in sedimentary deposits, mainly retrieved from lakes and wetlands, to reconstruct past vegetation, environments and climate. This is done by identifying the pollen assemblages, i.e., the assortments of pollen taxa, present at different levels in sediment from a sampling site (von Post, 1918). By looking at the pollen assemblages, inferences can be made about the vegetation, environment and climate at the site at the time of deposition (von Post, 1918; Fægri *et al.*, 1989). Since different levels in a sediment sequence have different ages, the lowest typically being oldest and the uppermost youngest, it is possible to chronologically trace vegetational development using pollen analysis (von Post, 1918; Fægri *et al.*, 1989). There are however situations where sediment chronology is not as straightforward, due to factors such as rebedding and hiatuses in sediment deposition (Fægri *et al.*, 1989), and to counter these issues, absolute dating methods such as radiocarbon dating are used (Peteet, 1992). By combining pollen analysis and an absolute dating method, it is thus possible to construct absolute chronologies of vegetational change.

In this thesis, focus has been put on the archaeological site Skatmossen in Halland, southwestern Sweden. Skatmossen is one of the oldest known archaeological sites in Sweden and potentially dates back to more than 15,000 cal yr BP (Nordqvist, 2003), a time when the recently deglaciated southern Scandinavia was only sparsely populated by the hunter-gatherers of the late Palaeolithic (Price, 2015). To better understand the world in which these hunter-gatherers, and the people that came after them, were living, pollen analysis has been used to reconstruct the vegetational development at Käringmossen, a fen situated approximately 2.3 km southwest of Skatmossen, from the Lateglacial period until the present. The main focus of the thesis has been the Stone Age, the time when Skatmossen was visited by humans for the first time.

# 2 Aims and research questions

The overarching aims of this study were (1) to use fossil pollen to reconstruct the environment in which some of the earliest settlers of Sweden, the hunter-gatherers at

Skatmossen, were living, and (2) to trace how this environment changed from the last deglaciation until the present, as humans were continuing to settle in and inhabit the Skatmossen area.

The aims were developed into the following two research questions:

- How did the vegetation change in the area surrounding the Skatmossen archaeological site in southwestern Sweden from the last deglaciation until the present?
- How can vegetational changes in the Skatmossen area during the studied time period be interpreted in terms of environmental and climatic change?

Although the aim of the thesis has been to reconstruct vegetation from the last deglaciation until the present, greatest focus was put on the Stone Age, corresponding largely to the Lateglacial period and the early and mid-Holocene.

# 3 Background

## 3.1 The last deglaciation

Throughout the Quaternary period, ice sheets have built up, spread and retreated in multiple cycles of glacials and interglacials. Sweden and Fennoscandia in general has been extensively affected by these glaciations. During the Last Glacial Maximum (LGM) approximately 26,500–20,000 cal yr BP (Clark *et al.*, 2009), the entirety of Fennoscandia was covered by kilometres thick ice (Goehring *et al.*, 2008; Stroeven *et al.*, 2016). Following the LGM, as climate was warming, deglaciation of Fennoscandia began around 20,000–19,000 cal yr BP (Clark *et al.*, 2009) and the entire region was ice free by 10,000–9,000 cal yr BP (Hughes *et al.*, 2016; Stroeven *et al.*, 2016).

Deglaciation of coastal Halland, where the Skatmossen archaeological site is situated, was slow. Here, the ice-margin retreated by at most around 10 km/1,000 years (Stroeven *et al.*, 2016). According to the two most recent reconstructions of the last Fennoscandian deglaciation by Hughes *et al*. (2016) and Stroeven *et al*. (2016), deglaciation of Halland started between 18,000–17,000 cal yr BP and the area was fully ice free by 14,000 cal yr BP. The process of ice retreat is however reconstructed differently in the two studies. Stroeven *et al.* (2016) have reconstructed a gradual and stepwise retreat along the Halland coast, starting between 17,000–16,000 cal yr BP. However, according to Hughes *et al.* (2016), deglaciation started already between 18,000–17,000 cal yr BP, after which the FIS reached a stand-still until 16,000 cal yr BP, when it started retreating again. After 16,000 cal yr BP, ice retreat was faster and between 15,000–13,000 cal yr BP, all of southern Sweden south of lakes Vänern and Vättern became ice free (Hughes *et al.*, 2016; Stroeven *et al.*, 2016).

When land is covered by thick ice sheets, the weight of the ice causes the Earth's crust to sink down into the mantle. As soon as the ice sheet starts to melt, the weight is removed from the crust and the crust starts to rebound, a process referred to as postglacial rebound (Lundqvist, 1994). This rebound causes a drop in relative sea level and it is still ongoing in all of Sweden following the last deglaciation (Vestøl *et al.*, 2019). The most rapid uplift happens immediately after deglaciation and the greatest uplift happens where the ice was thickest and thus weighed down the Earth's crust the most (Lundqvist, 1994). At the same time during glaciation, large amounts of glacial meltwater is released into the oceans, causing absolute increases in global sea level (Farrell and Clark, 1976). This leads to complex fluctuations in relative sea level in previously glaciated areas following deglaciation. Generally in Sweden, the relative sea level was at its highest at the time of

deglaciation, forming the highest coastline (Lundqvist, 1994). After the formation of the highest coastline, the trend in Sweden is for relative sea level to drop until the present, with some interruptions by relative sea level rise along the south- and west coasts. In Halland, the highest coastline varies from around 60 m a.s.l. in the south to 80 m a.s.l. in the north (Lundqvist, 1994).

## 3.2 Lateglacial and Holocene climate variability

### 3.2.1 Lateglacial climate

The general trend in Scandinavia following the LGM, during the Lateglacial period, is climate warming which resulted from increasing summer insolation (Berger and Loutre, 1991). This general warming trend was however interrupted by multiple colder periods (Björck *et al.*, 1998; Rasmussen *et al.*, 2014). The climate variability in Scandinavia during the Lateglacial period is often described using the chronostratigraphic subdivision proposed by Mangerud *et al.* (1974), that has been adapted to south-Swedish pollen records by Björck and Möller (1987). In these subdivisions, the Lateglacial period is divided into four main chronozones: Bølling, Older Dryas, Allerød and Younger Dryas, with Bølling said to be preceded by a less defined Oldest Dryas chronozone (Mangerud *et al.*, 1974). As the chronozone boundary ages presented by both Mangerud *et al.* (1974) and Björck and Möller (1987) are given in radiocarbon years, they have in this thesis been calibrated to calendar years using the IntCal20 calibration curve (Reimer *et al.*, 2020) in OxCal 4.4 (Ramsey, 2009). The Scandinavian chronozones largely reflect climatic events in the more recently proposed INTIMATE event stratigraphy based on Greenlandic ice-core records from the NGRIP, GRIP and GISP2 ice cores (Björck *et al.*, 1998; Rasmussen *et al.*, 2014). In the INTIMATE record, cold events are termed Greenland Stadials (GS) and warm events Greenland Interstadials (GI).

Deglaciation of southern Sweden began during the Oldest Dryas period, which is often set to have begun approximately 18,000 cal yr BP and ended with the entry into Bølling around 14,600 cal yr BP (Shakun and Carlson, 2010; Carlson and Winsor, 2012; Clark *et al.*, 2012). The Oldest Dryas period mostly overlaps with the GS-2.1a event (17,400–14,600 cal yr BP) in Greenland ice-cores (Rasmussen *et al.*, 2014). Although the Scandinavian ice sheet was melting in southern Sweden, the Oldest Dryas was a relatively cold period, a stadial, during the last deglaciation. This is reflected in Greenland ice-cores, where $\delta^{18}O$ levels are low during the GS-2.1a, indicating cold temperatures (Kindler *et al.*, 2014; Rasmussen *et al.*, 2014).

The Oldest Dryas period is followed by Bølling (14,600–14,100 cal yr BP), Older Dryas (14,100–13,900 cal yr BP) and Allerød (13,900–12,900 cal yr BP) periods, Bølling and Allerød being warmer and Older Dryas being colder (Björck and Möller, 1987). In the INTIMATE event stratigraphy, the events corresponding to the three periods are grouped into one period of relatively warmer climate, the GI-1 interstadial (Rasmussen *et al.*, 2014). Bølling corresponds largely to the GI-1e event occurring from 14,600–14,000 cal yr BP, Older Dryas to the short GI-1d cooling event between 14,000–13,900 cal yr BP, and Allerød to the again warmer GI-1a–GI-1c between 13,900–12,800 cal yr BP (Rasmussen *et al.*, 2014). Although cooling is inferred from ice cores during the Older Dryas (Kindler *et al.*, 2014; Rasmussen *et al.*, 2014), some have suggested that the main climatic effect in southern Scandinavia was drought (e.g., Berglund *et al.*, 1994; Mortensen *et al.*, 2011).

The last climatic event of the Lateglacial is the Younger Dryas cold period occurring between 12,900–11,500 cal yr BP (Mangerud *et al.*, 1974; Björck and Möller, 1987). This period can be related to the GS-1 event in the INTIMATE event stratigraphy, which is set to have occurred approximately between 12,800–11,700 cal yr BP (Rasmussen *et*

*al.*, 2014). The termination of this cold event is contemporary with the termination of the Pleistocene and the entry into the current Holocene epoch.

Although temperature records from Greenland ice-cores indicate significantly colder climate during the Lateglacial period compared to the Holocene (Rasmussen *et al.*, 2014), recent temperature reconstructions from Scandinavia indicate that climate may have been milder than previously thought (Schenk *et al.*, 2018, 2020; Wohlfarth *et al.*, 2018). In southern Scandinavia, mean July temperatures could have been as high as around 14–16°C during most of the Lateglacial period, including the Younger Dryas, as is indicated from plant macrofossil records from Denmark and southern Sweden (Wohlfarth *et al.*, 2018; Schenk *et al.*, 2020). This can be compared to south-Swedish beetle and chironomid inferred Younger Dryas mean July temperatures of approximately 8–10°C and 9–10°C (Coope *et al.*, 1998; Brooks and Langdon, 2014). In light of the new macrofossil based temperature records it has been suggested that the Younger Dryas in Scandinavia was mainly associated with strong continentality with short warm summers and harsh winters (Schenk *et al.*, 2018, 2020). This follows the earlier proposition by Denton *et al.* (2005) that Lateglacial European stadials were mainly associated with increased seasonality and cold winters, rather than summer cooling.

### 3.2.2 Holocene climate

The Holocene epoch is overall characterized by warmer and more stable climate than the Lateglacial period, although changes in climate were still occurring. In the Scandinavian chronostratigraphic subdivision proposed by Mangerud *et al*. (1974), a modified version of the Blytt-Sernander climatostratigraphic scheme (Blytt, 1876; Sernander, 1908) is used to divide the Holocene into different periods. These periods largely reflect the climate variability of the Holocene. In the subdivision, the Holocene begins with the Preboreal, which is followed by the Boreal, Atlantic, Subboreal and Subatlantic periods. This subdivision is in many ways regarded as outdated and the Holocene is now typically divided into three official sub-epochs, the Greenlandian, the Northgrippian and the Meghalayan (Walker *et al.*, 2019). The modified Blytt-Sernander scheme of Mangerud *et al*. (1974) is however still suitable for discussing Scandinavian climatic and environmental change and it has therefore been used in this thesis.

In the early Holocene, during the Preboreal (11,500–10,200 cal yr BP) and Boreal (10,200–8,900 cal yr BP) periods, climate in southern Sweden was characterised by rapid warming following the Younger Dryas stadial (Lemdahl, 1991; Antonsson and Seppä, 2007; Wohlfarth *et al.*, 2017). During this time, south Swedish climate was also exceptionally dry, with lake and groundwater levels reaching the lowest levels of the entire Holocene (Digerfeldt, 1988; Gaillard and Digerfeldt, 1991; Harrison and Digerfeldt, 1993). While climate was generally warming in the North Atlantic region during the early Holocene, several short cold events interrupted this trend (Björck *et al.*, 1997; Rasmussen *et al.*, 2014). In Sweden, there is however only evidence for one event, the 11.4 ka event, or the Preboreal Oscillation (PBO) (Wastegård, 2022).

The Atlantic period (8,900–5700 cal yr BP), which covers the mid-Holocene is characterised by warm climate and is largely contemporary with the Holocene Thermal Maximum (HTM), which in Sweden occurred approximately between 8,000–5,000 cal yr BP (Seppä *et al.*, 2009; Wastegård, 2022). This warm phase during the Atlantic period was however preceded by the 8.2 ka cold event, which has been recorded in several Swedish paleoclimate proxy records (e.g., Seppä, Hammarlund and Antonsson, 2005; Antonsson *et al.*, 2006; Antonsson and Seppä, 2007). During the HTM, peak temperatures were reached around 7,000 cal yr BP, after which a cooling trend, that continued on into the late Holocene Subboreal (5,700–2,600 cal yr BP) and Subatlantic (2,600 cal yr BP until present) periods, was gradually established (Antonsson *et al.*, 2006; Antonsson and Seppä, 2007; Seppä *et al.*, 2009). These two late Holocene periods are characterised by cooler and more unstable climate compared to the Atlantic.

## 3.3 Lateglacial and Holocene vegetational changes

### 3.3.1 Lateglacial vegetation

Immediately following deglaciation, during the Oldest Dryas, the first vegetation communities that developed in southern Scandinavia consisted of pioneer species adapted to the harsh environment (Iversen, 1973; Berglund *et al.*, 1994; Mortensen *et al.*, 2011; Wohlfarth *et al.*, 2018). The vegetation cover was sparse and dominated by herbs, shrubs and dwarf shrubs, as is indicated by plant macrofossil and pollen records (Mortensen *et al.*, 2011; Birks and Birks, 2014; Wohlfarth *et al.*, 2018). Later during Bølling and Older Dryas, a denser, but still herb and shrub dominated, vegetation has been inferred both in southern Sweden and Denmark (Mortensen *et al.*, 2011; Wohlfarth *et al.*, 2018). Some of the herbs and shrubs characteristic of this early Lateglacial vegetation in southern Scandinavia include *Salix polaris* and *S. herbacea*, *Betula nana*, *Dryas octopetala*, *Artemisia*, *Helianthemum* and *Hippophaë* (Iversen, 1973; Liedberg Jönsson, 1988; Mortensen *et al.*, 2011). Trees are generally interpreted to have been mostly absent in northwestern Europe during this time (Mortensen *et al.*, 2011; Birks and Birks, 2014; Mortensen, Henriksen and Bennike, 2014), but there have been scattered macrofossil finds of tree birch from Skåne, indicating at least minor presence in southern Sweden (Liedberg Jönsson, 1988; Hammarlund and Lemdahl, 1994; Wohlfarth *et al.*, 2018).

During Allerød, following the colder Older Dryas, tree birch became established in southern Sweden and Denmark (Liedberg Jönsson, 1988; Mortensen *et al.*, 2011; Birks and Birks, 2014; Wohlfarth *et al.*, 2018). Based on pollen and macrofossil records, the development of a patchy and heterogeneous vegetation has been inferred for this time, with vegetation varying from open and herb and dwarf shrub dominated, to denser *Betula* woodlands (Björck and Möller, 1987; Mortensen, Henriksen and Bennike, 2014). Along with this, there is macrofossil evidence from southernmost Sweden of *Pinus sylvestris* making its first appearance in Scandinavia during Allerød (Wohlfarth *et al.*, 2018). In southern Sweden, a marked phase of *Empetrum* expansion during the later part of Allerød has also been noted (Björck and Möller, 1987; Liedberg Jönsson, 1988; Berglund *et al.*, 1994). Because of the presence of high percentages of *Betula*, *Pinus* and *Empetrum* in pollen records from southeastern Sweden, Björck and Möller (1987) have suggested that this part of Sweden was dominated by open birch-pine woodlands and *Empetrum* heaths.

With the onset of the Younger Dryas period, climate became colder and the woodlands of Allerød disappeared or decreased (Björck and Möller, 1987; Berglund *et al.*, 1994). There is macrofossil evidence of tree-birch remaining in southernmost Sweden during this time (Liedberg Jönsson, 1988; Hammarlund and Lemdahl, 1994), while in Denmark tree-birch macrofossils are scarce and generally interpreted as redeposited (Mortensen, Henriksen and Bennike, 2014). At the same time, *Pinus* disappears from the one Swedish macrofossil record where it was noted during Allerød (Wohlfarth *et al.*, 2018) and *Empetrum* decreases in south-Swedish pollen records (Berglund, 1966; Björck and Möller, 1987; Berglund, Eriksson and Fernlund, 1994). Although the Younger Dryas represents a period of significant cooling when Allerød vegetation experienced a setback, many of the cold adapted species of earlier cold periods seem to not have returned to southern Scandinavia, possibly due to migration lags (Birks, 2008; Mortensen *et al.*, 2011).

### 3.3.2 Holocene vegetation

With the rapid Holocene warming following the Younger Dryas stadial, new plant taxa quickly started to immigrate to southern Sweden. The general immigration pattern of forest forming trees to southern Sweden was described already by von Post (1924) who

delineated three main immigration and expansion phases. In the first phase came *Betula* and *Pinus,* which reappeared after having been fully or largely absent during most of the Younger Dryas (von Post, 1924; Björck and Möller, 1987; Mortensen *et al.*, 2011; Mortensen, Henriksen and Bennike, 2014; Wohlfarth *et al.*, 2018). The reappearance of these tree taxa began already during the late Younger Dryas and Preboreal (Björck and Möller, 1987; Liedberg Jönsson, 1988) and their early Holocene expansion came at the cost of light demanding herbs and dwarf shrubs (Björck and Möller, 1987; Mortensen *et al.*, 2011).

The second immigration phase, that also took place largely during the early Holocene, consisted of *Corylus*, *Alnus* and *Quercetum mixtum* taxa (e.g., *Ulmus*, *Quercus* and *Tilia*) (von Post, 1924). *Corylus* and *Ulmus* often came first, and in southwestern Sweden, in the early Boreal period, very high *Corylus* values in pollen records have led to suggestions that forests were completely dominated by the taxon (von Post, 1924; Sandgren, 1944; Fries, 1951). *Betula* dominated forests with elements of *Corylus* and *Ulmus* have instead been suggested for southeastern Sweden, where *Corylus* also attained high, but not as high, levels during the early Holocene (Yu *et al.*, 2005). Later, an expansion and peak of *Quercetum mixtum* taxa has often been observed in association with the HTM during the mid Holocene (e.g., Gaillard, 1984; Yu *et al.*, 2005; Antonsson and Seppä, 2007).

Von Post's (1924) final immigration phase consisted mainly of *Picea* and *Fagus* and it occurred towards the late Holocene, after the HTM. Of these two, *Fagus* arrived first, appearing in Skåne in southernmost Sweden around 4,000 cal yr BP (Bradshaw and Lindbladh, 2005). It then spread fast and had established along the Swedish west coast by 3,000 cal yr BP and in most of its current range by 2,000 cal yr BP (Bradshaw and Lindbladh, 2005). *Picea* on the other hand, started reaching southern Sweden first after 2,000 cal yr BP (Giesecke and Bennett, 2004; Bradshaw and Lindbladh, 2005). During the middle to late Holocene there was also increased human influence on vegetation in southern Scandinavia. With the introduction of agriculture, around 6,000 cal yr BP, humans started changing and opening up the landscape through swidden farming and clearance for pasture (Andersen, 1990; Price, 2015). The effects of the increased human activity is seen in pollen records as increasing herb and weed pollen percentages, in expansions of heath forming taxa such as *Calluna*, and in decreasing tree pollen percentages (Iversen, 1941; Behre, 1981).

## 3.4 The Stone Age in southern Scandinavia

Following the last deglaciation, time in Scandinavia is by archaeologists divided into six main periods. These are the Stone Age, Bronze Age, Iron Age, Viking Age and the Mediaeval- and Modern periods. Because the Stone Age in Scandinavia covers a long period of time, during which major changes in climate, environment, human technology and social organization were taking place, it is typically subdivided into three main sub-periods: the Palaeolithic, Mesolithic and Neolithic. In this thesis, focus is put on the Stone Age and mainly the Palaeolithic and Mesolithic periods.

During the Palaeolithic, the first human settlers arrived in Scandinavia. These hunter-gatherers arrived not long after deglaciation and they belonged to the Hamburgian, Federmesser, Bromme and Ahrensburgian cultures, originally derived from the western European Magdalenian culture (Price, 2015). In southern Sweden, some of the oldest evidence of Lateglacial settlement comes from Skåne in the form of late Hamburgian flint tools and projectiles (Larsson, 1996), likely being of late Bølling or early Older Dryas age (Eriksen, 2002). Following this, the first more abundant settlement of southern Sweden was by people belonging to the Bromme culture, who lived in the birch woodlands of the Allerød period and remained in Scandinavia until the early Younger Dryas (Andersson and Knarrström, 1999; Price, 2015). The Bromme culture was then

followed by people of the Ahrensburgian culture, who occupied southern Sweden during the Younger Dryas and Preboreal (Price, 2015). At the same time, the closely related Hensbacka culture was occupying the Swedish west coast (Schmitt, 1995).

For all the Palaeolithic cultures of southern Sweden, reindeer hunting was a fundamental source of food (Andersson and Knarrström, 1999; Price, 2015), though perhaps slightly less so for the people of the Bromme culture who lived during the more lush Allerød period (Fischer, 1991; Andersson and Knarrström, 1999). Most settlements have been found inland, with the exception of the Hensbacka culture, which largely occupied the marine environment and likely had a more marine based diet (Schmitt, 1995; Price, 2015). This culture has been suggested to be a marine component of the Ahrensburgian, of which evidence can only be found on the Swedish and Norwegian west coasts because these areas have not been submerged by sea level rise (Schmitt, 1995). Because the Lateglacial shoreline in most of southern Scandinavia is now submerged, it has been suggested that earlier Palaeolithic cultures could also have had marine components to them and that occupation may not have been as centred inland as often thought (Fischer, 1996).

With the end of the Pleistocene and the entry into the Holocene, the Palaeolithic period transitioned into the Mesolithic approximately 11,000 cal yr BP. The archaeological evidence in southern Scandinavia from this transitional time indicates a period of reduced human occupation (Larsson, 1990), which has been related to the disappearance of reindeer in association with the warming climate (Price, 2015). Following this period of reduced settlement, southern Scandinavia was repopulated by increasingly more sedentary hunter-gatherers that to a large extent were living in and exploiting the marine and coastal environment (Price, 2015; Boethius, 2016, 2017). This way of life persisted until approximately 6,000 cal yr BP, when farming quickly spread throughout southern Scandinavia and the Neolithic period began (Price, 2015). Farming brought domesticated animals like cattle and pigs, and crops like barley and wheat, and led to increasing human impact on the vegetation and environment (Price, 2015).

### 3.4.1 Skatmossen

Skatmossen (English: Edge's Bog, alternatively Magpie's Bog) is an archaeological site (RAÄ: Ås 114:1) located approximately 13 km northeast of Varberg in northwestern Halland, southwestern Sweden (figure 1). The site was first discovered in the mid 1980's, but it was excavated first in the year 2000 (Nordqvist, 2003). Findings at the Skatmossen site consist of remains of flintworking that are typologically similar to finds belonging to the Magdalenian culture, and the site is assumed to have been a temporary or seasonal settlement (Nordqvist, 2003).

The Skatmossen archaeological site is situated on a saddle between two hilltops, just south of a small lake. In the early Lateglacial period, when the archaeological site is thought to have been occupied, the two hilltops and saddle would have constituted a small island (figure 2b) due to relative sea levels being higher than in the present. The dating of the archaeological finds at Skatmossen is based on some of the flint fragments found being rounded and likely wave washed. Because of this, it was assumed that the camp at Skatmossen must have been occupied when sea levels reached as high as the location of the wave-washed flint. In the original publication by Nordqvist (2003), the elevation of the site was estimated to 65 m a.s.l. and it was dated to around 13,000 $^{14}$C yr BP using a shoreline displacement curve for the northeastern Varberg area by Påsse (1990). More recent LiDAR based elevation measurements do however indicate that the Skatmossen site lies at 63 m a.s.l., but this does not significantly affect its radiocarbon age according to the shoreline displacement curve. By calibrating the radiocarbon age presented by Nordqvist (2003) using the IntCal20 calibration curve (Reimer *et al.*, 2020) in OxCal 4.4 (Ramsey, 2009), an age of around 15,500 cal yr BP can be estimated for the archaeological finds at Skatmossen. Since the construction of the shoreline

displacement curve used is not described in detail by Påsse (1990), it is however not possible to make exact calibrations. Later modelling of shoreline displacement in Sweden has set the Varberg shoreline of 15,000 cal yr BP to just above 60 m a.sl. (Påsse and Daniels, 2015), but the model does not go further back in time than this. Based on the shoreline displacement curves, the Skatmossen archaeological site is likely to have an age of somewhere between 15,500–15,000 cal yr BP. This means that the old campsite at Skatmossen is likely of an Oldest Dryas age, which makes it possibly the oldest, or one of the oldest, known archaeological sites in Sweden.

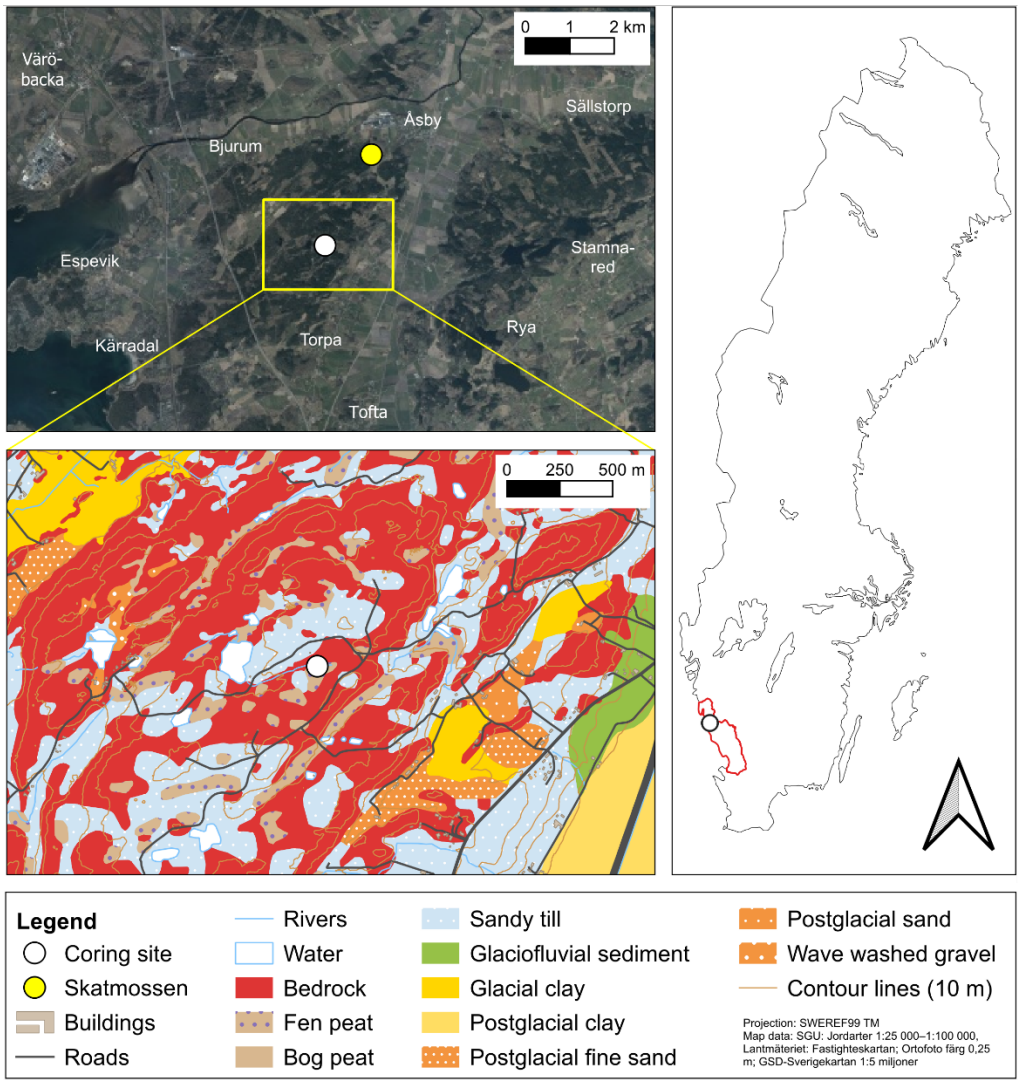


**Figure 1.** Overview and Quaternary deposit maps of the coring site at Käringmossen and the archaeological site at Skatmossen. In the overview map showing Sweden, the Halland province, where the study area is situated, is marked with a red outline.

In addition to the Palaeolithic artefacts found at Skatmossen, the local area is in general rich in archaeological remains of past human habitation. Only within a 1 km radius, there are three additional Stone Age settlements (RAÄ Ås 111:1; Ås 112:1; Ås 113:1), as well as settlements from the Bronze Age and early Iron Age (Altner and Streiffert, 2019), and a Viking Age grave field (Ängeby and Connelid, 2022). In the larger surrounding area, in Veddige, about 7 km northeast of Skatmossen, more potential evidence of early Stone Age human presence has been found in the form of a tanged point (flint projectile point) typologically similar to those of the Hamburgian culture (Nordqvist, 1996). From Veddige there is also evidence of early agriculture in the form of burned cereal grains dated to around 6,000 cal yr BP (Johansson *et al.*, 2011; Sørensen and Karg, 2014).

# 4 Methods

## 4.1 Study area

The immediate surroundings of the Skatmossen archaeological site are dominated by a thin soil cover and are lacking in sediments suitable for a palynological study concerned with longer time scales. Where soil cover is thicker, agricultural fields instead dominate, which is also unsuitable as the upper parts of the soil has been disturbed. Attempts were made at retrieving sediment cores from a small lake located in direct proximity to the archaeological site, but none produced cores deeper than 2 m. Because the cores were short, they were deemed unlikely to go as far back in time as the age of the Skatmossen archaeological site, and if they did, the temporal resolution of the sedimentary record was likely to be low. Instead, a different coring site had to be chosen. This site was Käringmossen (English: Old Hag's Bog; coordinates: 57°12'34.2"N, 12°16'52.7"E), a fen situated approximately 2.3 km southwest of Skatmossen (figure 1). Käringmossen was deemed a suitable replacement for sampling at Skatmossen itself since it is located fairly close to the archaeological site and within the same upland area. It is therefore likely that the vegetational development at the two sites has been similar. Considering the very mobile lifestyle of Palaeolithic hunter-gatherers (Price, 2015) it is also highly probable that Käringmossen was visited or passed by the Skatmossen occupants.

### 4.1.1 Relative sea level changes

The study area, constituting the area surrounding both Käringmossen and Skatmossen, is situated about 5 km east of the current coastline of northern Halland. Käringmossen lies at an elevation of approximately 80 m a.s.l., which is 17 m above the Skatmossen archaeological site at 63 m a.s.l.. With the highest coastline of northern Varberg being approximately 74 m a.s.l. (Påsse, 1990), Käringmossen was located above sea level at the time of the last deglaciation, while the Skatmossen site was not. Deglaciation of the two sites most likely happened between 16,000–15,000 cal yr BP (Hughes *et al.*, 2016; Stroeven *et al.*, 2016), however in the reconstruction by Hughes *et al.* (2016), the ice sheet margin was at a stand-still within the study area between 17,000–16,000 cal yr BP, meaning that deglaciation could have taken place also around this time.

At the time of the last deglaciation, Käringmossen would have been located on an island in the outer parts of an archipelago (figure 2a). Later, when relative sea levels had dropped to 63 m a.s.l. and Skatmossen was likely first occupied, the two sites would have been parts of neighbouring islands in the archipelago (figure 2b). At this time, the islands would have been separated by approximately 750 m of water. As relative sea levels in northern Halland continued to fall rapidly, the Skatmossen and Käringmossen islands were merged into one island around 13,500 cal yr BP (figure 2c) when sea levels reached 47 m a.s.l. (Påsse and Daniels, 2015). Later, around 11,100 cal yr BP, this island merged with the Halland mainland, but became an island again around 9,200 cal yr BP as relative sea level rose (Påsse and Daniels, 2015). Käringmossen and Skatmossen then remained parts of this island until around 4,700 cal yr BP when relative sea levels were decreasing again (Påsse and Daniels, 2015).

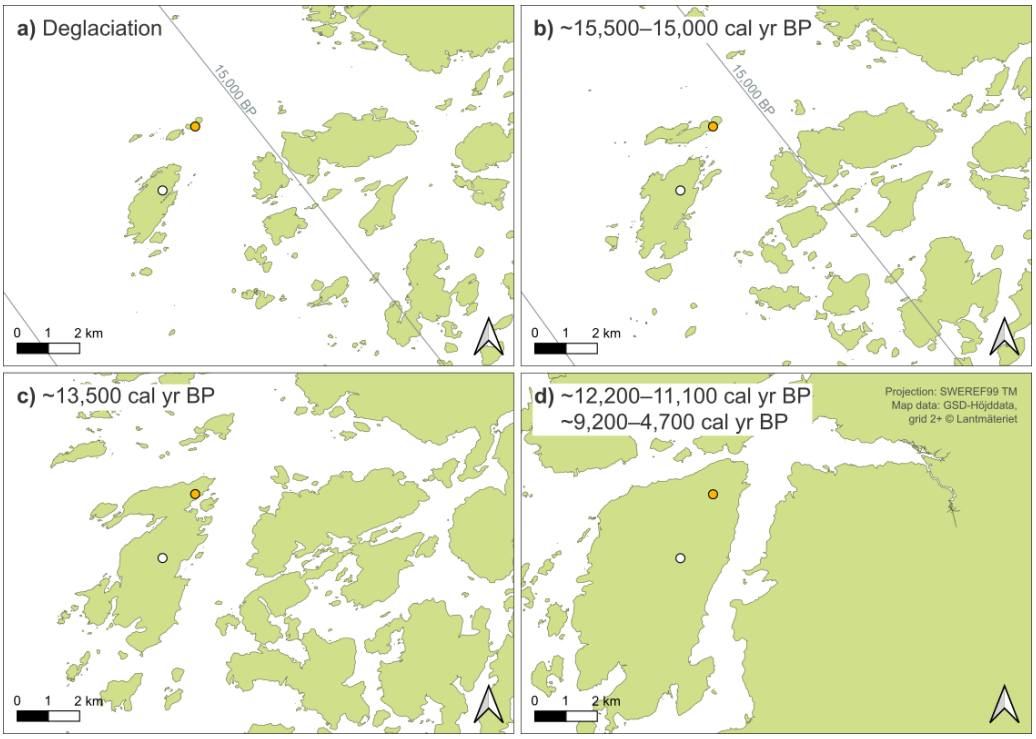


**Figure 2.** Sea levels at Skatmossen (orange dot) and Käringmossen (white dot) at different times: a) last deglaciation; b) around 15,500–15,000 cal yr BP, when the Skatmossen archaeological site was first occupied; c) around 13,500 cal yr BP; d) around 12,200–11,100 cal yr BP and 9,200–4,700 cal yr (Påsse, 1990; Påsse and Daniels, 2015). The grey lines in maps a) and b) reflect the position of the Fennoscandian Ice Sheet margin about 15,000 cal yr BP (Stroeven *et al.*, 2016).

### 4.1.2 Käringmossen

The present-day fen at Käringmossen, where the sediment cores used in this thesis were retrieved, has a surface area of approximately 1.7 ha. In mappings by the Swedish Geological Survey (SGU), the deposits at the site are classified as fen peat (figure 1). Similar to at Skatmossen, the fen surroundings are dominated by thin Quaternary deposits and bedrock outcrops, with thicker deposits generally found at lower points in the terrain and consisting mainly of sandy glacial till, or till overlain by fen peat (figure 1). The bedrock in the area is predominantly metamorphic and acidic and formed as part of the Sveconorwegian orogeny around 1,1–0,9 Myr BP (SGU, no date).

The present day climate of southern Sweden and at Käringmossen can, following the Köppen-Geiger classification, be described as warm-summer humid continental (Dfb) (Beck *et al.*, 2018). The mean annual temperature at the closest weather station in Varberg for the normal period 1991–2020 was 8.3°C and the mean temperatures of the warmest (July) and coldest (January and February) months of the year were 17.5°C and 0.2°C respectively (Swedish Meteorological and Hydrological Institute, 2021b). Mean annual precipitation for the same normal period at the closest measuring station, Veddige D, was 997.7 mm/yr (Swedish Meteorological and Hydrological Institute, 2021a).

Käringmossen is situated within the nemoral zone of coastal southern Sweden, meaning that vegetation is dominated by temperate deciduous forest. The hilly immediate surroundings of the fen where soil cover is thin are however dominated by planted coniferous forest, while the surrounding lowlands largely consist of agricultural fields. The local planted coniferous forest consists of *Pinus sylvestris* and *Picea abies*, with some occurrences of *Betula* spp. and *Quercus robur*. Lower forest vegetation is mainly *Juniperus communis*, *Vaccinium myrtillus* and *V. vitis-idaea*, as well as Poaceae spp. and *Hypnum cupressiforme* moss. Local vegetation on the fen itself is dominated by *Sphagnum* moss, on which ericaceous dwarf shrubs grow, including *Empetrum nigrum*,

*Calluna vulgaris*, *Erica tetralix*, *Vaccinium oxycoccos* and *V. uliginosum*. *Eriophorum angustifolium* and *E. vaginatum* are also abundant, along with *Carex* spp., *Drosera* spp. and *Polytrichum commune* moss. In drier areas and in the fen margins, smaller individuals of *Pinus sylvestris, Picea abies*, *Betula* spp. and *Larix* spp. occur, and *Nymphaea alba* grows in pools of open water.

## 4.2 Field methods

Field work was carried out on June 14th and 15th 2022 with the purpose of gathering material for palynological and stratigraphic analysis. For this, a Russian corer, producing half cylinder core segments with a length of 1 m and a diameter of 4 cm, was used to retrieve sediment cores from wetland sites. On the first day, coring attempts were made at Skatmossen and in minor peat deposits in its near surroundings. These attempts did however fail at producing cores deeper than 2 m and on the second day of field work, the search area for suitable coring sites was expanded. The first wetland site to produce deeper cores was Käringmossen. Since these cores seemed to cover a long period of time and had a possible Younger Dryas section with high minerogenic content starting about 1 m above the bottom of the core (figure 4), Käringmossen was chosen as the study site.

At Käringmossen, ten cores were retrieved in total, reaching a maximum depth of 471 cm. The first core (KÄR01), later chosen to be the master core, was taken at coordinates 57°12'34.2"N, 12°16'52.7"E. It consisted of five 1 m segments and stretched from the top of the fen down to a depth of 469 cm. As the master core was retrieved, it was described with respect to its colour and its estimated sediment type. All other cores were later described in relation to and aligned with the master core based on these descriptions. The nine additional cores were all retrieved as single 1 m segments within a 2 m radius of KÄR01 and they covered depths between 0 and 471 cm. Along with the sediment cores, one top sample, consisting of approximately 0.5 $dm^3$ live *Sphagnum* moss, was taken from the fen surface. This was done to have a representation of the present-day pollen deposition at Käringmossen.

After coring, all core segments were packaged individually in plastic and the surface moss sample was stored in a plastic bag. The top segment of the master core was however not kept as it was highly fragmented and it was replaced by another core covering the top metre of the fen, KÄR05. Because the KÄR05 core was also fragmented, it had to be cut into 2 cm slices and stored in plastic bags. The cores and top sample were then brought back to Stockholm University where they were kept in cold storage at 4°C until laboratory work could begin.

## 4.3 Laboratory methods

Laboratory work for this thesis was performed using mainly the master core, KÄR01, along with KÄR05 for depths between 0–100 cm, and KÄR09 between 339–370 cm. Core KÄR09 was correlated with the master core based on sediment characteristics such as colour variations and laminations, while KÄR05 was correlated with the master core based on depth. The rest of the retrieved cores were saved for tephrochronological analysis to be performed by Susanna Logård. The laboratory methods used were radiocarbon dating, loss on ignition and pollen analysis. The cores also underwent X-ray fluorescence scanning, but these results are not used in this study and the methods will therefore not be presented here.

### 4.3.1 Radiocarbon dating

Radiocarbon dating was carried out on the Käringmossen master core with the purpose of establishing an age-depth chronology for the core. Dating was done using accelerator

mass spectrometry (AMS) on macrofossils sampled from different parts of the core. This sampling was performed by Simon Larsson.

In the sampling process, half of the master core between 100–469 cm was cut into 1 cm thick slices. These slices were then individually dissolved in distilled water in a petri dish, whereafter they were searched for dateable organic material using a stereo microscope at 10–45x magnification. Macrofossils potentially useful for dating were then separated from the rest of the material, identified to the lowest taxonomic level possible using reference literature and photos (Myrbo, Morrison and McEwan, 2011; Mauquoy and van Geel, 2013) and stored in distilled water. Dateable macrofossils were found at 49 different depths throughout the core, but only material from ten depths was sent for dating. Which samples to send for dating was decided based on the type of material found and with the purpose of achieving an even spread of dates. As the focus of this thesis has been on the older parts of the Käringmossen core, these parts were however prioritised for dating. When possible, preferred dating materials were seeds and leaves from terrestrial plants and wood pieces with bark. Terrestrial material was prioritised to avoid potential reservoir effects (Philippsen, 2013), and twigs with bark were prioritised over those without to avoid using roots that may penetrate deep into sediments and generate too young ages.

AMS dating of the sampled macrofossils was performed at the Tandem Laboratory at Uppsala University. The radiocarbon dates were then used to construct a calibrated age-depth model for the core using the Bayesian statistics-based R package Bacon (Blaauw and Christen, 2011; R Core Team, 2023) and the Northern Hemisphere IntCal20 radiocarbon calibration curve (Reimer *et al.*, 2020).

After calibration of the radiocarbon dates, the modelled ages were used to calculate the sediment accumulation rates ($AR$) in the Käringmossen core. These were calculated by dividing the difference in depth between two radiocarbon samples ($\Delta d$) by the difference in calibrated weighted mean age ($\Delta t$), using the following equation:

$$AR = \frac{\Delta d}{\Delta t}$$

### 4.3.2 Loss on ignition

The organic content of sediments may be used to interpret depositional environments and aid in sediment classification. The proportion of organic matter in the Käringmossen core was determined using loss on ignition (LOI) (Ball, 1964; Davies, 1974; Heiri, Lotter and Lemcke, 2001). In LOI, sediments are burned in a furnace at a set temperature for a set amount of time. Dry samples are weighed prior to and after burning and the proportion of weight lost serves as a proxy for the original proportion of organic matter in the sediments (Heiri, Lotter and Lemcke, 2001).

LOI was carried out in accordance with the procedure recommended by Heiri, Lotter and Lemcke (2001). Samples of approximately 2 $cm^3$ of material were taken at regular intervals between every cm to every 2.5 cm from the master core. The only exception was between depths 339–370 cm, where all material from the master core had been taken for other analyses and core KÄR09 was used instead. Samples were then dried overnight in an oven at 105°C, after which they were pulverised using a mortar and pestle and placed into pre-weighed crucibles. The dried samples were weighed along with the crucibles, burned at 550°C for 4 hours in a muffle furnace and then reweighed after having cooled off in a desiccator. LOI, expressed as the percentage of dry weight lost after burning, was then calculated using the following equation:

$$LOI = \frac{DW_{105} - DW_{550}}{DW_{150}} \times 100$$

In the equation above, $DW_{105}$ represents the dry weight prior to burning at 550°C and $DW_{550}$ represents the dry weight after burning.

### 4.3.3 Pollen

*Sampling*

Sampling for pollen analysis was performed on core KÄR01 between depths 100–469 cm and on KÄR05 between 0–100 cm. A total of 31 sediment samples were taken from different parts of the cores and were, along with part of the fen surface sample, prepared in two batches of 16 samples each to be used for pollen analysis. The general objective when choosing where to sample was to get at least one sample in every stratigraphic unit and preferably subunit. The greatest focus was however put on the bottom two metres since these (prior to receiving the radiocarbon results) were deemed most likely to contain sediments deposited at the same time as the Skatmossen archaeological site was occupied. Between depths 100–469 cm, pollen samples were taken as 1 cm thick slices of half of the master core and from the top metre, approximately half of the bagged 2 cm thick core slices were used as samples.

As sediment sampling for pollen analysis was made, samples were weighed, and their approximate volume estimated (table C3). The volume of the samples was calculated using a weight-volume transformation table (table C2), constructed by taking 1 $cm^3$ sediment samples from the core using a plastic container with a 1 $cm^3$ volume and then weighing the samples. In this sampling process, the aim was to achieve the same level of compaction as the core itself. Samples for the weight-volume transformation table were taken in the middle of every apparently homogenous unit of the core (largely based on colour and the constituents of the sediment) and at intervals of between 5–36 cm, except for the top metre where samples were scarcer. To calculate the approximate volume of a sediment sample taken for pollen analysis ($V_p$), its wet weight ($W_p$) was then divided by the weight of the 1 $cm^3$ sediment sample ($W_s$) belonging to the same homogenous unit, hence:

$$V_p = \frac{W_p}{W_s}$$

*Preparation*

After pollen sampling, between 2–8 tablets containing *Lycopodium clavatum* spores (batch number 140119321, average spore count 19 855 spores/tablet) were added to each pollen sediment sample. These tablets were added for the purpose of estimating absolute pollen concentrations and influx rates (Benninghoff, 1962; Davis, 1969; Stockmarr, 1971). To achieve the ideal 1:1 ratio of added *Lycopodium clavatum* spores to pollen (Regal and Cushing, 1979) it was estimated that 4 tablets would be needed in the first lab batch. This was however too little for many of the peat and gyttja samples and too much for the lower clay gyttja and gyttja clay samples. In the second lab batch, 8 tablets were therefore added to all pollen samples above 411 cm and 2 to all below this depth.

Following the addition of *Lycopodium clavatum* spores, the sediment samples were prepared for pollen analysis largely in accordance with the method recommended by Berglund and Ralska-Jasiewiczowa (1986). First, to dissolve the *Lycopodium clavatum* tablets and to break down possible calcium carbonates in the samples, a 10% solution of HCl was added. The samples were then placed in a hot water bath at 96°C for 10 min, after which they were centrifuged at 3600 rpm for 5 min, decanted and washed with water two times. The washing procedure consisted of adding water, stirring the samples with a glass staff and then centrifuging and decanting. Post washing, a 10% solution of NaOH was added to the samples to remove humic acids, and they were then placed in a 96°C water bath for 20 min to react. After this, samples were centrifuged, decanted and washed with water three times.

Unlike what is recommended by Berglund and Ralska-Jasiewiczowa (1986), acetolysis was performed on the samples after the addition of NaOH and prior to hydrofluoric acid (HF) treatment. Since acetolysis removes cellulose and therefore a large portion of the non-pollen organic matter in the samples, this was done to better be able to determine which samples would need HF treatment. To prepare the samples for acetolysis by removing water, glacial acetic acid ($CH_3COOH$) was added, whereafter the samples were centrifuged and decanted. The acetolysis solution, consisting of nine parts acetic anhydride ($(CH_3CO)_2O$) and one part 95% sulfuric acid ($H_2SO_4$), was then added to the samples after which they were heated in a water bath at 96°C for 20 min. Samples were then centrifuged and decanted and $CH_3COOH$ was added again. The samples were then centrifuged and decanted once more, and a 10% NaOH solution was added. After this, samples were again centrifuged and decanted and washed with water two times.

After acetolysis, the samples with too high minerogenic content were treated with HF. To determine which samples would need treatment, microscope slides of samples from the more minerogenic parts of the core were prepared and they were observed under microscope. The samples where mineral grains to a large extent complicated pollen counting by diluting or obscuring pollen grains were then selected for HF treatment to remove silica. This was deemed necessary for all samples from a depth of 358 cm and below. To these samples a 40% HF solution was added, after which they were left to react for 14 days in the first lab batch and 5 days in the second. After this, samples were centrifuged, decanted and washed with water one time. 10% HCl solution was then added to the samples, and they were put in a 96°C water bath for 20 min to react. Lastly, 10% NaOH solution was added. Following HF treatment or acetolysis (if HF was not needed), all samples were put into smaller test tubes and stored in a 1:1 water/glycerine solution.

After the preparation procedure, some samples needed additional treatment to make pollen grains more visible. The top sample still contained large amounts of non-pollen organic matter and the HF treated samples contained a black sludge that obscured pollen grains and complicated pollen identification and counting. To remove larger organic matter, the top sample was sieved using a sieve with a 177 µm mesh size that allowed for pollen but not larger organic particles to pass through. The black sludge from the HF treated samples was removed using filter cloth with a mesh size of 10 µm, through which the sludge could pass but not pollen grains. To facilitate the passage of particles through such a small mesh size, sieving was performed in an ultrasonic bath. These two filtering procedures made pollen counting and identification in the uppermost and lower samples easier.

*Identification and counting*

After preparation, the pollen samples were subsampled and mounted on microscope slides in a 1:1 water/glycerine solution, using nail polish to seal the cover glass. The subsamples were then observed under a light microscope at 400x magnification, and pollen grains and added *Lycopodium clavatum* spores were identified and counted along eight transects in each microscope slide. Phase contrast and 1000x magnification was used to aid the identification of certain pollen grains with smaller and less visible structures. The grains were identified to the smallest taxonomic unit possible, from family to species level, and this was done using the keys in Fægri *et al.* (1989), Moore, Webb and Collinson (1991) and Beug (2015) (ordered from most to least used). Identification was also aided by the pollen type slide collection at the Department of Physical Geography at Stockholm University, as well as pollen photos in Reille (1992) and descriptions in Erdtman, Berglund and Praglowski (1961). As pollen grains were identified and counted, certain easily distinguishable non-pollen palynomorphs (NPPs) were also counted. These were identified using a NPP compilatory compendium by van Hoeve and Hendrikse (1998), with images and descriptions from van Geel (1978) and Kuhry (1985, 1997).

The goal for each pollen sample was to count at least 500 pollen grains (excluding NPPs). For some samples this was achieved through only one microscope slide subsample, but others required more counted slides. Due to the time limits of this study, a count of 500 pollen was not achievable at certain depths where pollen concentration was low. Therefore, a limit of five microscope slide subsamples per sample was set to not spend too much time at one single depth.

*Statistical analysis and pollen diagrams*

All pollen data was compiled and analysed in Tilia version 3.0.1 (Grimm, 1991). For the production of pollen diagrams, the relative abundance of the different pollen and NPPs was calculated in percents. The relative abundance of terrestrial angiosperms and gymnosperms was calculated using the sum of all terrestrial pollen at one depth, while the relative abundance of aquatic angiosperms and NPPs was calculated using the sum of terrestrial pollen and the different palynomorph subgroups. The palynomorph subgroups were aquatic angiosperms, pteridophytes, mosses, algae, fungi and amoebae. As such, the relative abundance of pteridophytes was, e.g., calculated using the terrestrial pollen sum and the pteridophyte sum. The relative abundances of pollen were then used for cluster analysis, using the CONISS tool (Grimm, 1987) in Tilia. This statistical tool groups pollen samples based on their dissimilarity and the results of the analysis were used to guide the division of the Käringmossen sediment core into different local pollen assemblage zones (LPAZ).

To be able to trace how pollen deposition has changed over time at Käringmossen, pollen influx rates were calculated for all pollen samples. This was done by first calculating the pollen concentration of the samples and then relating it to the deposition time of the sample, as indicated by the age-depth model (Davis, 1969). Calculation of pollen concentration was done by comparing the number of pollen grains counted in one sample to the number of *Lycopodium clavatum* spores counted. Since the total amount of *Lycopodium clavatum* spores added to the samples can be calculated by multiplying the average spore count of one tablet with the number of tablets added, the proportion of spores to pollen can be used to estimate the absolute pollen count of the sample (Stockmarr, 1971). By relating the absolute sample pollen count to the sample volume, an absolute pollen concentration in pollen grains/cm$^3$ can be estimated. Calculation of pollen concentrations was done in Tilia using the following equation, modified from Benninghoff (1962):

$$c = \frac{m_c \times L_t \times t}{L_c \times v}$$

In which, $c$=the concentration of pollen or NPPs in a sample; $m_c$=the number of pollen or NPPs counted in the sample; $L_t$=the number of *Lycopodium clavatum* spores in tablets added to the sample; $t$=the number of *Lycopodium clavatum* tablets added; $L_c$=the number of counted *Lycopodium clavatum* spores; and $v$=the volume of the sample. In the original equation, pollen concentration was calculated based on weight instead of volume (Benninghoff, 1962).

The pollen concentration of the samples was then used to calculate pollen influx rates following the method of Davis (1969), which gives an estimate of yearly pollen influx in grains/cm$^2$/yr. Calculation of pollen influx rates ($PI$) was done in Tilia by dividing the pollen concentration of a sample ($c$) with the accumulation time of the sample as given by the age depth model ($a$) using the following equation:

$$PI = \frac{c}{a}$$

# 5 Results

## 5.1 Stratigraphy

The division of the Käringmossen core into stratigraphic units was based on colour and estimated grain size variations described in the field and lab, on the results of LOI and on the types of plant remains found during radiocarbon sampling. Based on these measures, the core was divided into seven main stratigraphic units, with units 2 and 3 further divided into three and two subunits respectively (table 1; figure 3; figure 4).

**Table 1.** Stratigraphic units in the Käringmossen master core, KÄR01 and KÄR05 (0–100 cm).

| Stratigraphic unit/subunit | Depth (cm) | Description |
|---|---|---|
| 7b | 0–80 | *Sphagnum* peat; light brown; low humification |
| 7a | 93–165 | *Sphagnum* peat; brown; medium humification |
| 6 | 165–245 | Fen peat; dark brown; high humification; Cyperaceae fragments and twigs |
| 5 | 245–273 | *Sphagnum* peat; brown; low humification; abundant Cyperaceae remains; gradual transition at lower boundary |
| 4 | 273–293 | Fen peat; brown; low humification; Cyperaceae remains dominant; *Sphagnum* content increasing upwards |
| 3b | 293–303 | Gyttja; greenish brown; reed fragments |
| 3a | 303–352 | Gyttja; greenish brown to brown; fine detritus; homogenous; fairly sharp lower boundary |
| 2c | 352–363 | Clay gyttja; brownish grey; medium to coarse sand layer at 360 cm; frequent mica; fairly sharp upper boundary |
| 2b | 363–389 | Clay gyttja; greyish brown; mica |
| 2a | 389–464 | Clay gyttja with medium to coarse sand; colour from grey at the bottom to brownish grey at the top; darker laminations between 435–464 cm; mica |
| 1 | 464–469 | Gyttja clay with medium to coarse sand; grey with darker laminations; mica |

The lowermost unit, unit 1, is the thinnest of all units and covers only the lowest 5 cm of the core, between depths 469–464 cm (figure 3; table 1). It also has the lowest organic content at <6% and it consists mainly of grey, laminated gyttja clay with some inclusions of medium to coarse sand.

The second unit is thicker and has a higher LOI than the first. It consists of clay gyttja and covers depths between 464–352 cm (figure 3; table 1). This unit was further subdivided into three subunits largely based on the organic content of the sediments. Subunit 2a covers the lowermost depths, from 464 cm to 389 cm, and it has the lowest organic content of the subunits at <10% (figure 3). This subunit also contains some

medium to coarse sand and it varies in colour from grey at the bottom to brownish grey at the top. Subunit 2b stretches between depths 389–363 cm and has the highest organic content of the three subunits at >15% (figure 3). This subunit has a greyish brown colour and, unlike subunit 2a, contains no sand. Subunit 2c covers the uppermost parts of unit 2, from a depth of 363 cm to 352 cm. Its lower boundary was defined based on a decrease in organic content to below 15% that persists throughout the subunit until the fairly sharp upper boundary (figure 3). The unit has a brownish grey colour and contains a 0.5–1 cm thick layer with coarse sand at 360 cm.

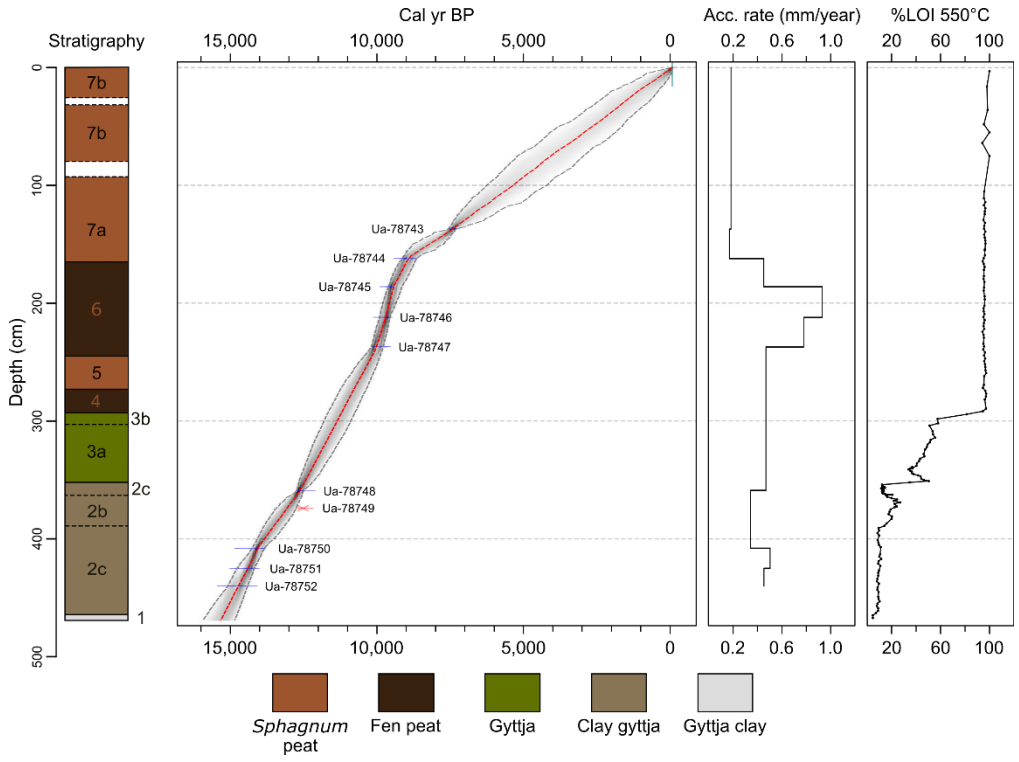


**Figure 3.** Stratigraphy, age-depth model, accumulation rate and loss on ignition for the Käringmossen master core (KÄR01) and KÄR05 (0–100 cm).

Unit 3 consists of greenish brown gyttja with LOI values between 30–60% and it covers depths between 352–293 cm (figure 3; table 1). The lower boundary between unit 2 and 3 is sharp. Unit 3 was divided into two separate subunits, 3a and 3b, with the main difference between the subunits being that 3b contains reed fragments, while 3a does not. Subunit 3b, which covers depths between 303–293 also has a higher organic content (>55%) than subunit 3a (figure 3).

The fourth unit consists of brown fen peat and stretches between depths 293–273 cm (figure 3; table 1). The unit has a high organic content at >95% and low humification, with the peat consisting largely of Cyperaceae fragments and some *Sphagnum* moss remains. *Sphagnum* content is lowest at the bottom of the unit and increases upwards until the gradual transition into the *Sphagnum* peat dominated unit 5 around 273 cm.

Sedimentary unit 5 consists of brown *Sphagnum* peat and starts at the gradual transition from unit 4 around 273 cm and ends at 245 cm (figure 3; table 1). This unit has a low degree of humification and LOI values of >95%. The peat in the unit consists mainly of *Sphagnum*, but Cyperaceae remains also occur.

Unit 6 covers depths between 245–165 cm and consists of highly humified fen peat (figure 3; table 1). The colour of the peat is dark brown and because of the high humification, plant remains were not easily distinguishable. When plant remains were distinguishable, these consisted mainly of twigs and Cyperaceae fragments.

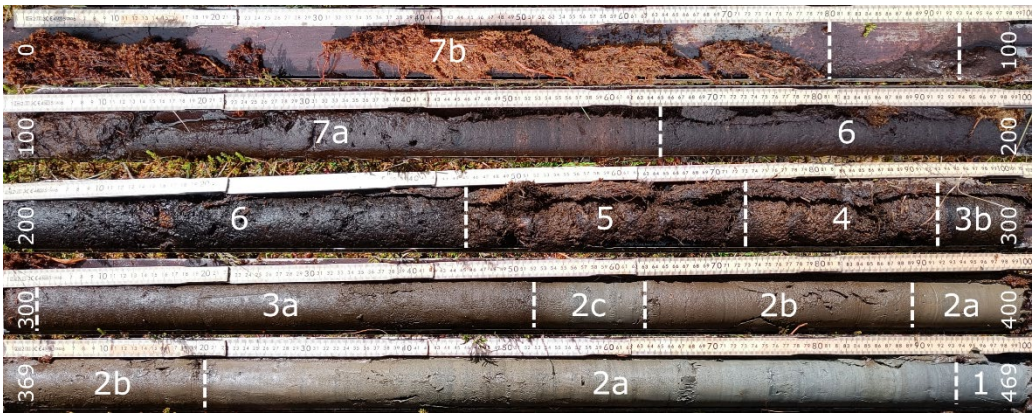


**Figure 4.** Photos of the Käringmossen master core (KÄR01) and core KÄR05 (between depths 0–100 cm) taken in the field, with stratigraphic units marked in white. Depths are given in cm at the ends of the core segments.

The seventh unit is the thickest of all units and covers the top of the Käringmossen core, between depths 165–0 cm (figure 3; table 1). This unit consists of *Sphagnum* peat and has an organic content between 94–100%. Based on variations in humification and colour, the unit was divided into two subunits, 7a and 7b. Subunit 7a covers depths between 165–93 cm and consists of brown, medium humified peat, while subunit 7b covers the top 80 cm and consists of light brown, low humified peat. In the top metre of unit 7, there are two gaps in the core, between 93–80 cm and 32–26 cm (figure 3). These parts were lost in the coring process due to the high water content of the peat.

## 5.2 Chronology

The results of the AMS radiocarbon dating are shown in table 2. The yielded radiocarbon ages varied from 12,553 $^{14}$C yr BP at a depth of 440 cm (Ua-78752) to 6,518 $^{14}$C yr BP at 137 cm (Ua-78743). For these dates, the one sigma standard deviation varied between ±64 and ±34 years.

Calibration and age-depth modelling was performed using nine of the ten radiocarbon ages yielded from the AMS dating. Sample Ua-78749 at 374 cm depth was excluded because it had a younger radiocarbon age than the sample above it and it was deemed most likely to be the outlier because it was based on less sample material than the other dates and was therefore, during the AMS dating, graphitized using a different method than the other samples. The results of the calibration and age-depth modelling are shown in table 2 and figure 3. The weighted mean of the modelled age of the oldest sample at 440 cm was 14,725 cal yr BP and 7,422 cal yr BP for the youngest sample at 137 cm. Modelling also provided an interpolated weighted mean age estimate of 15,326 cal yr BP for the bottom of the core at 469 cm.

Based on the calibrated radiocarbon ages, the accumulation rates throughout the Käringmossen master core were calculated (figure 3). In the lowermost parts of the core, between 440–408 cm, the accumulation rate is around 0.5 mm/yr. This later drops to about 0.3 mm/yr between 408–359 cm and then rises again to about 0.5 mm/yr between 359–237 cm. After this, the accumulation rate reaches its highest levels at approximately 0.8 mm/yr and 0.9 mm/yr between 237–212 cm and 212–186 cm. The accumulation rate then drops back to around 0.5 mm/yr between 186–162 cm, after which it decreases further to about 0.2 mm/yr for the rest of the core.

**Table 2.** Results of AMS radiocarbon dating of the Käringmossen master core.

| Laboratory number | Depth (cm) | Accumulation type | Sample material | Radiocarbon age ($^{14}$C yr BP) | Model weighted mean age (cal yr BP) | 95% confidence interval age (cal yr BP) |
|---|---|---|---|---|---|---|
| Ua-78743 | 137 | *Sphagnum* peat | 1 twig piece with bark | 6,518±34 | 7,422 | 7,287–7,559 |
| Ua-78744 | 162 | *Sphagnum* peat | 2 twig pieces with bark | 8,115±36 | 8,895 | 8,629–9,128 |
| Ua-78745 | 186 | Fen peat | 1 twig piece | 8,585±42 | 9,426 | 9,137–9,608 |
| Ua-78746 | 212 | Fen peat | 1 twig piece with bark | 8,676±37 | 9,705 | 9,559–9,892 |
| Ua-78747 | 237 | Fen peat | 1 twig piece | 8,754±37 | 10,026 | 9,805–10,185 |
| Ua-78748 | 359 | Clay gyttja | 1 wood fragment, 1 twig piece with bark | 10,578±41 | 12,626 | 12,489–12,729 |
| Ua-78749 | 374 | Clay gyttja | 2 leaf fragments, 1 *Betula* seed, 2 brown moss stems | 10,568±50 | *excluded* | *excluded* |
| Ua-78750 | 408 | Clay gyttja | 4 wood fragments, 2 *Ranunculus* seeds, 1 beetle carapace | 12,195±45 | 14,057 | 13,834–14,254 |
| Ua-78751 | 425 | Clay gyttja | 17 *Ranunculus* seeds, leaf fragments | 12,332±44 | 14,394 | 14,166–14,777 |
| Ua-78752 | 440 | Clay gyttja | 1 twig piece, 1 *Ranunculus* seed | 12,553±64 | 14,725 | 14,409–15,082 |

## 5.3 Local pollen assemblage zones

Based on the pollen assemblages of the different pollen samples, the Käringmossen core was divided into nine different LPAZ. This division was based on the results of the CONISS cluster analysis, which were deemed to accurately capture the general large-scale patterns in vegetation variability over time. The nine LPAZ vary in extent from 32–91 cm, cover time scales between 600–5,000 years and contain between 2–6 pollen samples each (figures 5a and 5b). In the following section, these zones are described with reference to pollen influx rates (figure 6) and the relative abundance of different pollen taxa and taxa groups (figures 5a and 5b).

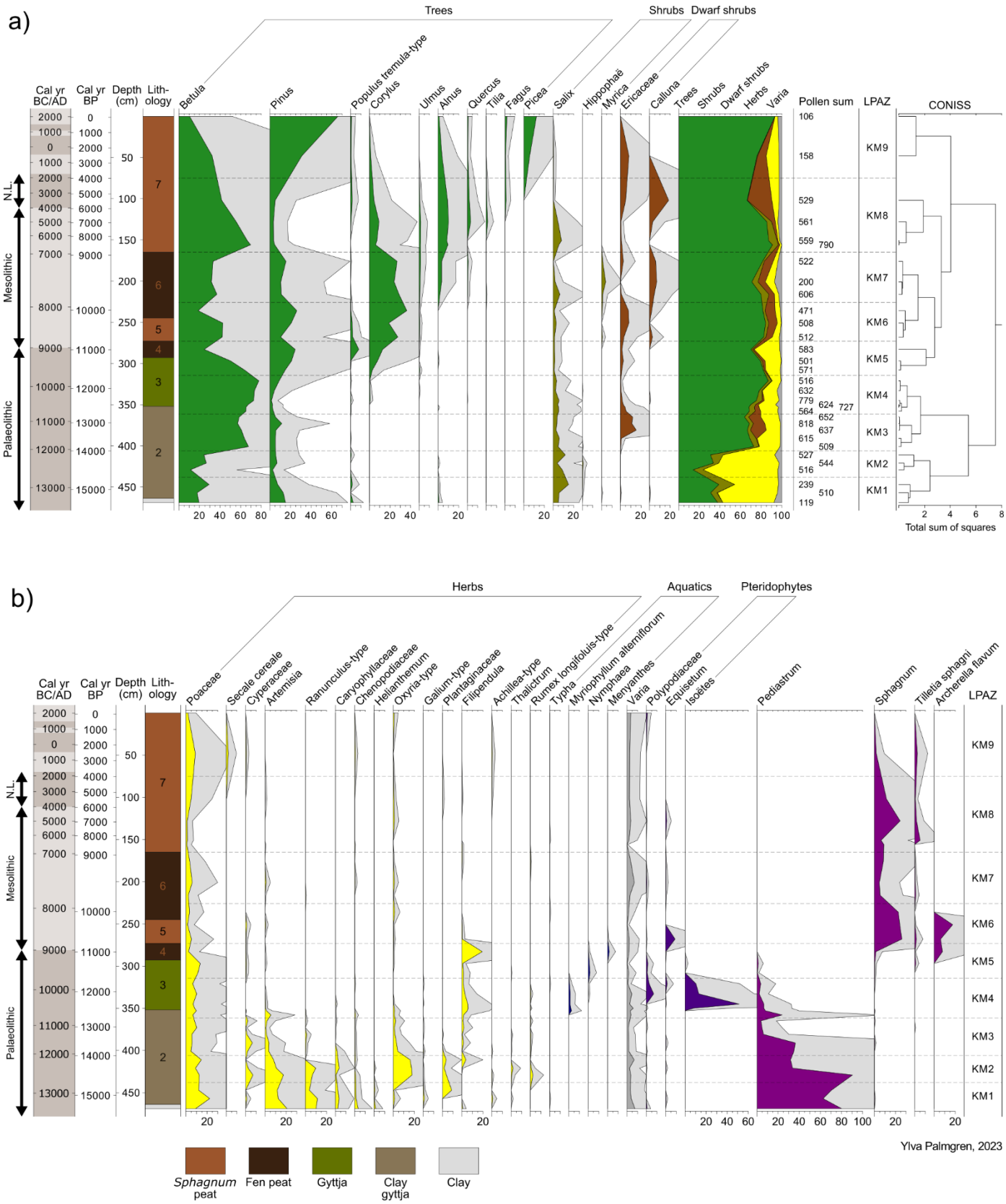


**Figure 5.** Pollen percentage diagrams for Käringmossen showing selected taxa of a) trees, shrubs and dwarf shrubs, and b) herbs, aquatic macrophytes, pteridophytes and other NPPs. Only taxa making up ≥1% of at least one pollen sample are included in the diagrams, along with *Hippophaë* and *Typha* that do not reach 1%. The grey shading is a 5x exaggeration of the percentage values. N.L. stands for Neolithic.

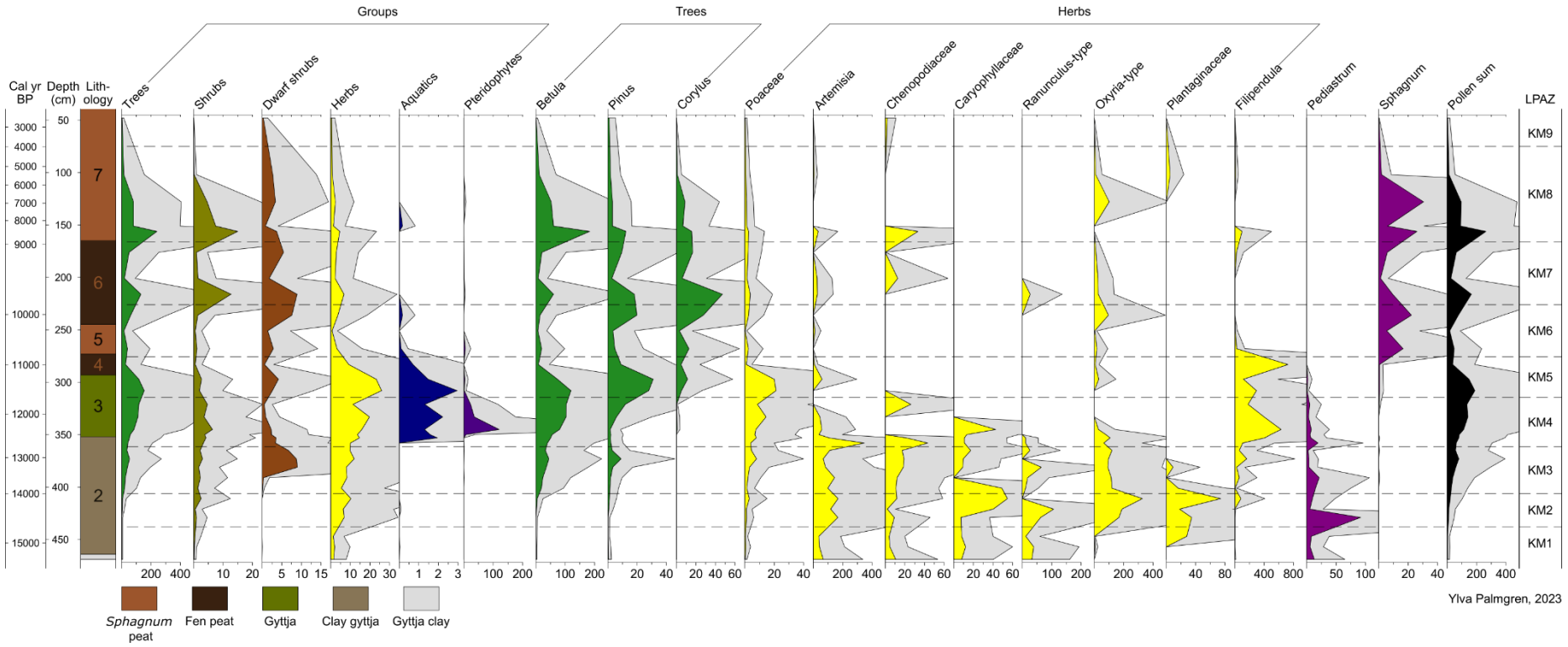


**Figure 6.** Pollen and spore influx rates in grains/cm$^2$/yr for plant taxa groups and the three most common tree taxa, eight most common herbs and two most common NPP taxa. All values except for the individual herb taxa are divided by 100. Poaceae values are also divided by 100. The grey shading is a 10x exaggeration of the influx values.

### 5.3.1 LPAZ KM1 (469–438 cm; 15,300–14,700 cal yr BP)

LPAZ KM1 has the lowest pollen influx rates of all pollen zones at just above 300 grains/cm$^2$/yr (figure 6). The zone is dominated by herb pollen (figure 5a) and of these, the three most abundant taxa are *Artemisia* (figure 7a) at 12–21%, Poaceae at 9–23% and *Ranunculus*-type at 4–11% (figure 5b). In addition to this, other taxa that reach peak percentages in KM1 include Caryophyllaceae, Chenopodiaceae, *Helianthemum* (figure 7b) and Plantaginaceae. Among the shrubs, *Salix* is the most abundant pollen taxa, and it reaches peak percentages at 15% in the uppermost sample of KM1. *Hippophaë* is also present in most of the zone. Tree pollen are, on the other hand, not very abundant in KM1. *Betula* pollen occur in percentages of between 15–30% and *Pinus* in up to 15%. *Populus tremula*-type pollen are also present, but do not occur in high percentages. Among the NPPs, *Pediastrum* reaches high percentages in zone KM1, between 60–80%.

### 5.3.2 LPAZ KM2 (438–406 cm; 14,700–14,000 cal yr BP)

In LPAZ KM2, pollen influx rates are still low, but considerably higher than in the previous zone, between 900–2,100 grains/cm$^2$/yr (figure 6). Herb pollen continue to be the dominant pollen type and in the lowermost sample of KM2 (429 cm), they reach peak percentages in the core at 73% (figure 5a). The most common pollen types of LPAZ KM2 are similar to KM1, with the exception of *Oxyria* which increases markedly and reaches peak values of around 17% (figure 5b). A peak in *Hippophaë* shrub pollen is also reached in zone KM2 at 1%. At the same time, tree pollen percentages remain continuously low at between 14–34% and *Betula* reaches one of its lowest percentages of the entire core at 11% in the 429 cm sample.

Similar to herb pollen, the green algae *Pediastrum* reaches its highest percentages in LPAZ KM2, peaking at 91% in the 429 cm sample (figure 5b). However, because of this high *Pediastrum* abundance compared to pollen, it was deemed unreasonable to count all algae in the sample at 429 cm. After having counted >2,000 *Pediastrum* and only 200 pollen, it was therefore conservatively estimated that the ratio of *Pediastrum* to pollen was 10:1, and an estimate of the *Pediastrum* count of the sample was calculated based on this ratio. Although *Pediastrum* values are by far highest in the sample at 429 cm, percentages are high also in the other samples of KM2, around 33%.

### 5.3.3 LPAZ KM3 (406–361.5 cm; 14,000–12,700 cal yr BP)

In the third pollen zone, pollen influx rates continue to rise, from about 2,800 grains/cm$^2$/yr in the lowest sample at 401 cm, to about 7,900 grains/cm$^2$/yr at 373 cm. After this peak, pollen influx rate does however drop to 5,600 grains/cm$^2$/yr in the uppermost sample of LPAZ KM3 (figure 6). The third pollen zone is characterised by a marked increase in tree pollen from less than 40% in previous zones, to around 70% (figure 5a). *Betula* is the dominant tree pollen type with percentages of about 65%, while the only other steadily occurring taxon, *Pinus*, occurs in percentages of around 5%. Along with the tree pollen increase, Ericaceae pollen (figure 7c) appear and reach peak values of 15% in the upper half of KM3. While tree and dwarf shrub pollen increase, the proportion of herb pollen decreases from more than 50% in previous zones to between 14–22% in KM3. Especially Poaceae and *Oxyria*-type pollen decrease, Poaceae from around 10–20% to 5–10% and *Oxyria*-type from around 17% to around 3% (figure 5b). Other herb taxa that were prominent in previous zones that decrease in KM3 include *Artemisia*, *Ranunculus* and Caryophyllaceae. In absolute numbers, there is however a slight increase in herb pollen in zone KM3, but it is obscured by greater increases in tree and dwarf shrub pollen (figure 6). Certain herbs from previous zones do still disappear, such as *Helianthemum* and Plantaginaceae. The shrub *Hippophaë* also disappears. At the same time, the relative abundance of *Pediastrum* algae is still high in the lower samples of zone KM3, but drops towards the upper samples, from around 35% to 5%.

### 5.3.4 LPAZ KM4 (361.5–314.5 cm; 12,700–11,700 cal yr BP)

Following the decrease in pollen influx rates of late KM3, pollen influx values of early KM4 also start out at about 6,100 grains/cm$^2$/yr, but they later rise to around 13,400 grains/cm$^2$/yr in the topmost sample (figure 6). LPAZ KM4 is characterised by the appearance, peak and disappearance of the aquatic angiosperm *Myriophyllum alterniflorum*, as well as the appearance and peak of the aquatic pteridophyte *Isoëtes* at 52% (figure 5b). *Nymphaea* also appears for the first time in the upper parts of KM4. Tree pollen abundance, both relative and absolute, increases further in the zone and *Betula* reaches peak percentages of 77% in the uppermost sample at 321 cm (figure 5a). *Pinus* pollen are however not abundant, occurring in percentages between 2–4% in all samples but the top one, where there is a rapid increase to 9%. In addition to this, mid- to late KM4 also marks the first appearances of *Corylus* and *Ulmus* pollen. At the same time, pollen from Ericaceae dwarf shrubs decrease throughout LPAZ KM4 after the peak in KM3, and many of the herbs that were already decreasing in KM3 continue to decrease. In absolute numbers, herb pollen are however increasing multifold in this pollen zone compared to previous zones (figure 6). Poaceae is the most common herb pollen taxa, followed by *Artemisia* and *Filipendula* that each have local peaks of around 6% at depths 358 cm and 350 cm respectively. A previously abundant herb pollen taxa that disappears in KM4 is however *Ranunculus*-type. *Pediastrum* increases rapidly in earliest KM4 to a peak at 24%, after which it decreases again to 8% and a decreasing trend is established for the rest of the zone.

### 5.3.5 LPAZ KM5 (314.5–275.5 cm; 11,700–10,800 cal yr BP)

In early LPAZ KM5, a peak in pollen influx rate is reached at 18,800 grains/cm$^2$/yr, which is then followed by a marked decrease to around 3,700 grains/cm$^2$/yr in the uppermost sample of the zone (figure 6). KM5 is otherwise characterised by a continuous increase in *Corylus* and *Pinus* pollen percentages at the expense of *Betula*, which reaches only 25% in the uppermost sample (figure 5a). At the same time Poaceae increases in the lower parts of KM5 to reach a local peak of 14% at 297 cm, after which it drops to 2.5% in the uppermost sample at 283 cm (figure 5b). *Filipendula,* on the other hand, reaches peak percentages of 19% at 283 cm. This pollen sample contained large clumps (>20 grains) of immature *Filipendula* pollen (figure 7e), which to a large extent contributed to the high percentage at this level. *Nymphaea* pollen also peaks with 1.6% in KM5 and so does also *Menyanthes*, which appears and peaks at 1.5% at 283 cm. *Pediastrum* algae that have previously been common in the core, disappear completely in zone KM5 after 297 cm and the aquatic pteridophyte *Isoëtes* does the same. Instead, *Sphagnum* spores, along with the testate amoebae *Archerella flavum*, start increasing toward the upper part of the zone.

### 5.3.6 LPAZ KM6 (275.5–226 cm; 10,800–9,900 cal yr BP)

In early to mid LPAZ KM6, pollen influx rates remain low after the decrease in late KM5, with values of <5,000 grains/cm$^2$/yr (figure 6). This is followed by an increase to 7,600 grains/cm$^2$/yr in the uppermost sample of the zone. In KM6, the main defining features are the peaks in *Corylus* pollen, *Sphagnum* spores and the *Archerella flavum* testate amoebae (figures 5a and 5b). *Corylus* pollen reach percentages between 24–36%, while *Sphagnum* occurs in values above 20% and *Archerella flavum* peaks at 18% in the sample at 251 cm. Ericaceae pollen also have a local peak in mid to late KM6 with percentages around 8%. Another defining feature is the decrease in herb pollen percentages from around 10–25% to 4–7%. This decrease in herb pollen is also seen in pollen influx rates. As *Corylus* attains high values in KM6, *Betula* percentages remain low after the drop in late KM5. A pronounced decrease in *Betula* percentages happens at 236 cm, when it drops from 43% to 19%. *Pinus* also decreases in the lowest sample of KM6, at 268 cm, to about 10% but increases again to >20% in the other samples. At

the same time, *Ulmus* starts occurring continuously from LPAZ KM6 in percentages of around 0.5%. In addition, KM6 marks the disappearance of aquatic taxa from the core after *Menyanthes* disappears in the middle of the zone.

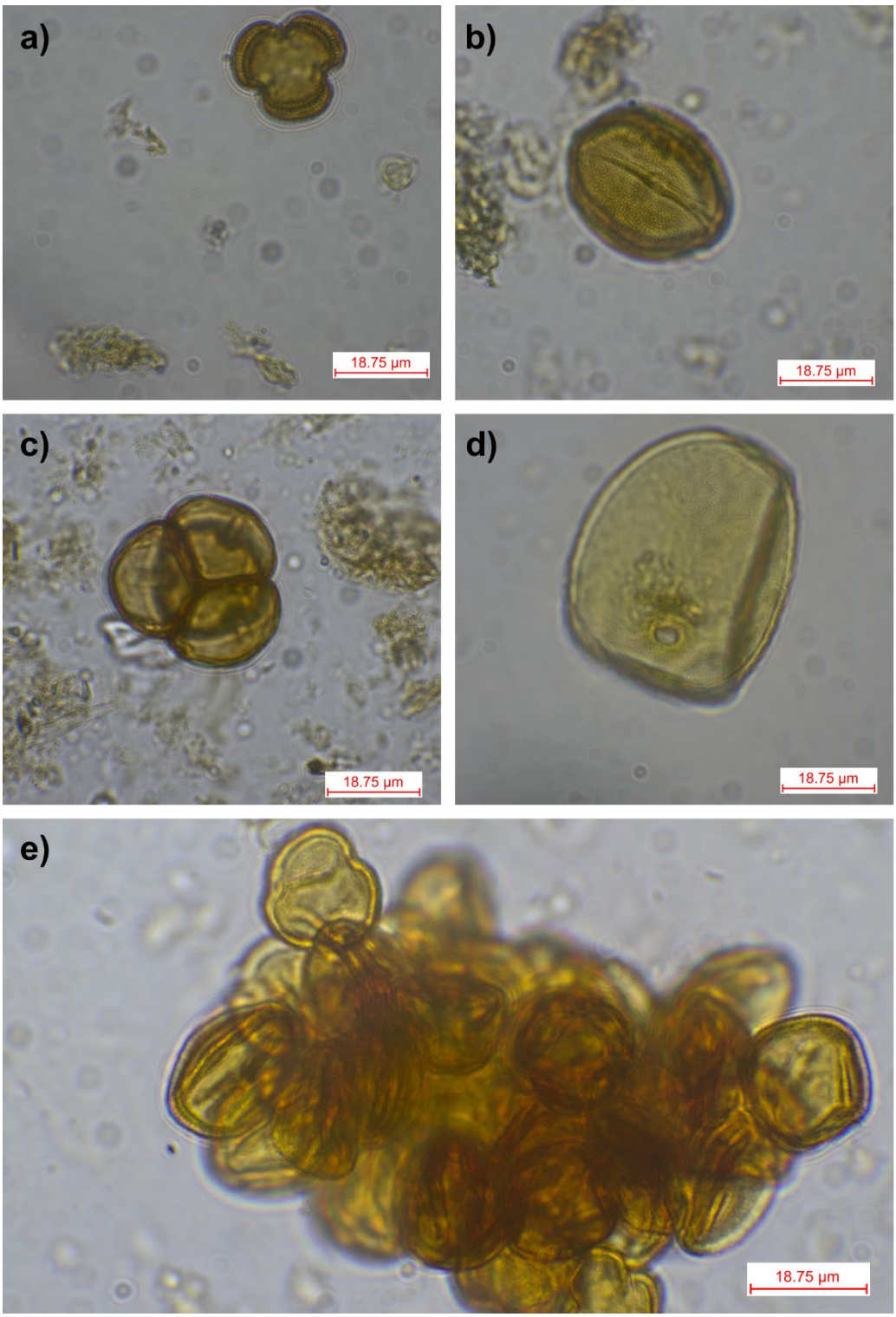


**Figure 7.** Pollen from the Käringmossen core at ×1000 magnification: a) *Artemisia*; b) *Helianthemum*; c) Ericaceae; d) *Secale cereale*; e) clumped *Filipendula* pollen.

### 5.3.7 LPAZ KM7 (226–166 cm; 9,900–9,000 cal yr BP)

In the seventh pollen zone, pollen influx rate peaks in the lowermost sample at 16,400 grains/cm$^2$/yr, but then decreases markedly to values below 7,000 grains/cm$^2$/yr (figure

6). The defining features of LPAZ KM7 are the appearances of *Alnus* and *Quercus* in the lowermost sample of the zone at 216 cm, along with the peak in *Calluna* pollen at 5–7% (figure 5a). Two other defining features are the decrease in *Sphagnum* to values <10% and the disappearance of the amoeba *Archerella flavum* (figure 5b). In addition to these defining features of the zone, *Corylus* retains high values, similar to those of KM6, *Betula* percentages remain relatively low at around 35% and *Pinus* pollen decreases to around 10%.

#### 5.3.8 LPAZ KM8 (166–75 cm; 9,000–4,000 cal yr BP)

In the lowest sample of LPAZ KM8, pollen influx rate reaches the highest peak of the entire Käringmossen core at 26,400 grains/cm$^2$/yr (figure 6). After this peak, influx rates drop by more than half to around 9,300 grains/cm$^2$/yr in the sample at 128 cm, and later to 1,300 grains/cm$^2$/yr in the uppermost sample at 102 cm. The zone is characterised by a marked decrease in *Corylus* pollen percentages, from highs of around 30% in LPAZ KM6 and KM7, to around 5–10% in KM8 (figure 5a). *Pinus* also decreases in the zone to values below 5%. At the same time, *Betula* pollen reaches a peak of 70% in the lowest sample of the zone at 156 cm, but then decreases to 56% in the uppermost sample at 102 cm. Of the other trees, *Alnus*, *Ulmus* and *Quercus* all have their highest relative and absolute abundances in zone KM8, and this zone is also the only in which *Tilia* occurs in two adjacent samples. *Alnus*, *Ulmus*, *Quercus* and *Tilia* all peak in the same sample, at 128 cm, with percentages between 1–10%. Additionally, *Fagus* makes its first appearance in zone KM8, in the uppermost sample at 102 cm. In this sample, ericaceous dwarf shrubs reach peak percentages of 24% after having been relatively scarce in the lower parts of KM8. This coincides with an increase in herb pollen percentages to 7% from around 2% in the rest of the zone. The herb pollen taxon making up most of this increase is Poaceae (figure 5b). Aquatic plants have completely disappeared from the pollen record by the entry into KM8, but *Sphagnum* spore abundances are high and a local peak of 24% is reached at 128 cm.

#### 5.3.9 LPAZ KM9 (75–0 cm; from 4,000 cal yr BP)

In the ninth and uppermost pollen zone, the pollen influx rate continues to decrease and reaches 700 grains/cm$^2$/yr in the sample at 48 cm (figure 6). However, no influx rate was calculated for the surface sample since it was retrieved with different methods than the cores. In zone KM9, the main characteristic features are the increase in *Pinus* pollen percentages and the appearance and increase in *Picea* pollen (figure 5a). In the Käringmossen surface sample, these two taxa reach their peak percentages, *Pinus* at 66% and *Picea* at 12%. At the same time, most other tree taxa decrease, with *Betula* being the most affected, decreasing first to 32% at 48 cm and then to 10% in the surface sample. Herb pollen percentages increase temporarily in the sample at 48 cm to 13%. In this sample, two pollen grains from rye, *Secale cereale* (figures 5b and 7d), were found. Overall, pollen sums in LPAZ KM9 were low (<200 grains).

# 6 Discussion

## 6.1 Correlation between LPAZ and Scandinavian chronozones

The Käringmossen local pollen assemblage zones correspond well in time to the Scandinavian chronozones proposed by Mangerud *et al.* (1974) and to the modified Lateglacial version of these units adapted by Björck and Möller (1987) specifically to south-Swedish pollen records (figure 8). Since neither of these subdivisions define the

Oldest Dryas/Bølling boundary, this boundary was here defined using the modified Kullaberg chronology from southwestern Sweden (Liedberg Jönsson, 1988; Wohlfarth *et al.*, 2018). This boundary also corresponds well to the Käringmossen LPAZ. In addition to the Scandinavian chronozones, the Käringmossen pollen record is also largely consistent with the INTIMATE ice-core event stratigraphy (Rasmussen *et al.*, 2014) for the Lateglacial period (figure 8). Because of the close agreement between the Käringmossen pollen record and Scandinavian chronozones, the discussion will be structured around these zones.

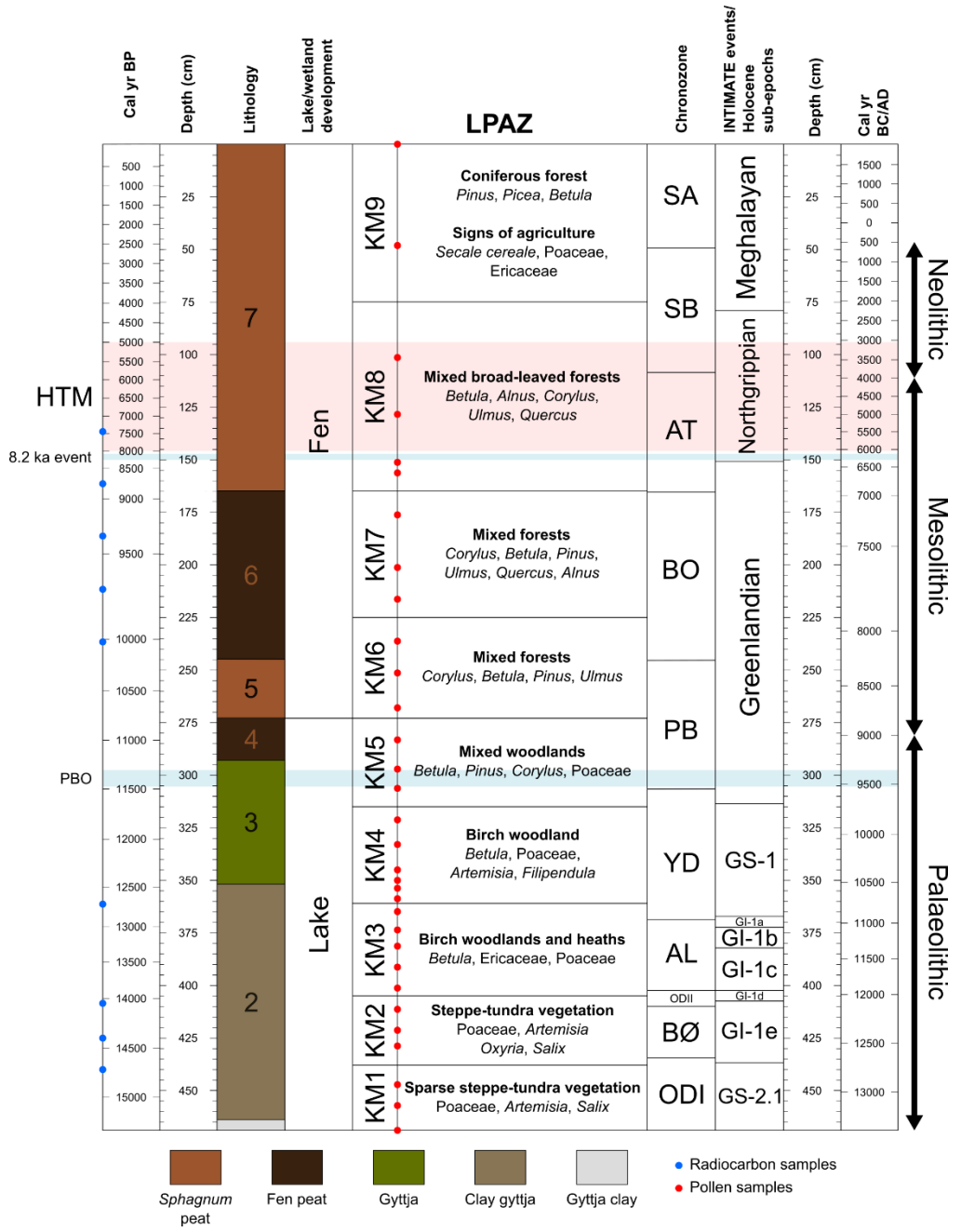


**Figure 8.** Summary figure of the Käringmossen core stratigraphy, lake/wetland stages and LPAZ related to Scandinavian chronozones (Mangerud *et al.*, 1974; Björck and Möller, 1987; Wohlfarth *et al.*, 2018), the INTIMATE event stratigraphy (Rasmussen *et al.*, 2014), Holocene sub-epochs (Walker *et al.*, 2019) and the Scandinavian Stone Age subdivisions (Price, 2015). For each LPAZ, the general interpretation of terrestrial vegetation is presented, along with characteristic taxa. Ages for the PBO and 8.2 ka event (blue) are from Rasmussen *et al.* (2014) and HTM (pink) boundaries from Wastegård (2022). Scandinavian chronozone boundaries have been calibrated in OxCal 4.4 (Ramsey, 2009) using the IntCal20 calibration curve (Reimer *et al.*, 2020).

In the Lateglacial period, LPAZ KM1, is largely contemporary to both the Oldest Dryas, as defined in the modified Kullaberg chronology (Liedberg Jönsson, 1988; Wohlfarth *et al.*, 2018), and GS-2.1 in the INTIMATE event stratigraphy (Rasmussen *et al*., 2014). KM2 covers approximately the same time as Bølling in the south-Swedish adaptation of the Scandinavian chronozones (Björck and Möller, 1987), and the GI-1e event in Greenland ice cores (Rasmussen *et al*., 2014). The Older Dryas period and the GI-1d event are however not reflected in any LPAZ, as this short cooling period is covered by only approximately 3 cm in the Käringmossen core, and as pollen sampling was performed prior to receiving the results of the radiocarbon dating, it was missed. The later Allerød period (Björck and Möller, 1987) and GI-1c–GI-1a events (Rasmussen *et al*., 2014) are represented in the Käringmossen pollen record by most of LPAZ KM3. The uppermost sample of KM3 at 265 cm does however have a Younger Dryas age of 12,800 BP. Along with this uppermost sample of KM3, the Younger Dryas period (Björck and Möller 1987) and the GS-1 event (Rasmussen *et al*., 2014) are represented by LPAZ KM4.

In the Holocene part of the Käringmossen core, pollen samples were not as closely spaced and LPAZ and chronozone boundaries, as defined by Mangerud *et al*. (1974), do therefore appear to not align as well as in the Lateglacial period (figure 8). All pollen samples within the pollen zones do however, with only two exceptions, align with the chronozones their respective LPAZ were assigned to. LPAZ KM5 and KM6 in the Käringmossen record are largely contemporary with the Preboreal period, although the uppermost sample of KM6 has an early Boreal age of 10,000 cal yr BP. This upper sample, along with LPAZ KM7, instead represents the Boreal period, while the later Atlantic period is represented by the three lower samples of LPAZ KM8. The uppermost sample of KM8 is of an early Subboreal age, and the two pollen samples of LPAZ KM9 belong to the Subatlantic. Because so few pollen samples were made in the Subboreal and Subatlantic periods, which span a time of approximately 5,700 years, these two periods will be discussed under a more general post-Atlantic headline.

The close agreement between the Käringmossen LPAZ and the Scandinavian chronozones, as well as the INTIMATE event stratigraphy (figure 8), indicates that the KÄR01 radiocarbon dates and age-depth model are fairly accurate. Especially in the Lateglacial and early Holocene part of the core, where pollen samples were more closely spaced, they indicate that modelled ages are accurate. This is important for LPAZ KM4–KM6, where there is a >1 m gap between radiocarbon dates. In the late Holocene, corresponding to uppermost LPAZ KM8 and KM9 in the Käringmossen core, where pollen samples are sparse, the accuracy of the age-depth model can however not be confirmed.

## 6.2 Lateglacial vegetational and environmental development

### 6.2.1 Oldest Dryas (18,000–14,600 cal yr BP) – LPAZ KM1

LPAZ KM1, which corresponds in time to the Oldest Dryas and the GS-2.1 event (figure 8), represents the earliest phase of vegetational development at Käringmossen following the recent deglaciation (Hughes *et al.*, 2016; Stroeven *et al.*, 2016). This is also the time period during which the archaeological site at Skatmossen was occupied (Nordqvist, 2003). In this earliest phase of vegetational development at Käringmossen, the low pollen influx rates (figure 6), along with the low organic content of the core sediments (figure 3), indicate that vegetation was sparse and biological productivity low. This is in line with previous studies on Oldest Dryas vegetation in southern Scandinavia (e.g., Iversen, 1973; Liedberg Jönsson, 1988; Mortensen *et al.*, 2011) and the inferred sparse vegetation could in part be a result of the cold climate of the time period (Kindler *et al.*, 2014; Rasmussen *et al.*, 2014). Another factor likely contributing to the low vegetation

density is the undeveloped mineral soils left behind by the deglaciating FIS (Berglund and Malmer, 1971). That soils were undeveloped in the study area during the Oldest Dryas is indicated by the presence of pollen from plants adapted to mineral soils, such as *Oxyria*, *Helianthemum* and *Hippophaë* (Iversen, 1954; Stenberg, 2018). Migration lags were also influencing vegetation at the time (Mortensen *et al.*, 2011) and could possibly have contributed to the poor vegetation cover as species able to fill certain niches may not yet have immigrated to northern Halland.

The dominance of herb pollen over arboreal pollen in LPAZ KM1 (figure 5a), indicates that herbs were dominant also in the local vegetation and that trees were absent or scarce. The two most common tree pollen taxa, *Betula* and *Pinus* do occur in percentages between 15–30% and 7–15% respectively in LPAZ KM1 (figure 5b). But as these taxa have been shown to occur in such proportions even in treeless tundra landscapes (Prentice, 1978), these values cannot be used as evidence for local presence. Part of the *Betula* pollen likely also come from dwarf shrub *B. nana*, which was present in southern Scandinavia during the Lateglacial period (e.g., Liedberg Jönsson, 1988; Mortensen *et al.*, 2011; Wohlfarth *et al.*, 2018). *B. nana* pollen were not systematically distinguished from tree birch in this study, but some smaller *Betula* grains possibly belonging to *B. nana* (Birks, 1968) were noted. Because of the low pollen production that can be inferred from low pollen influx rates in LPAZ KM1 (figure 6), long-distance transported pollen from anemophilous taxa with relatively high pollen production like *Betula* and *Pinus* (Erdtman, 1969) could easily outnumber local pollen. As pollen from both taxa are known to travel up to thousands of kilometres (Hjelmroos, 1991; Rousseau *et al.*, 2008), the arboreal pollen at Käringmossen could very well originate from continental Europe. Pollen influx rates of *Pinus* and *Betula* are also below the 500 grains/cm$^2$/yr threshold that was set by Hicks (2001) to represent the treeline in present day northern Finland. Further support for little to no tree cover is the presence of pollen from heliophilous taxa, such as *Artemisia*, *Hippophaë* and *Helianthemum* (Iversen, 1954). A treeless Oldest Dryas period is also consistent with plant macrofossil studies from southern Scandinavia, where no remains of trees have been found in deposits from the Oldest Dryas (Liedberg Jönsson, 1988; Mortensen *et al.*, 2011; Wohlfarth *et al.*, 2018). As such it is unlikely that trees were present at Käringmossen and Skatmossen during the Oldest Dryas.

The non-arboreal pollen in KM1 consists of both tundra and steppe taxa. The main tundra indicators are the high proportion of *Salix* pollen and the presence of *Oxyria*-type pollen (figures 5a and 5b). *Salix* pollen can be used as a tundra indicator in Oldest Dryas deposits, because the main *Salix* macrofossil remains found in Scandinavia from this time period come from arctic-alpine dwarf willows *S. polaris* and *S. herbacea* (Liedberg Jönsson, 1988; Birks and Birks, 2014; Wohlfarth *et al.*, 2018). Steppe elements at Käringmossen, on the other hand, include heliophilous taxa such as *Artemisia* and *Helianthemum* (Iversen, 1954). *Hippophaë*, which is present in KM1 (figure 5a), is also a common steppe element, although it at present in northwestern Europe is mainly associated with coastal settings (Iversen, 1954; Rousi, 1971). This combination of steppe and tundra taxa, has been observed in late Pleistocene glacial pollen records throughout northern Eurasia and North America, and it has been suggested to represent a dry steppe-tundra vegetation without a modern analogue (Hibbert, 1982; Blinnikov *et al.*, 2011). Steppe elements in Lateglacial Scandinavian pollen records have however in some cases also been suggested to be far-transported pollen from the steppes of central and eastern Europe (Iversen, 1973; Mortensen *et al.*, 2011; Birks and Birks, 2014). Since pollen influx rates during the Oldest Dryas are low, indicating very sparse vegetation, it is hard to determine whether the steppe pollen in KM1 come from locally present taxa or are the result of long-distance transport.

In addition to tundra and steppe related taxa, thermophilous taxa such as *Alnus*, *Hippophaë* and *Typha* occur in zone KM1 (figures 5a and 5b). *Alnus* pollen in this zone could however be rebedded pre-LGM pollen, since rebedding is common in Lateglacial

deposits (Mortensen *et al.*, 2011) and *Alnus* immigrated into Scandinavia first during the Holocene (Brewer *et al.*, 2017; Giesecke *et al.*, 2017). Whether *Typha* was locally present in the area surrounding Käringmossen during the Oldest Dryas is also questionable, since only one single pollen grain was found in one sample. *Hippophaë* on the other hand, occurs consistently from mid-KM1 through mid-KM2 and could therefore have been present in the environment. This is further supported by the shrub being common in pollen records from all over southern Scandinavia during the Lateglacial period (e.g., Iversen, 1954; Berglund, 1966; Berglund, Eriksson and Fernlund, 1994; Mortensen *et al.*, 2011). The presence of *Hippophaë* pollen indicates mean July temperatures of >10°C, since the shrub does not grow or reproduce in colder climates (Iversen, 1954; Wohlfarth *et al.*, 2017). This inferred mean July temperature is higher than beetle and chironomid inferred summer temperatures of <10°C in Scandinavia during the Oldest Dryas (Coope *et al.*, 1998; Brooks and Langdon, 2014). It is on the other hand in line with the results of recent plant macrofossil temperature reconstructions, that indicate that summer temperatures were well above 10°C (Wohlfarth *et al.*, 2018; Schenk *et al.*, 2020). This would lend support to the suggestion by Denton *et al.* (2005) that Lateglacial stadials in Europe were characterized mainly by strong seasonality and cold winters and not necessarily by summer cooling.

A possible additional indicator of relatively warm Oldest Dryas temperatures is the high proportion of *Ranunculus*-type pollen in KM1. Since Käringmossen was a freshwater lake during the Oldest Dryas, as indicated by the high presence of *Pediastrum* algae (Komárek and Jankovská, 2001), it is likely that the *Ranunculus*-type pollen at least in part comes from aquatic species in the *Batrachium* section. This assumption is supported by previous macrofossil finds of *Ranunculus* sect. *Batrachium* in Oldest Dryas and early Lateglacial deposits in Skåne and Denmark (Hammarlund and Lemdahl, 1994; Mortensen *et al.*, 2011; Wohlfarth *et al.*, 2018). High *Ranunculus* percentages during the early Lateglacial in southern Halland have also previously been attributed to *Ranunculus* sect. *Batrachium* (Berglund, Eriksson and Fernlund, 1994). If the pollen present in KM1 comes from aquatic *Ranunculus*, this further supports that mean July temperatures during the Oldest Dryas were at least 10°C (Kolstrup, 1979; Isarin and Bohncke, 1999).

The possible co-occurrence of tundra taxa, with heliophilous steppe taxa and the thermophilous *Hippophaë* and *Ranunculus* sect. *Batrachium* in the KM1 pollen record, indicates that not only climate was controlling vegetation in northern Halland during the time just following the last deglaciation. The early successional stage of the Oldest Dryas ecosystem at Käringmossen following the recent deglaciation (Hughes *et al.*, 2016; Stroeven *et al.*, 2016) and the continuous and rapid exposure of new land through postglacial rebound (figure 2) likely had great influence of the taxonomic composition of the vegetation. This is confirmed by many of the taxa present in the pollen record being pioneers, including *Hippophaë*, *Helianthemum*, *Salix polaris*, *Galium*, *Oxyria* and *Artemisia*, as well as many species in the Poaceae, Caryophyllaceae and Plantaginaceae families (Berglund, 1966; Mortensen *et al.*, 2011). These taxa, that are often heliophilous and poor competitors, likely benefited from the sparse vegetation cover and the lack of shading trees. Competition not being a major limiting factor for vegetation could possibly also explain the presence of arctic-alpine taxa in an inferred relatively warm environment, since many of these taxa are not limited in their range by temperature, but rather by competition from more thermophilous species (Birks, 2008).

### 6.2.2 Bølling (14,600–14,100 cal yr BP) – LPAZ KM2

In LPAZ KM2, which is largely contemporary to the Bølling warm period and the GI-1e event (figure 8), increasing pollen influx rates (figure 6) indicate that vegetation became denser than during the Oldest Dryas. Pollen influx rates are however still low compared to later zones, indicating that vegetation was still relatively sparse. That vegetation was still sparse is further supported by the LOI values in the KM2 part of the

core being similar to KM1 (figure 3), indicating that biological productivity in the Käringmossen lake and its near surroundings was low. An alternate interpretation of the rising pollen influx rates in LPAZ KM2 could therefore be that vegetation density did not increase significantly locally at Käringmossen during Bølling, but that vegetation density was increasing in areas located close to Käringmossen, perhaps on what was then the Halland mainland. Since most of the taxa present in the KM2 pollen record are anemophilous (figures 5a and 5b), their presence could in part be the result of long-distance transport. It is possible that establishment of vegetation following the last deglaciation was somewhat delayed at Käringmossen, since it during Bølling was still situated in an archipelago (figure 2) where water may have acted as a barrier to dispersal. Irrespective of whether vegetation density was increasing at Käringmossen or in an area close to Käringmossen, it was likely at least in part a result of the climate amelioration associated with Bølling (Kindler *et al.*, 2014; Rasmussen *et al.*, 2014). Increasing vegetation density could however also be related to more taxa having had the time to disperse to northern Halland following the last deglaciation, or it could be a result of soil development facilitated by the pioneer vegetation of the Oldest Dryas. Since the taxonomic composition does not change markedly between LPAZ KM1 and KM2, it does however appear that vegetation at, or close to, Käringmossen during the Bølling warm period was still in a pioneer phase and that soils were raw. The continued co-occurrence of steppe and tundra taxa, indicates that this pioneer vegetation was of a steppe-tundra character.

Other than the marked increase in pollen influx, the main difference between Bølling and the Oldest Dryas is the more than tenfold increase in *Oxyria*-type pollen (figure 5b). Assuming that the pollen belongs to the arctic-alpine species *O. digyna*, this further confirms that vegetation during Bølling was in a pioneer phase. Since this species is today known to colonise glacier forelands, snowbeds and settings with pronounced soil movement (Persson, 1964; Jóhansen, 1975; Pennington and Tutin, 1980), its high abundance indicates that growing conditions were harsh and especially that soils were undeveloped. The rapid *Oxyria*-type increase and peak could however also be linked to the Bølling climate amelioration, as high *Oxyria* abundances in Scandinavian Lateglacial records have previously been related to periods of milder, more maritime climate (Vorren *et al.*, 1988; Rundgren, 1995). In these cases, *Oxyria* percentages have however been higher than in LPAZ KM2. Despite this, an *Oxyria* indicated maritime climate during Bølling is in line with suggestions that Lateglacial interstadial climate in southern Scandinavia was maritime, while stadials were characterised by continental climate (Denton *et al.*, 2005; Schenk *et al.*, 2020). The Bølling peak in *Oxyria*-type pollen can as such be linked to the pioneer state of vegetation and possibly also to climate amelioration.

Since tree pollen percentages do not increase in Bølling compared to the Oldest Dryas (figure 5a), it is unlikely that trees were abundant in northern Halland during this period. Tree pollen influx rates do, on the other hand, increase compared to LPAZ KM1 and they continue to rise throughout KM2 (figure 6). In the uppermost sample of the zone, *Betula* influx even reaches just above the 500 grains/cm$^2$/yr tree-line threshold suggested by Hicks (2001). Considering that *B. nana* was not differentiated from tree-birch in the present study, it is however likely that part of the *Betula* pollen belongs to *B. nana*. It is thus likely that the Bølling situation for tree-birch at Käringmossen was similar to that of Denmark, where pollen percentages are fairly high (e.g., Iversen, 1954; Kolstrup, 1982), but no macrofossil evidence of *Betula* presence has been found (Mortensen *et al.*, 2011). Further evidence of little to no tree cover at Käringmossen during Bølling is the large proportion of heliophilous taxa in the KM2 pollen record, including the highly abundant *Oxyria*, *Artemisia* and Plantaginaceae, along with less frequent *Hippophaë* and *Helianthemum* (Iversen, 1954). However, in Skåne, in southernmost Sweden, there have been finds of tree-birch macrofossils dated to the Bølling period from four different sites (Liedberg Jönsson, 1988; Hammarlund and Lemdahl, 1994; Wohlfarth *et al.*, 2018),

which indicates that trees were present in southern Sweden at the time. At most of these sites, the tree-birch macrofossils are however few and scattered and at all they are less abundant than during the later Allerød period (Liedberg Jönsson, 1988; Hammarlund and Lemdahl, 1994; Wohlfarth *et al.*, 2018), thus indicating limited local presence. Since there are no Lateglacial macrofossil records from northern Halland, it is hard to definitively determine whether trees had spread this far north during the Bølling period. Rising *Betula* pollen influx rates in the upper KM2 could indicate local presence of tree-birch, but they could also reflect the proximity to the birch stands that were establishing in southernmost Sweden.

Similar to during the Oldest Dryas, *Pediastrum* algae reach high percentages in the LPAZ KM2 record, indicating continued freshwater lake conditions. Although *Pediastrum* percentages are highest in the KM2 and KM1 zones (figure 5b), influx rates are similar to later zones where the alga is present (figure 6). High percentage values in the early Lateglacial are as such more a reflection of low pollen production, rather than high *Pediastrum* productivity. The only exception from this is the lowermost sample of KM2, in which *Pediastrum* peaks in both relative and absolute abundance. This is likely a result of increased lake productivity in response to Bølling climate amelioration. Similar increases in *Pediastrum* abundance have been observed in Bølling lake records from other parts of southern Scandinavia (Liedberg Jönsson, 1988; Mortensen *et al.*, 2011; Wohlfarth *et al.*, 2018), which supports that the increased *Pediastrum* productivity observed at Käringmossen is a response to regional climatic changes.

### 6.2.3 Allerød (13,900–12,900 cal yr BP) – LPAZ KM3

LPAZ KM3, with the exception of the uppermost sample at 365 cm belongs to the Allerød period and INTIMATE events GI-1c–GI-1a (figure 8). During this period, pollen influx rates continue to rise (figure 6), indicating that vegetation at Käringmossen was becoming increasingly dense. Rising LOI values in the KM3 part of the core (figure 3) confirm that local biological productivity was increasing and not only the regional productivity. At the same time, there is a marked increase in *Betula* pollen percentages to values above 60% (figure 5a), which leads to trees overtaking herbs as the dominant pollen taxa group in the Käringmossen record. This *Betula* increase indicates that tree-birch became established at Käringmossen during the Allerød period and that these trees were likely partly responsible for the increased biological productivity at the site. The *Betula* pollen rise could also consist of *B. nana*, but since tree-birch expansion has been noted in both pollen and macrofossil records from all of southern Scandinavia (e.g., Berglund, 1966; Björck and Möller, 1987; Liedberg Jönsson, 1988; Berglund, Eriksson and Fernlund, 1994; Paus, 1995; Ising, 2001; Mortensen *et al.*, 2011; Wohlfarth *et al.*, 2018), this is unlikely. Tree-birch expansion is also supported by the decrease in and disappearance of heliophilous and shade-intolerant taxa such as *Oxyria*, *Hippophaë* and *Helianthemum* during or just prior to LPAZ KM3 (figures 5a and 5b). Similar decreases and disappearances have been noted in contemporary pollen records from southern Halland (Berglund, Eriksson and Fernlund, 1994), indicating regional change. As such, the start of Allerød, around 13,900 BP, likely marks the time when trees became established at Käringmossen and in Halland.

While the *Betula* percentage curve rises sharply in LPAZ KM3, the *Pinus* curve does not change compared to previous zones (figure 5a). *Pinus* abundance remains at around 5% throughout the zone, with the exception of a peak in the second uppermost sample at 373 cm. Such a peak in *Pinus* pollen is typical for late Allerød records in Denmark, where it occurs in association with reduced pollen influx rates, decreases in *Betula* pollen and increasing herb pollen values (Andresen *et al.*, 2000; Mortensen *et al.*, 2011). Here, it has been related to deteriorating climate during the short GI-1b cold event, and the increasing *Pinus* pollen is attributed to long-distance transport rather than local presence (Andresen *et al.*, 2000; Mortensen *et al.*, 2011). The same interpretation could be made

for the *Pinus* peak in the Käringmossen record, although it is not associated with the same decrease in pollen influx rate (figure 6) and relative increase in herb pollen as in the Danish records. Another explanation for the late Allerød *Pinus* peak could instead be the local presence of pine trees at Käringmossen. This is possible as *Pinus* pollen influx rate surpasses the 500 grains/cm$^2$/yr pine tree-line threshold developed by Hicks (2001) in the 373 cm pollen sample at 900 grains/cm$^2$/yr. Further indications that pine was present in Sweden during Allerød, and therefore could also have been present at Käringmossen, are *Pinus* macrofossil finds from Skåne, in southwestern Sweden (Wohlfarth *et al.*, 2018), and high pollen percentages in pollen records from Blekinge in the southeast (Wohlfarth *et al.*, 2018). As such it is possible that the *Pinus* peak in KM3 instead represents local presence, rather than long-distance transport of pollen. The peak could however also just reflect the establishment of pine closer to Käringmossen, in Skåne and Blekinge. To definitively be able to determine whether *Pinus* was able to spread as far northwest as Halland, macrofossil or eDNA evidence is needed.

Along with the Allerød tree expansion, ericaceous dwarf shrubs expand rapidly in mid-KM3 (figure 5a). This is consistent with the *Empetrum* expansion seen in many southern Scandinavian pollen records from this time (e.g., Berglund, 1966; Björck and Möller, 1987; Berglund, Eriksson and Fernlund, 1994; Birks, 1994; Ising, 2001; Wohlfarth *et al.*, 2006), implying that the KM3 Ericaceae peak also consists mostly of *Empetrum*. Since this dwarf shrub is highly tolerant of cold, tolerating mean July temperatures as low as 6°C (Elvebakk and Spjelkavik, 1995), climate was likely not a factor limiting its spread prior to mid-Allerød. Instead the development of stable soils has been suggested as a main cause for the *Empetrum* expansion (Berglund, 1966). Soil development would also favour the inferred establishment of tree-birch. In addition to indicating soil development, the Allerød expansion of Ericaceae, likely *Empetrum*, also indicates that although trees were becoming established at Käringmossen, vegetation remained fairly open. Since *Empetrum*, like many other ericaceous shrubs, is heliophilous, its high presence in mid to late Allerød has been used to indicate the development of heathland or open *Betula-Empetrum* woodlands (Berglund, 1966; Björck and Möller, 1987). The expansion of Ericaceae (likely *Empetrum*) at Käringmossen is, like in many other south-Scandinavian pollen records (e.g., Berglund, 1966; Björck and Möller, 1987), associated with decreasing *Betula* percentages and can therefore possibly be linked to the gradual start of the climate deterioration that would lead into the Younger Dryas.

Based on the KM3 pollen record, the transition into the Allerød period appears to have been associated with a significant change at Käringmossen compared to the Oldest Dryas and Bølling periods. Vegetation productivity and density likely increased, and tree-birch and ericaceous dwarf shrubs established and became dominant elements in the vegetation. Since many Lateglacial temperature proxy records indicate that the Allerød period was about as warm as Bølling (Coope *et al.*, 1998; Kindler *et al.*, 2014; Wohlfarth *et al.*, 2018; Schenk *et al.*, 2020), it is likely that not only climatic factors were controlling these vegetational changes. Soil development, as indicated by the Allerød assumed expansion of *Empetrum*, could, e.g., have facilitated other vegetational changes, and migrational lags may have kept taxa from establishing at Käringmossen prior to Allerød. Since many Scandinavian plant species survived the LGM in refugia in southern, central and eastern Europe (Birks and Willis, 2008; Svenning, Normand and Kageyama, 2008), the dispersal rates of different taxa determined how fast they could appear in Scandinavia after conditions became favourable. Migration lags of *Betula pubescens* in Norway during the early Holocene have, e.g., been estimated to between 400–600 years (Birks, 2015). With the Bølling period lasting for only about 500 years in southern Sweden (Wohlfarth *et al.*, 2018), it is possible that tree-birch did not have enough time to disperse into northern Halland before Allerød. As such, although climate amelioration may have been a prerequisite for many taxa to be able to establish in Scandinavia following the last deglaciation, other factors likely played parts in controlling the exact timing of the establishment.

### 6.2.4 Younger Dryas (12,900–11,500 cal yr BP) – Upper LPAZ KM3 and KM4

The entry into the Younger Dryas stadial (INTIMATE event GS-1), can be recognized in the uppermost sample of LPAZ KM3 at 365 cm, where pollen influx rates decrease (figure 6) likely as a response to the deteriorating climate. At the same time, there is a drop in the organic content of the core (figure 3), which indicates that biological productivity in the Käringmossen lake and its near surroundings was also decreasing. In the early KM4, pollen influx rates and LOI remain around the same values as in the uppermost sample of LPAZ KM3, indicating a prolonged period of reduced biological productivity. The deteriorating climate in the beginning of the Younger Dryas can also be recognized as a peak in *Artemisia* pollen in lowermost KM4 and as rapidly decreasing Ericaceae (likely *Empetrum*) percentages around the same time (figures 5a and 5b). The increasing *Artemisia* percentages can be related to climate deterioration, since this genus was common at Käringmossen in the steppe-tundra vegetation of the Oldest Dryas and Bølling. The *Empetrum* decrease, which has been widely observed in southern Sweden and Norway during the Younger Dryas (e.g., Berglund, 1966; Björck and Möller, 1987; Berglund, Eriksson and Fernlund, 1994; Birks, 1994; Ising, 2001), is however more likely indirectly linked to climate as the dwarf shrub is highly tolerant of cold (Elvebakk and Spjelkavik, 1995). Due to its preference for acidic leached soils, the *Empetrum* decrease has instead been tied to increased soil erosion and movement facilitated by the deteriorating climate (Berglund, 1966). That soil erosion was increasing at Käringmossen during the Younger Dryas is supported by the presence of the sand layer in early KM4, at a depth of about 360 cm (table 1). Decreasing Ericaceae/*Empetrum* abundance, together with increasing *Artemisia* percentages and decreasing biological productivity, constitutes strong evidence for early Younger Dryas climate deterioration in the Käringmossen record.

Although pollen influx rates and LOI values start decreasing already from around 365 cm in the Käringmossen core, in LPAZ KM3, the changes in *Empetrum* and *Artemisia* abundance do not happen until KM4 (figures 5a and 5b). This is likely in part why the CONISS cluster analysis classifies the pollen sample at 365 cm as more similar to Allerød pollen samples, than other samples from the Younger Dryas. That changes in the taxonomic composition of vegetation at Käringmossen do not happen before LPAZ KM4, around 12,600 cal yr BP, indicates that there was a somewhat lagged response of vegetation to the Younger Dryas cooling that started in Greenland about 12,800 cal yr BP (Kindler *et al.*, 2014; Rasmussen *et al.*, 2014). Similar lagged responses to Greenland cooling have been noted in multiple proxy records from different parts of northwestern Europe (Lohne, Mangerud and Birks, 2013; Rach *et al.*, 2014; Muschitiello and Wohlfarth, 2015; Obreht *et al.*, 2020). One suggested explanation for this is that the initial cooling in the Arctic caused a shift in the westerly wind system, leading to warming in northwestern Europe during the early GS-1 event (Rach *et al.*, 2014; Obreht *et al.*, 2020). Warming during the earliest Younger Dryas at Käringmossen is however not in line with decreasing pollen influx rates and LOI values already from 365 cm, corresponding to an age of approximately 12,800 cal yr BP. There may as such be other reasons for the lag in vegetation composition changes during the early Younger Dryas.

After the decrease during the early Younger Dryas, pollen influx rate starts to increase again from 353 cm and reaches levels higher than ever before already at 350 cm (figure 6). At the same time LOI values rapidly increase at a depth of 352 cm as clay gyttja transitions into gyttja (figure 3; table 1). These changes in organic content and pollen influx rates indicate increasing vegetation density and biological productivity at Käringmossen from around 12,500–12,400 cal yr BP. This in turn indicates that the Younger Dryas climate at Käringmossen started to improve already during this time, despite Greenland ice-core records indicating that the cold event continued until 11,700 cal yr BP (Kindler *et al.*, 2014; Rasmussen *et al.*, 2014). That Younger Dryas cooling affected Käringmossen for only about 300–400 years is further supported by the

*Artemisia* peak in LPAZ KM4 prevailing only for one sample, at 358 cm (figure 5b). In the next pollen sample at 353 cm, *Artemisia* percentages drop to levels similar to Allerød. The only indication that local growing conditions may have remained somewhat unfavourable is that Ericaceae/*Empetrum* percentages remain low throughout KM4 (figure 5a). Since the Ericaceae/*Empetrum* decrease is only indirectly linked to climate through its effect on soil conditions (Berglund, 1966; Björck and Möller, 1987), other factors could however be the cause for its continued low presence in the pollen record.

Other evidence of the mid- and late Younger Dryas being relatively mild is the first appearances of *Corylus* and *Nymphaea* pollen in mid-KM4, at depths of 345 cm and 333 cm respectively (figure 5a and 5b). Although the percentages of thermophilous *Corylus* are not high enough to indicate regional presence according to the 1% threshold set by Lisitsyna, Giesecke and Hicks (2011), its appearance in the pollen record suggests that it was approaching northern Halland in its Lateglacial migration, and that climate was mild enough for it to do so. *Nymphaea* on the other hand is likely to have occurred locally since it is entomophilous (Wiersema, 1988) and its pollen is therefore unlikely to be transported far. The presence of this taxon indicates that mean July temperatures were at least 13.6°C (Schenk and Väliranta, 2020) from mid-Younger Dryas, around 12,100 cal yr BP. With this evidence, it appears that the Younger Dryas climate deterioration had its greatest effect on northern Halland in its early phase and that climate after about 12,500–12,400 cal yr BP was fairly mild. This is in agreement with previous studies indicating that the start of climate amelioration in southern Sweden began around 12,500–12,400 cal yr BP (e.g., Björck and Möller, 1987; Lemdahl, 1991; Jiang and Klingberg, 1996; Hammarlund *et al.*, 1999; Isarin and Bohncke, 1999).

An alternative explanation for why only the early part of Younger Dryas appears to have been cold in the Käringmossen record is possible issues with the age-depth model. Since the radiocarbon dates on either side of LPAZ KM4 are more than 1 m apart (figures 3 and 8; table 2), it is possible that the sedimentation rate at Käringmossen was not constant between those two samples. This is highly possible since the major sediment type changes two times between the dates, from clay gyttja, through gyttja, to peat (figure 3; table 1). With the lower biological productivity in the early Younger Dryas that can be inferred from low pollen influx rates and organic content in the sediments between depths 363–352 (figures 3 and 6), it is possible that sediment accumulation rates were lower during this time than further up in the core. If accumulation rates were lower in early KM4, this would lead to overestimation of later ages and Younger Dryas warming would appear to happen earlier than it actually did. However, since the Ericaceae/*Empetrum* increase in early Younger Dryas was interpreted to be a result of increased soil erosion, accumulation rates do not need to have decreased during this time period, even if biological productivity did. Reduced input of biological material could have been balanced by greater input of minerogenic material through soil erosion. Furthermore, CONISS cluster analysis classifying pollen samples in LPAZ KM1–KM4 as more similar to samples in KM5 than samples in LPAZ KM6–KM9 (figure 5a) is in favour of the age-depth modelling correctly estimating the ages of the different parts of the core. As such, it does appear that most of the Younger Dryas in northern Halland, after around 12,500–12,400 cal yr BP, was not characterised by harsh climatic conditions.

While Younger Dryas climate deterioration can be inferred at least from the early part of KM4, trees seem to not disappear from the local environment. In the early Younger Dryas, *Betula* percentages increase compared to the last Allerød sample at 373 cm, and they continue to increase throughout LPAZ KM4 (figure 5a). Along with this, *Betula* pollen influx rates also increase throughout KM4 after an initial decrease in the first Younger Dryas sample at 365 cm (figure 6). These rising values indicate that tree-birch remained locally in the Käringmossen area and that it continued to be a prominent part of the regional vegetation throughout the Younger Dryas, especially since the pollen

influx rates are far above the 500 grains/cm$^2$/yr tree-line threshold set by Hicks (2001). The other alternative would be if the *Betula* curve consists largely of *B. nana* and this species was regionally dominant at Käringmossen during the Younger Dryas. Tree-birch, which requires mean July temperatures of at least 11°C (Birks, 2015), surviving the Younger Dryas in southern Sweden is inconsistent with chironomid and beetle inferred summer temperatures of <9°C for the period (Coope *et al.*, 1998; Brooks and Langdon, 2014), but would be possible with plant macrofossil inferred minimum mean July temperatures of ≥14°C (Wohlfarth *et al.*, 2018; Schenk *et al.*, 2020). Younger Dryas macrofossil finds of tree-birch in Skåne in southernmost Sweden (Liedberg Jönsson, 1988; Hammarlund and Lemdahl, 1994) also indicate that birch presence at Käringmossen would have been possible. With the high and rising *Betula* pollen percentages of LPAZ KM4, it is therefore likely that tree-birch was still present in the Käringmossen area during the Younger Dryas.

Although tree-birch appears to have been present in the northern Halland region throughout the Younger Dryas, the lower pollen percentages and influx rates in the earliest samples at 365 cm and 358 cm (figures 5a and 6) indicate that it became less common in the landscape at this time. In the early Younger Dryas cold phase, the increasing *Artemisia* percentages (figure 5b) indicate a partial return to the steppe-tundra-like environment of the Oldest Dryas and Bølling. Following this, the steadily increasing *Betula* pollen percentages and influx rates indicate development of increasingly dense *Betula* woodlands in which *Empetrum* heaths were not as important features as during Allerød. The late Younger Dryas *Empetrum* expansion seen in many pollen records from southern Sweden (e.g., Berglund, 1966; Björck and Möller, 1987; Ising, 2001) is not represented in KM4, perhaps due to Käringmossen at the time being situated in a rocky archipelago environment (figure 2c) where soil development may have been slower than in other parts of southern Scandinavia. As the Younger Dryas progressed, the marked rise in *Pinus* pollen percentages from the sample at 333 cm (12,100 cal yr BP) could indicate local establishment, especially as the *Pinus* pollen influx rate of this sample surpasses Hick's (2001) 500 grains/cm$^2$/yr tree-line threshold. Since the influx rate is still fairly low at 600 grains/cm$^2$/yr, it is however likely that *Pinus* was only a minor component in the *Betula* dominated woodlands of the Younger Dryas.

In LPAZ KM4, the appearance of the aquatic macrophytes *Myriophyllum alterniflorum* and *Isoëtes* (figure 5b) indicates change in the Käringmossen lake system during the Younger Dryas. The simultaneous disappearance of the presumed aquatic and previously abundant *Ranunculus*-type pollen supports the interpretation of a change. Since many of the current Swedish *Ranunculus* sect. *Batrachium* species are related to nutrient rich waters (Stenberg, 2018), while *Myriophyllum alterniflorum* and *Isoëtes* primarily occur in oligo- to mesotrophic waters (Rørslett and Brettum, 1989; Sattler and Poschlod, 2023), the change in aquatic macrophyte flora can be related to decreasing nutrient availability in the lake. Such a shift from more to less nutrient-demanding aquatic taxa during the mid- to late Younger Dryas has also been observed in pollen records from southeastern Sweden (Berglund, 1966). These decreasing lake nutrient levels could at Käringmossen possibly be related to increased terrestrial nutrient uptake (Birks, Battarbee and Birks, 2000) as the terrestrial vegetation became denser after the early Younger Dryas cold period.

## 6.3 Holocene vegetational and environmental development

### 6.3.1 Preboreal (11,500–10,200 cal yr BP) – LPAZ KM5 and KM6

The Preboreal period, characterised by rapid climate warming, is in the Käringmossen pollen record represented by LPAZ KM5, along with all samples but the uppermost one of KM6 (figure 8). The Preboreal climate amelioration is well reflected in both KM5 and

KM6. It can be seen as a peak in pollen influx rate (figure 6) and high LOI values in early KM5 (figure 3), as well as in rising *Corylus* and *Pinus* percentages, and the establishment of a continuous *Ulmus* presence in the pollen record (figure 5a). Already in the first sample of KM5, all three of the above mentioned trees have reached percentages above the threshold values developed by Lisitsyna, Giesecke and Hicks (2011) to indicate regional presence, 1% for *Corylus*, 10% for *Pinus* and 0.5% for *Ulmus*. Later in KM5 and KM6, *Pinus* and *Corylus* also reach threshold values developed by Giesecke *et al.* (2017) to indicate regional dominance of the tree taxa, 25% and 20% respectively.

With the appearance and expansion of new tree species, the Preboreal period represents a time of change in the Käringmossen forest ecosystem. The increase in *Pinus* and *Corylus* pollen at the expense of *Betula* throughout zone KM5 (figure 5a), indicates a shift from *Betula* dominated vegetation to more mixed forest vegetation during the first 900 years of the Preboreal. This increase marks the start of the Preboreal *Pinus-Betula-Corylus* phase of southwest Swedish forest vegetation that was initially described by Fries (1951). This forest phase later reached its culmination at Käringmossen during the last 900 years of the Preboreal, in LPAZ KM6, when both *Pinus* and *Corylus* attain high percentages. Similar high *Corylus* percentages have been noted in many other Preboreal pollen records from southern Sweden (e.g., von Post, 1924; Fries, 1951; Berglund, 1966; Yu *et al.*, 2005; Antonsson and Seppä, 2007) and Fries (1951) has suggested that they in coastal Bohuslän (north of Halland) indicate the formation of almost pure *Corylus* forests where the main secondary tree component would have been *Ulmus*. The *Corylus* values of 20–30% in KM6 are however lower than the values of around 50–60% (of all arboreal pollen) recorded in coastal Bohuslän by Fries (1951). *Corylus* values in KM6 are closer to the 15–20% recorded in southeastern Sweden by Yu *et al*. (2005) and in Bohuslän by Antonsson and Seppä (2007), who have instead suggested that the *Corylus* peak can be related to *Betula* dominated, mixed deciduous forests. As *Corylus* pollen are slightly more common at Käringmossen than in the studies by Yu *et al*. (2005) and Antonsson and Seppä (2007), it is however likely that taxon was more abundant in the deciduous forests at Käringmossen.

In addition to the Preboreal changes in forest composition, decreasing herb pollen percentages and a significant drop in herb pollen influx rate in KM6 (figures 5a and 6), indicate that forests were becoming denser from the mid- to late Preboreal. Since trees easily outcompete herbs for or sunlight, the disappearance of herbs in the Käringmossen pollen record indicates that more open habitats such as grasslands and/or sparse woodlands were disappearing. The KM6 Ericaceae increase could however indicate that some open habitats remained, as this family includes many shade-intolerant taxa such as *Empetrum*. It is possible that these ericaceous dwarf shrubs were occupying the upland areas with thin soil cover in the Käringmossen surroundings (figure 1), where competition from trees may have been reduced. As many ericaceous dwarf shrubs also grow in association with fens, the presence of Ericaceae pollen could also be a result of local growth on the Käringmossen fen and does therefore not have to indicate open habitats in the surrounding landscape. Since mid- to late Preboreal closing of forests has been inferred from other south Swedish pollen records (e.g., Berglund, 1966; Yu *et al.*, 2005; Antonsson and Seppä, 2007), it is likely that forests also at Käringmossen became more dominant in the landscape from the mid- to late Preboreal (around 10,800 cal yr BP), even if Ericaceae dominated heaths could have remained in rocky upland areas.

As changes were happening in the terrestrial vegetation during the Preboreal, Käringmossen itself went through major change as it transitioned from a lake to wetland in LPAZ KM5. This change is reflected in the core stratigraphy, where gyttja transitions into fen peat at a depth of 293 cm (figure 3; table 1), reflecting an age of approximately 11,200 cal yr BP. The change is also seen in the pollen record, where lake taxa are replaced by wetland related taxa between the samples at 297 cm and 283 cm (figure 5b).

In the pollen record, the lake related taxa that disappear are *Nymphaea*, *Isoëtes* and *Pediastrum* (Komárek and Jankovská, 2001; Stenberg, 2018), while the wetland indicating taxa include *Menyanthes*, *Sphagnum* and *Archerella flavum* (Payne *et al.*, 2012; Hallingbäck, 2016; Stenberg, 2018). Additionally, the reappearance of *Cyperaceae* in KM5 and the occurrence of large clumps of immature *Filipendula* pollen in the sample at 283 cm indicate a shift towards wetland conditions (Stenberg, 2018). Especially the *Filipendula* pollen indicate wetland or shallow water conditions at the very site of coring, since clumped immature *Filipendula* pollen has previously been associated with deposition of entire flowerheads in bloom (Whittington, 1993; Tipping, 1994; Clarke, 1999). Entire flowerheads being deposited at the coring site thus indicates that *Filipendula* was growing in very close proximity, which in turn would suggest wetland conditions at the site of coring.

The lake-fen transition at Käringmossen happened during a period of exceptionally low lake and groundwater levels in southern Sweden that has been linked to a shift towards drier climate (Digerfeldt, 1988; Gaillard and Digerfeldt, 1991; Harrison and Digerfeldt, 1993). These low groundwater levels could also be the cause of the rapid transition from fen- to *Sphagnum* peat in the core stratigraphy (figure 3; table 1) that is accompanied by a pronounced increase and peak in *Sphagnum* spores in LPAZ KM6. During this time, a general lowering of groundwater levels may have led to reduced input of groundwater bearing nutrients to the Käringmossen basin, which in turn would have promoted *Sphagnum* growth over more nutrient-demanding taxa. This suggestion is supported by the transition from fen- to *Sphagnum* peat occurring around 10,800 cal yr BP, a time when south Swedish lake and groundwater levels were at an extreme low (Digerfeldt, 1988; Gaillard and Digerfeldt, 1991). That *Sphagnum* peat transitions back to fen peat further up in the core, at 245 cm (10,200 cal yr BP), when lake and groundwater levels were again increasing (Digerfeldt, 1988; Gaillard and Digerfeldt, 1991) further supports this theory. Similar oscillations from *Sphagnum*- to fen- to *Sphagnum* peat have previously been observed in association with climatic change in northern Canada (Van Bellen *et al.*, 2013). The early Holocene development of the Käringmossen lake-fen system is as such a reflection of variations in the contemporary climate.

Although long-term climate change during the early Holocene can clearly be discerned from the Käringmossen pollen record, there is only little evidence for the major short-term climatic event of the time period, the PBO (Björck *et al.*, 1997; Rasmussen *et al.*, 2014). The main indication that the PBO cold event could have affected Käringmossen is a minor decrease in LOI values in the KÄR01 core between 311–303 cm, reflecting weighted mean ages of between 11,600–11,400 cal yr BP (figure 3). This is close to the time of the PBO, which is centred around 11,400 cal yr BP (Rasmussen *et al.*, 2014). In the pollen record there is however little evidence of the setback in tree vegetation that has been mentioned as the main evidence for the PBO in southwest Swedish pollen records (Björck *et al.*, 1997). Decreasing pollen influx rate between the samples at 297 cm and 283 cm could be viewed as an indication of climate cooling, but it is more likely to result from the transition from gyttja to fen peat in the core, as pollen influx rates are sensitive to changes in accumulation types and sedimentation rates (Hicks and Hyvärinen, 1999). These two pollen samples are also slightly too young, with weighted mean ages between 11,300–11,000 cal yr BP. The most likely explanation for the lack of evidence for the PBO in the Käringmossen pollen record is that no pollen sample was made in the part of the core corresponding to the event. The pollen samples closest in age to the PBO are located at depths 308 cm and 297 cm and have weighted mean ages of approximately 11,500 and 11,300 cal yr BP. It is however also common to not find strong evidence of the PBO in Swedish climate proxy records (Wastegård, 2022).

### 6.3.2 Boreal (10,200–8,900 cal yr BP) – Upper LPAZ KM6 and KM7

In the Boreal period, which is represented by the uppermost sample of LPAZ KM6 and LPAZ KM7 in the Käringmossen pollen record (figure 8), pollen influx rates and LOI values are not comparable to the Lateglacial period, due to the change in depositional environment from lake to fen that happened during the mid-Preboreal. With the rapidly changing peat accumulation rates between depths 237–166 cm (figure 3) it is also hard to compare pollen influx rates between samples, as pollen influx rates are highly sensitive to these changes (Hicks and Hyvärinen, 1999). Since peat accumulation rates change rapidly in the parts of the peat where radiocarbon dates are closely spaced (237–186 cm), it must be taken into consideration that such changes may occur also where no radiocarbon dates were made. Pollen influx rates therefore become less useful for determining biological productivity and vegetation density at Käringmossen following the Preboreal lake-fen transition. Similarly, LOI also becomes less useful for determining biological productivity and vegetation density as peat is formed by organic matter.

The Boreal period in the Käringmossen record, is in many ways similar to the second half of the Preboreal, in that *Corylus*, *Betula* and *Pinus* are the main tree taxa present in the pollen record (figure 5a). Forests can as such be assumed to have been constituted mainly by these three taxa, along with *Ulmus* that was also present already in the Preboreal. However, in addition to these taxa, *Alnus* and *Quercus* also appear and likely become established at the start of KM7, around 9,700 cal yr BP. This is largely in accordance with other pollen records from southern Sweden (von Post, 1924; Fries, 1951; Gaillard, 1984; Yu *et al.*, 2005; Antonsson and Seppä, 2007; Greisman and Gaillard, 2009). *Alnus* and *Quercus* were however not likely making up a substantial part of the vegetation, as they do not surpass the threshold percentage values for regional dominance (12% and 14% respectively) developed by Giesecke *et al*. (2017). *Tilia* also appears as one grain in one sample at 216 cm, but as it only occurs once it is unlikely that trees of the genus were locally present. Since *Tilia* is primarily entomophilous (Anderson, 1976) and its pollen therefore generally does not disperse far (Andersen, 1970), it is however likely that it was occurring at least sporadically in vegetation fairly close to Käringmossen. This immigration of new thermophilous tree taxa during the Boreal is likely a reflection of the still rapidly warming climate (Antonsson and Seppä, 2007), although the exact time of immigration may also be affected by factors such as dispersal rates and the location of glacial refugia (Svenning and Skov, 2007). The trend of continuous immigration of new taxa following the Holocene warming that began in the Preboreal period does as such continue in the Boreal.

The relatively low *Alnus* values (figure 5a) recorded at Käringmossen differ from Bohuslän, located north of Halland, where Fries (1951) recorded percentages high enough (20–75% of all arboreal pollen) to name the Boreal period the *Alnus*-*Ulmus* period. An explanation for the low values at Käringmossen could be the upland setting of the fen, with thin and thus likely dry soils. As *A. glutinosa*, the only *Alnus* species present in southern Sweden today, is related to wet, alkaline habitats (Bennett and Birks, 1990), it is possible that the Käringmossen environment was not very suitable for the species. When discussing early Holocene *Alnus* distribution, the possibility that *Alnus* pollen could come from *A. incana* must however be taken into consideration. This species has a different ecology from *A. glutinosa* and today has a primarily northerly distribution in Sweden (Engelmark and Hytteborn, 1999). As such it is hard to draw definitive conclusions about the local environment based on the comparatively low presence of *Alnus* pollen at Käringmossen.

Along with new immigrating tree taxa, the Boreal period also marks the time during which *Calluna* expands and establishes a constant presence in the vegetation (figure 5a). As it expanded it appears to have replaced other ericaceous shrubs, since other Ericaceae pollen in LPAZ KM7 markedly decrease compared to KM6. The presence of Calluna

can be used as an indication that fairly open habitats still remained in the landscape (Berglund, 1966) and it is possible that *Calluna* dominated heath vegetation existed alongside *Pinus* in the rocky upland habitats surrounding Käringmossen. Just as with other ericaceous dwarf shrubs, *Calluna* pollen could however also simply come from shrubs growing on or along the margins of the Käringmossen fen.

In addition to vegetational change, Boreal climatic change can also be inferred from the Käringmossen record. Based on the transition from *Sphagnum*- to fen peat in the core stratigraphy just prior to the KM7 pollen zone (figure 3; table 1), and the decrease in *Sphagnum* spores and disappearance amoeba *Archerella flavum* in KM7 (figure 5b), it appears that climate became wetter during the Boreal. This is in accordance with south-Swedish lake level records that show increasing lake levels during the Boreal after the extreme lows of the Preboreal (Digerfeldt, 1988; Gaillard and Digerfeldt, 1991; Harrison and Digerfeldt, 1993). As such, the Käringmossen record confirms that climate was likely getting wetter towards the end of the early Holocene.

### 6.3.3 Atlantic (8,900–5,700 cal yr BP) – LPAZ KM8

A marked change in the vegetation at Käringmossen can be inferred from LPAZ KM8, representing the Atlantic period and the HTM. The change in the pollen record consists of a doubling of *Betula* pollen percentages, while the previously frequently occurring taxa *Corylus* and *Pinus* decrease (figure 5a). Although the *Betula* peak at Käringmossen occurs in samples with weighted mean ages of between 8,600–8,300 cal yr BP, the peak could be a reflection of deteriorating climate in association with the 8.2 ka event (Alley *et al.*, 1997; Rasmussen *et al.*, 2014). This would assume that there is a slight offset in the age-depth model during the early Atlantic period. The simultaneous peak in pollen influx rate in the samples where *Betula* increases (figure 6) does however not indicate that climate was deteriorating, although the peak could also be related to the change from fen- to *Sphagnum* peat that happens between KM7 and KM8 (figure 3; table 1). The increase in *Alnus* pollen in early KM8, assuming that it belongs to thermophilous *A. glutinosa*, is also not in favour of deteriorating climate. Neither is the lack of similar *Betula* peaks in other contemporary pollen records from southern Scandinavia (e.g., Berglund, 1966; Gaillard, 1984; Digerfeldt and Håkansson, 1993; Yu *et al.*, 2005; Antonsson and Seppä, 2007) that could confirm that *Betula* expansion was a regional response to large-scale climatic changes. An alternate explanation for the *Betula* increase could instead be local establishment of birch on, or in close association with, the Käringmossen fen, since very close proximity of *Betula* to the coring site could lead to overrepresentation in the pollen record (Jackson, 1990). Fries (1951) has noted that *Betula* and *Alnus* overrepresentation is common in Atlantic pollen records from Bohuslän, likely due to local growth of the taxa in wet areas. The high *Betula* values of the early Atlantic may therefore not reflect large-scale vegetational changes, but rather very local ones.

Similar to most south Scandinavian HTM pollen records (e.g., von Post, 1924; Sandgren, 1944; Fries, 1951; Iversen, 1960; Berglund, 1966; Yu *et al.*, 2005; Antonsson and Seppä, 2007), *Quercetum mixtum* taxa reach peak values in zone KM8 (figure 5a). This high abundance can be related to the warm climate, with the simultaneous peak in all *Quercetum mixtum* taxa occurring around 7,000 cal yr BP, which is the estimated time of HTM peak temperatures (Seppä, Hammarlund and Antonsson, 2005; e.g., Antonsson and Seppä, 2007; Seppä *et al.*, 2009). The peak pollen percentages can be related to the expansion and later dominance of broad-leaved forests in southern Scandinavia during the time (von Post, 1924; Fries, 1951; Berglund, 1966). Values for these taxa are however lower at Käringmossen than in many other Atlantic pollen records (e.g., Fries, 1951; Berglund, 1966; Gaillard, 1984; Antonsson and Seppä, 2007) and they are all below the percentage thresholds for regional dominance (4% for *Tilia* and *Ulmus*; 14% for *Quercus*) set by Giesecke *et al.* (2017). The low pollen percentages at Käringmossen

could possibly be explained by the assumed overrepresentation of *Betula* in the pollen record, but it could also indicate that *Quercetum mixtum* taxa were not as widespread in the area as in other parts of southern Sweden. Since the coring site would have been located on a rocky inner-archipelago island during the Atlantic period (figure 2d), it is possible that local growing conditions for *Quercetum mixtum* taxa were not optimal. Berglund (1966) has, e.g., noted that *Pinus* forests were common on rocky ground and in the archipelago in southeastern Sweden during this time, when broad-leaved trees were otherwise dominating. *Pinus* percentages are however exceptionally low in LPAZ KM8. Lack of suitable habitats for the *Quercetum mixtum* taxa could still, along with possible *Betula* overrepresentation, be a contributing factor to their relatively low percentages during the Atlantic period.

### 6.3.4 Post-Atlantic (from 5,700 cal yr BP) – Upper LPAZ KM8 and KM9

The time following the Atlantic period until the present is in the Käringmossen pollen record represented by the uppermost sample of KM8 at 102 cm and the two samples of KM9 at 48 cm and from the fen surface (figure 8). These samples are far separated in age (>2,000 years) and represent the earliest part of the Subboreal (102 cm) and the early and late Subatlantic (48 cm and the fen surface sample). Because of the low temporal resolution of the samples, it is not possible to in detail trace vegetational changes at Käringmossen in the late Holocene. The ages of the different pollen samples in this part of the Käringmossen core are also uncertain, as the uppermost radiocarbon sample was made at 137 cm. Because the time span covered in the core from 137 cm to the top of the fen surface is approximately 7,400 years, ages between the top radiocarbon sample and the fen surface have 95% confidence intervals spanning up to 2,000 years (figure 3).

In the earliest post-Atlantic sample at 102 cm, with a weighted mean age of 5,400 cal yr BP, a change in the local environment compared to the Atlantic period can be discerned. Here, *Quercetum mixtum* taxa, *Corylus* and *Betula* all decrease, while *Calluna* and other ericaceous dwarf shrubs increase (figure 5b). Dropping *Quercetum mixtum* and *Corylus* percentages could possibly be related to the cooling that followed the HTM temperature peak (Antonsson and Seppä, 2007; Seppä *et al.*, 2009). The changes in vegetation are however more likely a result of human activities, as agriculture was first introduced in southern Scandinavia around 6,000 cal yr BP (Price, 2015) and there have been finds of burned cereal grains from the same time in Veddige, about 7 km northeast of Käringmossen (Johansson *et al.*, 2011; Sørensen and Karg, 2014). Forest clearance for cultivation and pasture could as such be the cause for decreasing tree pollen percentages, while the *Calluna* peak could be associated with development of heaths on cleared and grazed land (Iversen, 1941; Behre, 1981). Increasing Poaceae percentages in the sample at 102 cm could also indicate increasing openness in the vegetation surrounding Käringmossen, and Plantaginaceae pollen, if they belong to *Plantago lanceolata*, could be indicative of fallow land (Iversen, 1941; Behre, 1981). There are however no cereal pollen present in the 102 cm pollen record, but this is expected since the first cereals cultivated in Scandinavia, wheat and barley, are predominantly autogamous and thus produce little pollen (Iversen, 1941). Cereal pollen are as such not necessary to conclude that early Subboreal vegetational changes at Käringmossen were likely at least in part caused by humans.

Although the pollen sample at 102 cm likely contains evidence of early agriculture in southern Scandinavia, the exact age of the sample is questionable due to the uncertainties in the age-depth model. An indication that the 102 cm sample is not as old as its weighted mean age of about 5,400 cal yr BP is the presence of *Fagus* pollen in values just above the 1% threshold for regional presence set by Lisitsyna, Giesecke and Hicks (2011). As 5,400 cal yr BP is about 1,400 years before *Fagus* is typically thought to have established in southern Sweden (Björkman, 1997; Bradshaw and Lindbladh, 2005), it is likely that the weighted mean age of the 102 cm sample is too old. Since the 95% confidence

interval for the 102 cm sample spans 4,400–6,300 BP, the presence of *Fagus* makes is likely that the true sample age lies towards the younger end of this range. However, even 4,400 cal yr BP is slightly too old for *Fagus* presence, as the results of Bradshaw and Lindbladh (2005) indicate that the tree established in northern Halland first between 4,000–3,000 cal yr BP. However, as *Fagus* does occur sporadically in Swedish pollen records older than 4,000 BP (e.g., Gaillard, 1984; Antonsson and Seppä, 2007), a higher temporal resolution of the late Holocene pollen samples would be necessary to determine whether the *Fagus* in the sample at 102 cm is a one-time occurrence or not.

In the two later post-Atlantic samples from LPAZ KM9, pollen sums are low compared to other LPAZ (figure 5a). These low pollen sums increase the probability that counted pollen are not representative of the true pollen assemblages in the peat, meaning that results from KM9 are less reliable than from other parts of the Käringmossen core. The low pollen sums are likely a result of the low humification of the peat in the top 80 cm of the core (table 1), as low decomposition of non-pollen material in peat will lead to reduced pollen concentrations compared to highly decomposed peat. Despite these issues, a clear change in vegetation compared to the early post-Atlantic sample can be discerned in LPAZ KM9. A marked increase in *Pinus* and the appearance of *Picea*, while *Quercetum mixtum* taxa decrease, likely reflects a vegetational response to the climate cooling following the mid-Holocene peak in temperatures (Antonsson and Seppä, 2007; Seppä *et al.*, 2009). What differentiates Käringmossen from many other late Holocene pollen records from southern Sweden (e.g., Berglund, 1966; Digerfeldt and Håkansson, 1993; Yu *et al.*, 2005; Antonsson and Seppä, 2007) is that *Pinus*, rather than *Betula*, appears to replace the mid-Holocene *Quercetum mixtum* taxa. An explanation for this could be the rocky immediate surroundings of Käringmossen (figure 1), to which *Pinus* is better adapted than *Betula* (Stenberg, 2018).

Similar to in the early post-Atlantic sample, humans were exerting influence on vegetation also in the later part of the post-Atlantic, corresponding to the Subatlantic period. In the lower sample at 48 cm, with a weighted mean age of approximately 2,500 cal yr BP, there is direct evidence of agriculture in the form of *Secale cereale* (rye) pollen (figure 5b). Further evidence of agriculture in this sample is increasing herb pollen percentages (figure 5a) that indicate that the landscape became more open, likely due to forest clearance. This fits with archaeological evidence of continuous settlement in the near vicinity of Käringmossen, from the Neolithic period until the Viking Age (Altner and Streiffert, 2019; Ängeby and Connelid, 2022). As *Secale cereale* was not introduced to southern Sweden until around 2,000 cal yr BP (Behre, 1992; Grabowski, 2011), it is however likely that the lower KM9 sample is younger than the weighted mean age of approximately 2,500 cal yr BP from the age-depth model. 2,000 cal yr BP is still within the 95% confidence interval of the sample age (figure 3), and as such, the lower KM9 sample most likely constitutes evidence of Iron Age agriculture and rye cultivation in the Käringmossen surroundings. Later, the domination of *Pinus* and *Picea* pollen in the KM9 top sample is also an indication of human presence in the landscape, but it reflects a change in land use, from Iron Age agriculture to present-day commercial forestry in which coniferous trees are favoured.

# 7 Conclusions

From the sedimentary deposits at Käringmossen fen, it has been possible to reconstruct vegetational, environmental and climatic changes in northern coastal Halland, close to the archaeological site at Skatmossen. The reconstruction stretches from the early Lateglacial period, around 15,300 cal yr BP, until the present. Shortly after the last

deglaciation of the area, during the Oldest Dryas period, when some of the first humans to visit Sweden were making camp at Skatmossen, Käringmossen was a lake situated on an island in an outer archipelago. The vegetation was sparse, and it was dominated by pioneer herbs and shrubs adapted to cold steppe and tundra environments, such as *Artemisia*, *Hippophaë*, *Salix* and *Oxyria*. With the entry into the Bølling warm period about 14,600 cal yr BP, vegetation in the Käringmossen surroundings grew denser, but it was still dominated by pioneer herbs and shrubs. Trees came to Käringmossen first around the start of the Allerød period, about 13,900 cal yr BP, as tree-birch became established and woodlands started developing. Towards the latter half of Allerød, ericaceous dwarf shrubs, likely of the *Empetrum* genus, also established and heaths and birch woodlands were dominating the vegetation. The Younger Dryas cooling, around 12,800 cal yr BP, appears to have caused reduced biological productivity at Käringmossen, but tree-birch likely remained in the landscape. The Allerød heathlands were however greatly reduced in their landscape presence and likely in part replaced by steppe-tundra related herbs, such as *Artemisia*. Although a response to cooling in the early Younger Dryas is seen in the Käringmossen record, recovery seems to have happened already after about 400 years, and by 12,400 cal yr BP, pollen influx rates and LOI values indicate that vegetation was denser and more productive than during the Allerød period. At the end of Younger Dryas and the Lateglacial period, the landscape, which was now situated in an inner archipelago environment, was dominated by increasingly dense *Betula* woodlands where *Pinus* was likely starting to appear.

From the start of the Holocene, around 11,500 cal yr BP, more trees started appearing at Käringmossen in association with the rapid climate warming that was taking place. *Pinus*, *Corylus* and *Ulmus* were the first tree taxa to appear, and they had become established already in the early Preboreal period. At the same time, woodlands grew denser and by the mid- to late Preboreal, closed forests had likely developed. As these changes were happening in the terrestrial vegetation, the Käringmossen lake transitioned into a fen in association with a period of extremely low groundwater levels in southern Sweden. From the late Preboreal and during the Boreal period, between about 10,700–9,200 cal yr BP, *Corylus* had a peak in landscape presence, and was a dominant forest forming tree, along with *Betula* and *Pinus*. In the Boreal period, *Alnus* and *Quercus* also appeared as new forest elements, but likely only in small numbers. These two taxa later increased along with *Ulmus* and *Tilia* as forests became dominated by broad-leaved trees during the Atlantic period, between 8,900–5,700 cal yr BP. The main taxon of the broad-leaved forests at Käringmossen does however appear to have been *Betula*, as opposed to other parts of southern Sweden during this time, where *Quercetum mixtum* taxa (e.g., *Ulmus*, *Quercus* and *Tilia*) were prominent.

After the Atlantic period, increasing human influence in the landscape can be recognized in the Käringmossen pollen record. During the Subboreal period, decreasing tree pollen percentages and increasing *Calluna* and herb percentages, indicate increasing landscape openness. This can be related to early Neolithic agricultural practices, in which forests were cleared for cultivation and pasture. Later, around 2,000 cal yr BP and during the early Subatlantic period, further evidence of agriculture at Käringmossen includes the presence of *Secale cereale*, rye, in the pollen record. In the present day, anthropogenic influences in the landscape are instead recognized in high percentages of coniferous tree pollen (*Pinus* and *Picea*), which reflect a change in land use from agriculture to modern commercial forestry.

# Acknowledgements

First, I wish to thank my supervisor Martina Hättestrand from the Department of Physical Geography at Stockholm University for her invaluable guidance and support in the field, in the lab and in the writing process of this thesis. I also want to thank Felix Riede from the Department of Archeology and Heritage Studies at Aarhus University for coming up with the original idea of making a pollen analytical study at Skatmossen, and Stefan Wastegård from the Department of Physical Geography at Stockholm University for putting us in contact. Thank you also Stefan for accompanying Martina and I in the field, for giving advice during the sampling process in the lab, and for proof reading and providing comments on the unfinished manuscript of this thesis. I deeply thank Simon Larsson from the Department of Physical Geography at Stockholm University for performing the sampling of macrofossils for radiocarbon dating, and for teaching me how to use R for age-depth modelling. And thank you to Stefan, Simon and Susanna Logård, master student at the Department of Physical Geography at Stockholm University, for bringing me back to Käringmossen one year after the initial coring at the site. I also thank my examiner Peter Kuhry and assessor Qiong Zhang, both from the Department of Physical Geography at Stockholm University, for reading and giving comments on this thesis. Lastly, I wish to thank everyone who have supported me throughout the writing of this thesis, my family, my fellow master students at the Department of Physical Geography, and all other friends.

Funding for the field work and radiocarbon dating that were part of this thesis has been provided through the European Research Council and the Swedish Research Council.

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# Appendix

## Appendix A: Modelled ages of Käringmossen pollen samples

**Table B1.** Ages for the Käringmossen pollen samples based on age-depth modelling. Minimum and maximum ages are given with a 95% confidence interval.

| Depth (cm) | Weighted mean age (cal yr BP) | Minimum age (cal yr BP) | Maximum age (cal yr BP) |
|---|---|---|---|
| 0 | −71 | −73 | −69 |
| 48 | 2,534 | 1,584 | 3,627 |
| 102 | 5,423 | 4,407 | 6,326 |
| 128 | 6,929 | 6,216 | 7,327 |
| 151 | 8,310 | 7,858 | 8,797 |
| 156 | 8,608 | 8,184 | 8,975 |
| 176 | 9,233 | 8,927 | 9,478 |
| 201 | 9,589 | 9,373 | 9,789 |
| 216 | 9,751 | 9,600 | 9,943 |
| 236 | 10,009 | 9,793 | 10,170 |
| 251 | 10,313 | 9,997 | 10,661 |
| 268 | 10,669 | 10,297 | 11,068 |
| 283 | 10,992 | 10,576 | 11,427 |
| 297 | 11,288 | 10,863 | 11,715 |
| 308 | 11,531 | 11,096 | 11,939 |
| 321 | 11,797 | 11,375 | 12,177 |
| 333 | 12,057 | 11,668 | 12,376 |
| 345 | 12,316 | 11,954 | 12,566 |
| 350 | 12,429 | 12,109 | 12,635 |
| 353 | 12,496 | 12,252 | 12,658 |
| 358 | 12,605 | 12,459 | 12,714 |
| 365 | 12,788 | 12,571 | 13,060 |
| 373 | 13,030 | 12,745 | 13,358 |
| 381 | 13,268 | 12,924 | 13,642 |
| 391 | 13,562 | 13,202 | 13,900 |
| 401 | 13,863 | 13,553 | 14,099 |
| 411 | 14,126 | 13,904 | 14,341 |
| 421 | 14,319 | 14,085 | 14,676 |
| 429 | 14,482 | 14,235 | 14,858 |
| 447 | 14,870 | 14,518 | 15,277 |
| 457 | 15,081 | 14,682 | 15,557 |
| 469 | 15,326 | 14,854 | 15,900 |

## Appendix B: Taxa common names

**Table C1.** Scientific and English and Swedish common names for all taxa mentioned in the thesis.

| Scientific name | English common name | Swedish common name |
|---|---|---|
| | Trees | |
| *Alnus* | Alder | Al |
| *Alnus glutinosa* | Common alder | Klibbal |
| *Alnus incana* | Grey alder | Gråal |
| *Betula* | Birch | Björk |
| *Betula nana* | Dwarf birch | Dvärgbjörk |
| *Betula pubescens* | Downy birch | Glasbjörk |
| *Corylus* | Hazel | Hassel |
| *Fagus* | Beech | Bok |
| *Picea* | Spruce | Gran |
| *Pinus* | Pine | Tall |
| *Populus tremula* | Aspen | Asp |
| *Quercus* | Oak | Ek |
| *Tilia* | Linden/lime | Lind |
| *Ulmus* | Elm | Alm |
| | Shrubs | |
| *Hippophaë* | Sea buckthorn | Havtorn |
| *Myrica* | Bog-myrtle | Pors |
| *Salix* | Willow | Sälg/vide |
| | Dwarf shrubs | |
| *Calluna* | Common heather | Ljung |
| Ericaceae | Heather family | Ljungväxter |
| *Empetrum* | Crowberry | Kråkbär |
| | Herbs | |
| *Achillea* | Yarrows | Röllikor |
| *Artemisia* | Mugworts/wormwoods | Malörter |
| Caryophyllaceae | Carnation family | Nejlikväxter |
| Chenopodiaceae | Goosefoot | Mållor |
| *Cyperaceae* | Sedges | Halvgräs |
| *Filipendula* | Dropwort/meadowsweet | Älggrässläktet |
| *Galium* | Bedstraw genus | Måror |
| *Helianthemum* | Rock rose | Solvändor |
| *Oxyria* | Mountain sorrel | Fjällsyra |
| *Plantaginaceae* | Plantain family | Grodbladsväxter |
| Poaceae | Grasses | Gräs |
| *Ranunculus* | Buttercups | Smörblommor |
| *Ranunculus* sect. *Batrachium* | Water crowfoots | Möjor |
| *Rumex longifolius* | Northern dock | Gårdsskräppa |
| *Secale cereale* | Rye | Råg |
| *Thalictrum* | Meadow-rue | Rutor |
| | Aquatic angiosperms | |
| *Menyanthes* | Bogbean | Vattenklöver |

| Scientific name | English common name | Swedish common name |
|---|---|---|
| *Myriophyllum alterniflorum* | Alternate watermilfoil | Hårslinga |
| *Nymphaea* | Water lilies | Näckrosor |
| *Typha* | Reedmace/cattail | Kaveldun |
| | Pteridophytes and other NPPs | |
| *Archerella flavum* | - | - |
| *Equisetum* | Horsetails | Fräkenväxter |
| *Isoëtes* | Quillworts | Braxengräs |
| *Pediastrum* | - | Tagghjul |
| Polypodiaceae | Polypod ferns | Stensöteväxter |
| *Sphagnum* | - | Vitmossor |

# Appendix C: Raw pollen data

**Table C1.** Raw pollen data from the Käringmossen core expressed for each taxon as the number of counted pollen grains/NPPs per sample.

| **Depth (cm)** | **0** | **48** | **102** | **128** | **151** | **156** | **176** | **201** | **216** | **236** | **251** | **268** | **283** | **297** | **308** | **321** | **333** | **345** | **350** | **353** | **358** | **365** | **373** | **381** | **391** | **401** | **411** | **421** | **429** | **447** | **457** | **469** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Alnus* | 1 | 6 | 49 | 57 | 48 | 75 | 18 | 7 | 11 | | | | | 1 | | | | | | 2 | | | | | | | | 2 | | 1 | 2 | 1 |
| *Betula* | 11 | 51 | 220 | 312 | 371 | 550 | 173 | 63 | 223 | 88 | 216 | 215 | 143 | 251 | 364 | 400 | 463 | 565 | 419 | 474 | 367 | 381 | 466 | 387 | 391 | 344 | 128 | 144 | 58 | 70 | 90 | 23 |
| *Populus tremula*-type | 1 | 1 | 8 | 3 | | | 1 | | 1 | 2 | 8 | 11 | 47 | 1 | | 1 | | 4 | 1 | 1 | 1 | | | | 1 | | 4 | | | 4 | | 3 |
| *Carpinus* | | | 1 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *Fagus* | 2 | 1 | 6 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *Picea* | 13 | 9 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *Pinus* | 70 | 49 | 27 | 19 | 20 | 37 | 81 | 21 | 67 | 123 | 105 | 53 | 143 | 105 | 85 | 46 | 27 | 12 | 16 | 18 | 19 | 35 | 95 | 37 | 32 | 27 | 30 | 37 | 14 | 18 | 66 | 18 |
| *Quercus* | 1 | 1 | 11 | 19 | | 5 | | 1 | 3 | | | | | | | | | 1 | | | | | | | | | | | | | | |
| *Tilia* | | | 3 | 8 | | | | | 1 | | | | | | | | | | | | | | | | | | | | | | | |
| *Ulmus* | | | 3 | 9 | 8 | 10 | 7 | 2 | 4 | 1 | 3 | 2 | 1 | | 3 | | 1 | | | | | | | | | | | | | | | |
| *Corylus* | | 2 | 23 | 52 | 41 | 47 | 140 | 48 | 174 | 171 | 96 | 141 | 75 | 39 | 16 | 1 | 3 | 5 | | | | | | | | | | 5 | 3 | 1 | 1 | |
| *Hippophaë* | | | | | | | | | | | | | | | | | 1 | | | | | | | | | 1 | | | | | | |
| *Myrica* | | | | | | 6 | | 8 | 7 | 3 | | 4 | | | | | | | | | | | | | | | | | | | 1 | |
| *Rosa* | | | | | | | | | | | | | | | | | | | | | | | | | | | 1 | 1 | 1 | | | |
| *Salix* | | 1 | 2 | 27 | 46 | 45 | 2 | 4 | 40 | 6 | 16 | 8 | 9 | 9 | 6 | 18 | 15 | 45 | 29 | 39 | 31 | 26 | 31 | 19 | 38 | 25 | 63 | 22 | 46 | 36 | 30 | 6 |
| *Calluna* | | | 98 | 17 | | | 31 | 14 | 27 | 10 | | 14 | | | | | | 2 | | | | | | | | | | | | | 1 | |
| *Ericaceae* | | 13 | 27 | 3 | 5 | 11 | 15 | | 6 | 37 | 42 | 17 | 9 | 14 | 8 | 2 | 4 | 14 | 18 | 33 | 31 | 78 | 91 | 98 | 6 | 2 | | | | | 1 | |
| *Achillea*-type | | 1 | 1 | | | | | | | | | | | | | | | | | | | | | | | 1 | | | 2 | | 5 | |
| *Artemisia* | | | 2 | | | 1 | | 2 | 1 | | 3 | | 1 | 2 | | | 2 | 4 | 3 | 10 | 32 | 13 | 7 | 9 | 24 | 18 | 43 | 59 | 91 | 28 | 64 | 25 |
| *Asteraceae* | | | | | | | | | | | | | | | | | | | | | | 1 | | | | | | | 1 | | | |
| *Papaver* | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 2 | |
| C.f. *Sedum* | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 1 | | | |

| **Depth (cm)** | **0** | **48** | **102** | **128** | **151** | **156** | **176** | **201** | **216** | **236** | **251** | **268** | **283** | **297** | **308** | **321** | **333** | **345** | **350** | **353** | **358** | **365** | **373** | **381** | **391** | **401** | **411** | **421** | **429** | **447** | **457** | **469** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| C.f. *Spergula* s.l. | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 1 | |
| *Campanula*-type | | | | | | | | | 1 | 1 | 1 | | 3 | | | | | | | | | | | | | | | | | | | |
| *Caryophyllaceae* | | | | | | | | | | | | | | | | | | 3 | 1 | 1 | 1 | 2 | 1 | 1 | | 9 | 14 | 20 | 4 | 6 | 18 | 3 |
| *Centaurea scabiosa* | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 1 | | 1 | |
| *Chamaenerion*-type | | | | | | | | | | | | | | | | | | 1 | | | | 1 | | | | | | | | | | |
| *Chenopodiaceae* | | 1 | | | | 1 | | 1 | | | | | | | | 1 | | | | 2 | 4 | 2 | 2 | 2 | 2 | 2 | 3 | 1 | 5 | 3 | 7 | 4 |
| *Cichorium intybus*-type | | | | | | | 1 | | | | | | | | | | 1 | | | | | | | | | 1 | | | | | | |
| *Cirsium*-type | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 1 | | | |
| *Cichorieae* | | | | 1 | | | | | 1 | | | | | | | | | | 1 | | | | | | | | 1 | | | | 2 | |
| *Cyperaceae* | | 1 | | | | | | | | | 5 | 2 | 2 | 3 | 3 | | | | | 1 | | 14 | 2 | 8 | 39 | 10 | | 13 | 36 | | 5 | |
| *Elymus* s.l. | | | | | | | | | 1 | | | | | | | 2 | | | | | | | | | | | | | | | | |
| *Filipendula* | | | 1 | | | 3 | 2 | | | | 2 | 3 | 113 | 4 | 9 | 7 | 18 | 44 | 37 | 38 | 10 | 7 | 17 | 3 | 10 | 1 | 21 | 1 | | | | 1 |
| *Galium*-type | | | | | | | | | | | | | | | | 1 | | 1 | | | | 1 | 2 | 1 | | 2 | | 1 | 1 | 1 | 5 | |
| *Helianthemum* | | | | | | | | | | | | | | | | | | | | | | | | | | | | 2 | | 2 | 1 | 2 |
| *Oxyria*-type | 1 | | 3 | 6 | | | 1 | 2 | 1 | 6 | 1 | 2 | 1 | 1 | | | | 2 | 6 | 10 | 6 | 14 | 10 | 10 | 19 | 22 | 84 | 94 | 92 | 1 | 7 | |
| *Plantaginaceae* | | | 2 | | | | | | | | | | | | | | | | | | | | | 1 | | 3 | 19 | 9 | 19 | 21 | | |
| *Poaceae* | 2 | 14 | 26 | 7 | 8 | 8 | 19 | 12 | 14 | 16 | 8 | 27 | 15 | 68 | 65 | 33 | 65 | 52 | 52 | 72 | 37 | 53 | 83 | 36 | 36 | 24 | 77 | 49 | 66 | 29 | 115 | 11 |
| *Polygonum bistorta*-type | | | | | | | | | | | | | | | | | | | | | | | | | | 1 | | | 1 | | | |
| *Potentilla* | | | | | | | | | | | | | 2 | | | | | | | | | | | 2 | | 1 | | 1 | | | | |
| *Ranunculus*-type | | | | | | | | | 1 | | | | | | | | | | | 1 | 1 | 3 | | 7 | 3 | 2 | | 53 | 34 | 9 | 58 | 12 |
| *Rosaceae* | | | | | 1 | | | | 2 | | | | 3 | | | | | | | | | 1 | 1 | 1 | 1 | | 3 | 1 | 3 | | | |
| *Rumex longifoluis*-type | | | | | | | 1 | | | | | | | | | | 3 | | 2 | | | 3 | | 3 | 2 | 1 | | 5 | 13 | | | |

| **Depth (cm)** | **0** | **48** | **102** | **128** | **151** | **156** | **176** | **201** | **216** | **236** | **251** | **268** | **283** | **297** | **308** | **321** | **333** | **345** | **350** | **353** | **358** | **365** | **373** | **381** | **391** | **401** | **411** | **421** | **429** | **447** | **457** | **469** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Saussurea*-type | | | | | | | | | | | | | 1 | | | | | | | | | | | | | | | | | | | |
| *Secale cereale* | | 3 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *Solidago*-type | | | 1 | | | | | 1 | 3 | | | 1 | 2 | 1 | | | | | | | 1 | | | | | 2 | | 1 | | 1 | 4 | |
| *Thalictrum* | | | | | | | | | | | | | | | 1 | | | | | | | | | 2 | 1 | 1 | | 10 | 4 | | 2 | |
| *Umbelliferae* | | | 2 | | | 1 | | | | | | | 1 | | 1 | | | 4 | 2 | 1 | 1 | | | | | | | | | | | 1 |
| *Typha* | | | | | 1 | | | | | 1 | | | | | | 1 | | | | | | | | | | | | | | | 1 | |
| *Callitriche* | | | | | | | | | | | | | | | | | | | | | | | | | | | | 1 | | | | |
| *Menyanthes* | | | | | | | | | | | | 1 | 9 | | | | | | | | | | | | | | | | | | | |
| *Myriophyllum alterniflorum* | | | | | | | | | | | | | | | | 3 | 8 | 9 | 12 | 18 | | | | | | | | | | | | |
| *Nymphaea* | | | | | | | | | | | | | 2 | 5 | 9 | 1 | 2 | | | | | | | | | | | | | | | |
| Varia | 4 | 4 | 13 | 21 | 11 | 1 | 19 | 14 | 17 | 7 | 2 | 12 | 12 | 2 | 10 | 4 | 29 | 20 | 37 | 24 | 22 | 17 | 10 | 10 | 10 | 9 | 36 | 13 | 19 | 8 | 21 | 9 |
| *Equisetum* | | | | 6 | | | 1 | 1 | 1 | | | 51 | 1 | | | 9 | | 3 | | | | | | | 3 | | | 2 | | | 2 | |
| *Isoëtes* | | | | | | | | | | | | | | 3 | | 63 | 104 | 834 | 53 | | | | | | | | | | | | | |
| *Lycopodium* | | | | 1 | | | | | | | | | | | | | | 1 | 1 | | | 3 | | | 2 | | | | | | | |
| *Lycopodium complanatum-type* | | 1 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *Lycopodium selago* | | | | | | | | | | | | | | | | | | | | | 2 | | | | | | | | | | | |
| *Polypodiaceae* | 1 | | | 1 | | | | 1 | 2 | | | 1 | | 7 | 5 | 17 | 55 | 2 | 2 | | | 1 | 2 | | | 1 | | 1 | | | | 1 |
| *Sphagnum* | | 3 | 69 | 181 | 38 | 78 | 49 | 10 | 35 | 138 | 162 | 181 | 9 | 2 | 2 | 1 | | | | 1 | | 1 | | | 2 | | | | | | 1 | |
| *Pediastrum* | | | | | | | | | | | | | | 6 | 2 | 19 | 14 | 54 | 44 | 63 | 177 | 25 | 41 | 41 | 352 | 275 | 246 | 276 | 5160 | 575 | 855 | 483 |
| *Archerella flavum* | | | | | | | | | | | 109 | 34 | 50 | | | | | | | | | | | | | | | | | | | |
| *Tilletia sphagni* | | 4 | 3 | 10 | 30 | | 1 | 1 | 5 | | 1 | 8 | 1 | 4 | | | | | | | | | 1 | | | | | | | | | |
| Added *Lycopodium clavatum* | 153 | 617 | 489 | 133 | 28 | 28 | 340 | 532 | 306 | 236 | 796 | 818 | 387 | 104 | 57 | 145 | 87 | 298 | 134 | 223 | 177 | 362 | 153 | 324 | 367 | 491 | 343 | 370 | 394 | 1071 | 1028 | 630 |

**Table C2.** Wet weight-volume transformation table constructed to calculate the volume of sediment samples taken for pollen analysis in core KÄR01 between 100–465 cm and KÄR 05 between 0–100 cm.

| Depth (cm) | Wet weight/volume ($g/cm^3$) |
|---|---|
| 2–26 | 1.145 |
| 32–80 | 1.12 |
| 93–113 | 0.642 |
| 113–145 | 0.778 |
| 145–165 | 0.918 |
| 165–183 | 0.913 |
| 183–209 | 0.9 |
| 209–223 | 0.995 |
| 223–245 | 0.939 |
| 245–273 | 1.008 |
| 273–293 | 1.007 |
| 293–303 | 0.985 |
| 303–315 | 0.915 |
| 315–348 | 1.035 |
| 348–352 | 0.962 |
| 352–355 | 1.288 |
| 355–369 | 1.402 |
| 363–389 | 1.307 |
| 389–435 | 1.553 |
| 435–460 | 1.545 |
| 460–469 | 1.837 |

**Table C3.** Sample weight, volume and the number of added *Lycopodium clavatum* spore tablets for every pollen sample from the Käringmossen core.

| Depth (cm) | Sample weight | Sample volume | Added *L. clavatum* tablets |
|---|---|---|---|
| 0 | 0.204471 | - | 4 |
| 48 | 0.154936 | 1.1 | 4 |
| 102 | 0.648323 | 0.6 | 8 |
| 128 | 0.188053 | 1.2 | 8 |
| 151 | 0.416617 | 2.9 | 4 |
| 156 | 0.320669 | 2.3 | 4 |
| 176 | 0.30323 | 1.8 | 8 |
| 201 | 0.231213 | 1.8 | 8 |
| 216 | 0.221661 | 1.6 | 8 |
| 236 | 0.30762 | 2.6 | 8 |
| 251 | 0.12493 | 1.4 | 4 |
| 268 | 0.112398 | 1 | 8 |
| 283 | 0.201365 | 1.5 | 4 |
| 297 | 1.024241 | 1.2 | 4 |
| 308 | 0.324628 | 2 | 4 |
| 321 | 0.36439 | 2 | 8 |
| 333 | 0.41022 | 1.9 | 4 |
| 345 | 0.314278 | 1.7 | 8 |
| 350 | 0.288014 | 2 | 4 |
| 353 | 0.586849 | 1.5 | 4 |
| 358 | 1.098075 | 1.7 | 4 |
| 365 | 0.734398 | 1.8 | 8 |
| 373 | 1.067771 | 1.8 | 4 |
| 381 | 0.88284 | 1.8 | 8 |
| 391 | 2.135038 | 2.4 | 8 |
| 401 | 2.111196 | 2.1 | 8 |
| 411 | 2.409991 | 2.6 | 4 |
| 421 | 2.693126 | 2.7 | 2 |
| 429 | 2.621548 | 2.6 | 2 |
| 447 | 3.176763 | 2.6 | 4 |
| 457 | 3.636628 | 2.8 | 2 |
| 469 | 4.170107 | 2.3 | 4 |