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Local pollen analysis in a boreal forest setting – vegetation and land-use history at the summer farm Finnerudseter in south-eastern Norway

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Master of Science in Ecology

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The summer farm Finnerudseter

Preface

This thesis marks the end of my master degree in General Ecology at the Department of Ecology and Natural Resource Management (INA), Norwegian University of Life Sciences (NMBU).

First of all, I want to give a big thanks to Mikael Ohlson for good supervising!

All photos are by the author if not otherwise stated.

Norwegian University of Life Sciences

Ås, 18th of May 2016

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Abstract

Traditional cultural landscapes are threatened in Europe due to changed land-use practices. However, the historical extent of this human land-use practice is not yet fully known. This thesis describes the vegetation history and human land-use at the summer farm Finnerudseter located in Nordmarka, the forested area north of Oslo. Historical documents states that the human land-use goes back to AD 1600 at this summer farm. However, extensive human land-use at Finnerudseter most likely predates AD 1600, and pollen and charcoal from a small forest hollow situated near Finnerudseter were analysed to reconstruct the local vegetation history at the site. The aims of the study was to document the general vegetation history, and to estimate in how long time and to what extent human land-use have taken place at Finnerudseter. The period investigated covered the vegetation history at the site from *c.* 2587 to 1334 cal. yr. BP (cal. yr., and all following dates are also presented as cal. yr.). Based on the results from the pollen count, the vegetation history was divided into 4 vegetation zones. Zone I *Pinus* period (*c.* 2587–2452 BP); Zone II *Betula–Pinus–Alnus* period (*c.* 2425–2237 BP); Zone III *Betula–Pinus–Alnus–Picea* period (*c.* 2183–1779 BP); Zone IV *Picea–Betula* period (*c.* 1630–1334 BP). *Pinus* was the dominant tree species from *c.* 2587–2452 BP. In addition, *Picea* established locally at the site during this period, *c.* 2479 BP. A local fire *c.* 2452 BP led to a shift in the tree species composition with a reduction in *Pinus* and increase in the pioneer trees *Betula* and *Alnus*. The finding of a single pollen from Cerealia may indicate small-scale cultivation *c.* 2425 BP. Small-scale livestock grazing seem to have been present from *c.* 2290 BP. *Picea* increased in amount *c.* 2183 BP, and the varying presence from *c.* 2183 to 1779 BP seem to be due to further forest clearing and human land-use. *Picea* became the dominant tree species *c.* 1630 BP, at the same time as human impact at Finnerudseter increased. The results clearly showed that human impact at Finnerudseter predated AD 1600 and probably started already in the Early Iron Age. However, there is gap from *c.* 1334 BP to 350 PB (AD 1600), which has not been investigated in this thesis, further research is therefore needed to get a more complete vegetation history at the summer farm Finnerudseter.

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1 Introduction

The traditionally managed cultural landscapes, such as pastures and meadows, are amongst the most species rich habitats in Europe (Kull & Zobel 1991; Myklestad & Sætersdal 2004; Nedkvitne et al. 1995; Robinson & Sutherland 2002). However, the extent of this type of landscapes has decreased markedly over the past 60 years due to more rationalized agricultural practices (Bryn & Flø 2011; Critchley et al. 2004; Robinson & Sutherland 2002). This in turn has caused a serious threat to the biodiversity that is dependent on habitat qualities maintained by traditional management of cultural landscapes (Høiland 1996; Jacquemyn et al. 2011; Nedkvitne et al. 1995). In general, most of our knowledge about cultural landscape history is based on archaeological excavations and historical documents. However, palaeoecological studies of the vegetation history can give supplementary and valuable information to archaeological records, and thereby enable a better understanding of the age and extent of human land-use (Kvamme 1988; Moore et al. 1991; Overballe-Petersen & Bradshaw 2011; Overland & Hjelle 2009).

Palaeoecological methods such as analysis of plant macrofossils, charcoal fragments and stored pollen can be used to reconstruct the vegetation history of a given area (Bradshaw 1992). However, to reconstruct past vegetation, pollen analysis is the most widely used method (Fægri & Iversen 1989). Wind pollinating species produce a lot of pollen, which is mixed by atmospheric turbulence, spread by the wind and deposited relatively evenly in the landscape (Birks & Birks 1980; Bradshaw & Sykes 2014; Fægri & Iversen 1989). Because the amount of pollen deposited from each species depends on the abundance of a species in the landscape at a certain time, pollen analysis can be used to quantitatively reconstruct past vegetation (Birks & Birks 1980).

Reconstruction of past vegetation is possible because the pollen grain can be stored for several thousand years in peat and sediments (Bradshaw & Sykes 2014; Fægri & Iversen 1989). The outer exine layer that conceals the pollen grain contains a very resistant substance called sporopollenin (Birks & Birks 1980; Fægri & Iversen 1989) which makes it resilient to decay (Bradshaw & Sykes 2014). Oxidation destroys the sporopollenin-layer, but the layer is unaffected by acids. Pollen grains are therefore well preserved under acid and anaerobe conditions such as those found in sediments and peats, and are resilient to the acids used during preparation for pollen analysis (Birks & Birks 1980; Fægri & Iversen 1989; Jacobson &

Bradshaw 1981; Jardine et al. 2015). Where the decomposition is slow or non-existing, peat layers act as an archive for biological fossils such as pollen grains (Bradshaw & Sykes 2014). Because pollen grains are small and the amount of pollen that is stored in peat is high, only small volumes of peat are needed to do a statistically representative sampling and analysis (Birks & Birks 1980).

The pollen stored in the stratigraphic record derives mostly from the nearest vegetation, but some long-distance pollen is also present (Sugita 1994). A lake or large bog receives pollen from an area of several thousand hectares (Jacobson & Bradshaw 1981; Overballe-Petersen & Bradshaw 2011) and the stratigraphic records from these can therefore be used to reconstruct regional vegetation changes such as changes in the forest landscape (Jacobson & Bradshaw 1981). On the other hand, small forest hollows receive pollen mainly from the vegetation that is 20-100 m away (Andersen 1970; Jacobson & Bradshaw 1981; Sugita 1994). Stratigraphic records from small forest hollows are therefore useful in the study of local vegetation changes (Andersen 1970; Bradshaw & Sykes 2014; Calcote 1995; Jacobson & Bradshaw 1981; Lindbladh & Bradshaw 1995; Mitchell 2005; Sugita 1994).

As well as pollen, charcoal fragments are useful to study local vegetation changes and fire dynamics (Scott 2010). It is then important to ensure that the fragments are only from the nearest surroundings. This can be done by selecting a size limit (Emanuelsson 2001), where fragments larger than 500 µm (macroscopic charcoal) usually originates from local fires (Ohlson & Tryterud 2000). Moreover, findings of macroscopic charcoal fragments at the same time as there is an alteration in the pollen record is a good indicator of local fires (cf. Hörnberg et al. 2012; Segerström et al. 2008).

With the help from pollen analysis and macroscopic charcoal fragments it is possible to detect the transition from a undisturbed (forest) landscape to a human-influenced landscape (Birks & Birks 1980; Fægri & Iversen 1989). Local pollen-analytic studies (stand-scale palynology) may connect small-scale disturbances, such as human land-use, to changes seen in the pollen record (Bradshaw 2007). Although, traces of extensive land-use are more difficult to detect through pollen analysis than traces of more intensive land-use (Behre 1981). Traces of land-use in marginal forested areas may therefore be more difficult to detect (Lagerås 2007).

Nevertheless, there are several approaches to identify human land-use. One approach used in palaeoecolgy is the indicator species approach (Behre 1981), which is rather qualitative. As

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well, pollen assemblages from modern analogs of cultural landscapes has been used to identify important cultural species associated with different types of land-use and distinguishing them from each other (Gaillard et al. 1992; Hicks 2007). Presence of pollen from anthropochores – which are species indicative of cultivation such as cereal pollen type (e.g. *Secale cereale* L.), and/or apophytes – plants favored by grazing, such as e.g. J*uniperus communis* L., *Rumex* L. and *Plantago* species, are strong indicators of human land-use (Behre 1981; Gaillard 2007; Josefsson et al. 2014). Moreover, human land-use such as clearing may be indicated by an increase in non-arboreal pollen (NAP) species and a reduction in arboreal pollen (AP) species in the pollen record (see e.g. Bjune et al. 2009), however this approach is not always a good indicator of landscape openness (Sugita et al. 1999).

Furthermore, macroscopic charcoal fragments that occur at the same time as anthropogenic indicators in the stratigraphic record, may be interpreted as being the result of human induced fires. Forest fires induced by human land-use has been an important disturbance factor in many forest ecosystems, due to slash-and-burn agriculture and burning to improve grazing grounds (see e.g. Bele & Norderhaug 2008; Bradshaw & Hannon 1992; Molinari et al. 2005; Overland & Hjelle 2013; Segerström et al. 1994; Segerström et al. 1996). However, findings of indicator species along with macroscopic charcoal fragments can only *indirectly* be interpreted as being the result of clearance by fire, cultivation and/or improving grazing grounds (Behre 1981), and natural causes cannot be out-ruled.

Through regional pollen analysis it has been possible to reconstruct past climatic trends (see e.g. Bjune et al. 2005; Helama et al. 2012; Seppä & Birks 2001), but of course there are several pitfalls related to this approach, where soil erosion and human influence for example may affect the results (Prentice 1986). For example, *Picea abies* (L.) H.Karts. has taken over as the dominant tree species in large parts of the Norwegian forest landscape during the last 1000 calibrated years BP (before present, 1950) (Seppä et al. 2009). The main cause may have been changed climatic conditions and fire regimes, and the causes of the rapid expansion of *Picea* in Norway has been discussed in several papers (see e.g. Hafsten 1992; Ohlson et al. 2011; Tryterud 2003). It has also been suggested that human impact may have contributed to the rapid establishment of *Picea* in some places due to openings in the forests (Bjune et al. 2009; Hafsten 1992; Molinari et al. 2005; Overland & Hjelle 2013).

Climate was long seen as the major driver for vegetation changes, and human impact was not regarded as very important (Fægri & Iversen 1989). In Europe it has been difficult to separate the effects of climate and human impact on vegetation changes (Bradshaw & Hannon 1992; Hafsten 1956). However, several pollen-analytical studies (Bradshaw & Hannon 1992; Molinari et al. 2005; Segerström et al. 1994) suggest that human influence has indeed played a significant role in Europe for several thousand years. Forests that have been regarded as "natural and old growth" have shown to be influenced by humans even in rather recent times (Molinari et al. 2005; Segerström et al. 1994).

Human impact on the vegetation has been important in Norway throughout time (Bele & Norderhaug 2013; Nedkvitne et al. 1995; Schjerden 1997). Because of the tradition of summer farming and outland grazing in Norway, many marginal areas have a history of diverse agricultural use (see e.g. Bjune et al. 2009; Hafsten 1956; Molinari et al. 2005; Nedkvitne et al. 1995; Overland & Hjelle 2013; Schjerden 1997). The practice with using infields and outlying land in forest and mountain areas was already important in Norway 2000 years ago (Moen et al. 1999), and the man-made coastal heathlands are likely to have been in use since *c.* 6000 BP (Norderhaug et al. 1999). Moreover, according to several pollen-analytical studies (Bjune et al. 2009; Overland & Hjelle 2009; Overland & Hjelle 2013), human land-use may have affected the vegetation in Norway for at least 6000 years, although low-impact. Considerable parts of the nature we see as untouched today, has actually been subjected to prolonged human land-use (Nedkvitne et al. 1995; Reinton 1961). However, the extent and age of this influence on vegetation throughout the Holocene in Norway is not yet fully known (Kvamme 1988; Nedkvitne et al. 1995).

According to pollen-analytical (Hafsten 1956) and archaeological (cf. Solheim 2012) studies, agriculture came to the Oslo area in south-eastern Norway already in the beginning of the Late Stone Age. However, the age and extent of human land-use in the areas situated on the more unfertile soils, such as the forested area Nordmarka north of Oslo, has not been investigated thoroughly. According to Reinton (1961), the tradition of using outlying areas for summer farming and livestock grazing in Nordmarka is the oldest in the country, however no pollen-analytical studies can confirm this and it is thus far from clear that this statement is correct.

My study focuses on the vegetation history near the summer farm Finnerudseter located in Spålen-Katnosa nature reserve in northern Nordmarka. According to historical documents,

human land-use at Finnerudseter started in AD 1600 when Finnish immigrants cleared and burned the forest to sow rye in the ash (Grønbech & Nesheim 1997). Based on other pollen-analytical findings from south-east Norway (Hafsten 1956; Molinari et al. 2005; Overland & Hjelle 2013), and Reinton (1961) assumptions, one can question if the cultural influence around Finnerudseter did begin in AD 1600, or indeed earlier. A local pollen-analytic investigation could provide supplementary information to historical documents and archaeological records. Moreover, pollen analysis at the marginal site Finnerudseter may give a better understanding of the land-use practice in Nordmarka in general. Furthermore, knowledge about the age and extent of human land-use at the site through time can contribute in the debate about the importance of keeping these biodiversity spots from the past. My main aim in this thesis is to describe and discuss:

1. The general vegetation history at Finnerudseter from c. 2587 to 1334 BP
2. The extent and start of anthropogenic land-use

2 Study area

Nordmarka is the forested area of *c.* 550 km^2 situated north of Oslo (Figure 1). Four counties share this area – Oslo, Akershus, Buskerud and Oppland. Nordmarka verges to Krokskogen and Bærumsmarka forest in the west, agricultural land at Hadeland to the north, the river Hakadalselva to the east, and to the city of Oslo in the south. The name *Nordmarka* was first mentioned in 1760, although the name might be older than that (Blix & Blix 1952). Different parts of the Nordmarka forest have had several owners through the centuries, but today Løvenskiold-Vækerø and the municipality of Oslo are the main owners. Nordmarka is an important recreational area for citizens living around and at the border of these forests (e.g. Frislid & Andersen 1996).

This study focuses on the summer farm Finnerudseter which is located in the Spålen-Katnosa nature reserve northeast in Nordmarka. The reserve was established in 1995, but expanded in 2014 and has now a total area of *c.* 8134 ha (Lovdata 2014). Several red-listed species are registered within the reserve, among them *Usnea longissima* and *Amylocystis lapponica*, which both are listed as endangered (EN) on the Norwegian species red list of 2010 (Kålås et al. 2010). As well, several cultural elements such as old roads, floating installations, old farms and summer-farms are present.

The summer farm Finnerudseter, which is the study site in this thesis, is located in a south-facing slope south-east of the lake Spålen (60°9´N; 10°32´E) (Figure 1), Buskerud county in Ringerike municipality.

2.1 Topography, geology and deposits

Nordmarka's topography is characterized by high hills. The highest hills are located in the north-western part, with Svarttjernshøgda 717 m.a.s.l. as the highest one. The whole area slopes slightly downwards from the north and northwest to the south and southeast. Because of this, all larger rivers in Nordmarka runs in a northwest-southeast direction (Thorstensen 1952). Most of the area in the Spålen-Katnosa nature reserve, in which my study area is located, lies 450-618 m a. s. l. The landscape is typical for the Nordmarka forest, with small forested hills (Løset et al. 2012).

Figure 1: Map showing the forests of Nordmarka in relation to Oslo and location of the sampling site (A), and the sampling site at Finnerudseter (B).

The groundworks of the Nordmarka-landscape was already laid *c.* 250 million years ago (Dons & Bockelie 1996). The bedrock in Nordmarka constitutes of hard plutonic rock that once solidified in the depths. Erosion of the crust through millions of years have exposed these hard rocks (Dons & Bockelie 1996; Størmer 1952), and can today be seen as the high hills in Nordmarka (Thorstensen 1952). Some remains of the crust are still left as islands of Cambro-Silurian and Permian lava in some places, e.g. at Svartor and Blankvann (Størmer 1952). Deciduous forest grow on these islands unlike the hard plutonic rock and morainic deposits which mostly support coniferous forest (Størmer 1952). The contact between the magma and the Cambro-Silurian rock led to the formation of minerals such as iron, copper, lead and zinc. It is in these contact zones that we today can find signs from the former mining in Nordmarka (e.g. Grua, Sognsvann, Vettakollen, Gaustad) (Dons & Bockelie 1996; Størmer 1952).

The deposits in the Oslo area derives from the melting of the ice sheet that covered South Norway 10 000 years ago. These deposits can roughly be put in two categories – those that were deposited above 205 to 220 m.a.s.l. and those that were deposited under this border. Those that are located under 205 to 220 m a. s. l. today are marine deposits of sand, gravel and clay. These deposits were transported into the sea at a time when seawater covered the lowlands in the Oslo area *c.* 10 000 years ago (Dons & Bockelie 1996; Størmer 1952). The Oslo area was lower than today because of the pressure of the ice sheet that covered Fennoscandia (Dons & Bockelie 1996; Størmer 1952). This is the reason why fertile soils in the Oslo area are located below *c.* 200 m a. s. l (Størmer 1952).

Deposits located above this border are mostly ground moraines and terminal moraines. A halt in the deglaciation in the Oslo area created the terminal moraines that today retains water in Bogstadvannet, Sognsvann and Maridalsvannet (Dons & Bockelie 1996; Størmer 1952). In Nordmarka the deglaciation occurred at a constant speed; consequently, there are no terminal moraines there (Størmer 1952). Instead, ground moraines were left in the valley by the receding glacier. Because of this, farms in Nordmarka are located on the few deposits that ended up as ground moraines and that was not washed away (Thorstensen 1952).

The study site Finnerudseter is located *c.* 500 m a. s. l., the bedrock constitutes mostly of titanite-biotitesyenite (NGU 2015a) and the deposits of thick layers of morainic material (NGU 2015b). The inclination of the meadow on the upper part is higher than 1:3, the rest has an inclination between 1:5 and 1:3 (NIBIO 2015a).

2.2 Climate

The climate in Nordmarka is slightly continental, with warm summers and long cold winters (Thorstensen 1952). The average January temperature is -5,6 °C and the average July temperature is 13,6 °C at Tryvannshøgda 528 m a. s. l. (Norwegian Meteorological Institute 2015). Because of the topography, the areas north of Oslo has a mean annual precipitation that is higher than the rest of South-East Norway. Humid air coming from the South and East meets the hills in the Nordmarka (Thorstensen 1952), leading to sharp gradients in precipitation rates between the city of Oslo and the areas just north of the town. For example, while Blinderen in Oslo (94 m a. s. l.) has mean annual precipitation rates of 763 mm, Tryvannshøgda in the Nordmarka forest has means of 1180 mm (Norwegian Meteorological Institute 2015).

2.3 Vegetation

Nordmarka lies within the middle-boreal and southern boreal vegetation zones (Moen et al. 1999), and is characterized by forests that are dominated by Norway spruce (*Picea abies*). Actually, this tree species makes up 95 % of the Nordmarka forests, while Scots pine- (*Pinus sylvestris* L.) and deciduous forests constitutes the remaining 5 % (Groven et al. 2002). Because of former and current forestry, the forests are mostly young, but areas of old-growth forests still exists (NIBIO 2015b). The forests are mostly low-productive, but has elements of richer nature-types such as tall-herb vegetation (Fylkesmannen i Oslo og Akershus 2013).

The forests of Spålen-Katnosa nature reserve are dominated by *Picea*. Mapping of the first area that was protected (18 440 ac in 1995), showed a 98 % cover of *Picea* (Fylkesmannen i Buskerud 2012). *Picea* forests with *Vaccinium myrtillus* L. is the dominating vegetation type. In addition there are *Picea* forests with small-fern and tall-ferns and perennials such as *Aconitum lycoctonum* ssp. *septentrionale* (Koelle) Korsh. and *Cicerbita alpina* (L.) Wallr. (tall-herb *Picea* forest), and in wetter areas one can find swampy *Picea* forest. *Pinus* woodlands dominated by *Calluna vulgaris* (L.) Hull, *Empetrum nigrum* L. and *Vaccinium uliginosum* L. are also common (Fylkesmannen i Buskerud 2012; Løset et al. 2012). In addition, the area has a lot of marshes, which are mostly poor (Løset et al. 2012).

Two thirds of the forested areas in Spålen-Katnosa consists of old semi-natural forests with middle to high productivity. The oldest and most natural forests are situated on ridges, hills, hillsides and along water systems. The oldest registered *Picea* is over 240 years old, whilst the oldest *Pinus* is 320 years old (Fylkesmannen i Buskerud 2012). Forestry was an important

activity within the area from around 1600 to 1960, where selective logging was the main method, but clear-cutting near the water system was performed after second world war (Fylkesmannen i Buskerud 2012). Today forestry is an important activity outside the protected area (Løset et al. 2012).

During a botanical investigation of the meadow at Finnerudseter, Grønbech and Nesheim (1997) found 105 vascular plant species, where most were associated with cultural landscapes. They found species associated with mowing and grazing such as *Trollius europaeus* L., *Bistorta vivipara* (L.), *Silene vulgaris* (Moench) Garcke, *Veronica officinalis* L., *Ranunculus acris* L. and *Leucanthemum vulgare* Lam. Moreover, within the area west of the meadow that has been forested the last 40 years, there were still 29 different vascular plant species associated with cultural landscapes. The area still showed clear sign of earlier land-use in 1997. During a field trip in 2013, I found several of the species from their list. A great amount of *Nardus stricta* L., a species characteristic of old cultural landscapes (Bele & Norderhaug 2008), still grows in the area. Finnerudseter is registered as a locally important (value code C) pasture in Naturbase (Miljødirektoratet 2015). Finnerudseter is grazed to some extent by livestock, and part of the area is mown each summer. Vascular plant names follow nomenclature by Lid et al. (2005).

2.4 Land-use history in Nordmarka as inferred from archaeological and historical documents

Information about the land-use history in Nordmarka is extracted from several books, both old and new, current databases, archives and articles. There were some challenges regarding the search for detailed information on the topic. Because of limited access to historical archives about the use of Nordmarka, not all the facts about its use have been discovered. Hence, the following chapter has a more narrative style which provides an overview and understanding, but does not provide detailed information about the historical use of Nordmarka.

2.4.1 Archaeological findings and earliest history

Several findings from the Stone Age in Nordmarka over the years indicate that hunters and gatherers where the first people to exploit these forests (Blix 1952; Riksantikvaren 2015). Remnants of 5000 years old Stone Age settlements have been found near Sandungen and Hakkloa north in Nordmarka (Riksantikvaren 2015), and traces of cultivation from the Middle Age have been found near Sandungen. Some spread remnants of slag heaps from bog iron ore exploitation dated to the Iron Age-Middle Age have also been discovered, as well as traces of

charcoal production from the same period (Riksantikvaren 2015). Several other settlement-activity-remnants originating from the period between the Stone Age and the Middle Age have been found in Nordmarka over the years (Riksantikvaren 2015).

During the Middle Age the number of farms in the fertile areas around Nordmarka increased, and the need for new grazing areas led to the establishment of summer farms and outland-grazing in Nordmarka (Blix 1952). However, according to Holmen (1973) there are some uncertainties about the age of summer-farming in Nordmarka, but Reinton (1961) suggests that the tradition of summer-farming in this area is the oldest in the country. Also, laws about common lands were already established *c.* AD 1000 (Holmen 1973). This implies that this tradition started even before the Middle Age. Yet, only small-scale summer farming was practised in earlier times, and the impact on the vegetation was likely also small scaled. Summer-farming in Nordmarka had its peak in the middle of the 19th century (Reinton 1969). In 1952 there were 65 summer farms located in Nordmarka (Blix 1952).

2.4.2 Forest industry

Exploitation of the forest of Nordmarka has a long history, and small-scale timber trade started already in the 13th century. With the introduction of the saw-mill around 1500, timber production and export to Europe increased (e.g. the Netherlands) (Blix & Blix 1952). At first, saw-mills were spread in the forest and located to the areas where the timber was taken out, but in 1600s, the saw-mill activity was centralised and moved to the rivers Lysakerelva and Akerselva south of Nordmarka (Lange 1952).

These mills needed a lot of timber, and floating became necessary to transport timber from the forests. Several dams were built, and most waterways and lakes in Nordmarka were regulated. This allowed harvest of timber even up north, as the timber could be floated to its destinations, Bogstadvannet and Maridalsvannet, in the south (Blix & Blix 1952; Lange 1952). The two most important water-ways for floating were the ones going from Storflåtan to Bogstadvannet and from Bjørnsjøen to Maridalsvannet (Holmen 1973). According to Cristophersen and Svensson (1984), the forests in proximity to the water-ways were completely harvested several times.

The period from 13th century to the middle of 20th century was characterized by selective logging of large dimensions (Blix & Blix 1952) and *Picea* was the favoured tree species (C. G. Rye-Florentz, Løvenskiold Skog, personal communication 2016).

2.4.3 Ironworks

The ironworks in Bærum and Hakadal were established between 1539 and 1600, in addition to the mines at Sognsvann and Grua (Blix & Blix 1952; Frislid & Andersen 1996). Both the ironworks and the mines needed charcoal, and the need for fuel had great influence on the forests (Lange 1952). Unlike the selective logging for timber production, all dimensions were of interest for charcoal production. In addition, according to Hauge (1953) large forest areas burnt because of little precaution during the production of charcoal.

Some of the sites were charcoal was produced include Hakedalsskogene, Krokskogene and the Hadelandsskogene (Lange 1952), but the production was also spread to several other sites in Nordmarka (Blix & Blix 1952). Most charcoal was produced south of a line going from Søndre Heggelivann – Stuevann – Svarten – Sandungen gård – Gjerdingen. North of this line the timber was floated to Bogstad- and Maridalsvannet before burnt into charcoal (Lange 1952). Farmers living in Nordmarka were obliged to deliver charcoal if they were situated within the circumference.

Hakadal and Bærum ironworks had their most active period from the beginning of 1600 to 1875-1880 (Lange 1952). As an example of the influence the ironworks had on the forests, I will use the consumption of wood by the Bærum ironworks. According to Hauge (1953) the ironwork of Bærum had a circumference of 40 kilometres in the 1600s, and had all rights to the timber within this area to avoid competition with the saw-mills. During the 1600s, the yearly timber consumption for charcoal production for Bærum ironworks was about 4.687 m^3, in the 1700s it increased to 25.000 m^3 a year. At the most during the 1700s, 62.500 m^3 of timber was needed for charcoal production yearly (Hauge 1953). Because of great demands, timber for charcoal production was also gathered outside the circumference.

Bærum was not the only ironwork or industry, and one can picture how large the damage on the forests in Nordmarka must have been (Hauge 1953). The forests delivered wood material to the ironworks (charcoal), fire-setting to blow mines, saw-mills, building of ships, houses, dams and so on (Hopstock 1997). The overexploitations of the forests led to the removal of all

trees over large areas (Hauge 1953). Because of the overexploitation, the authorities decided in the 1800's to put restrictions on the timber export from Oslo.

2.4.4 The first settlers

An increase in forestry and charcoal production necessitated spread permanent settlements in the forests (Blix & Blix 1952). The first settlers in Nordmarka were therefore dam keepers and foresters. These settlers were often farmers in addition to foresters, and had animals and exploited the areas around the farms (Løvenskiold 2016a). Before 1600 there was no permanent settlement in Nordmarka (Aabel 1985; Frislid & Andersen 1996), but in the period from 1660 to 1800, the number of inhabitants in Nordmarka increased (Blix & Blix 1952) and the census of 1801 counted around 140 residents (spread over 20 households) (Moland 2006). The census from around 1940 counted *c.* 250 residents in Nordmarka (Aabel 1985).

Around 1600, Finnish immigrants discovered these forests. Places with names such as Finnerud, Finnstad and Finnvoll indicate Finnish settlers (Frislid & Andersen 1996). The Finnish immigrants cleared and burned forest to sow rye, a slash-and-burn agriculture that require large forested areas (Frislid & Andersen 1996; Holm 2013). New forest had to be burned every two to five years with this method (Holm 2013). The rye (*Secale cereale* L.) they grew in the ashes was adapted to old *Picea* forests, which enabled the Finnish to exploit areas that were not very suited for agriculture, such as the forests of Nordmarka (Holm 2013). The Finnish census from 1686 registered 20 residents in Nordmarka, although according to Aabel (1985) this number is probably too low.

2.4.5 After 1940

After 1940, clearcutting became the main harvesting method in Nordmarka (Groven et al. 2002; Lange 1952) and most of the settlements in connection with forestry were abandoned (Løvenskiold 2016a). At the same time, Nordmarka experienced a reduction in grazing activity and summer farming. Grazing activity is still present in Nordmarka, but the reduction in extent and pressure has led to the reduction of cultural landscape elements within these forests (see e.g. Frislid & Andersen 1996). Although restoration of many of these remnants has been performed over the last years (Løvenskiold 2016c). Moreover, floating of timber in Nordmarka stopped around 1960 (Aabel 1985; Holmen 1973) when roads took over as the main transport-way, but signs of floating are still visible (Holmen 1973).

Today, forestry in Nordmarka is regulated through the "Marka regulation" (*Markaforskriften*) (Løvenskiold 2016b). Nordmarka is an important recreational area, and according to the regulations, forestry should not affect the natural environment, landscape, cultural monuments, water supplies or outdoor activities in significant degree (Løvenskiold 2016b). Løvenskiold-Vækerø, the main owner of Nordmarka, has harvested around 60-70 000 m^3 of timber during the last 25 years (C. G. Rye-Florentz, Løvenskiold Skog, personal communication 2016). Timber from Nordmarka is used for material – for house making amongst others, and the smaller dimensions are used in paper production. The timber is harvested every 70-100 years (Løvenskiold 2016b).

2.5 Finnerudseter

The study site Finnerudseter lies in an area with several traces of human land-use activity. Remnants from bog iron ore exploitation originating from the Iron Age-Middle Age have been found near Åbortjern 3 km south of Finnerudseter (Riksantikvaren 2015). Also, just north of Finnerudseter there is an area called "Sinderdalen". According to Grimstad (2013), the name "Sinderdalen" indicates that iron was produced in the area, where "sinder" in Norwegian are the leftovers after bog iron ore exploitation.

Floating constructions are still visible in Spålen, the lake next to Finnerudseter. And Katnosdammen not far from Finnerudseter, has been important in relation to the timber floating in Nordmarka. Great quantities of timber was floated through this dam, given the inlet north of the dam the name "Leveringsvika" (Løset et al. 2012). Traces of selective logging are visible in the forest near the site, and a little further away there are also old traces from clear-cutting (Løset et al. 2012). The forest in this area has been important in the timber production due to the good floating possibilities south to Maridalsvannet and timber (Moland 2006). Grazing by livestock has been, and is still present to some degree within the area. These areas were common lands for the farmers at Ringerike (Figure 1), at the north-eastern border of Nordmarka, and there are several summer farms present within the area (Moland 2006).

Farming at the study site Finnerudseter has mostly been small-scale. According to written and historical sources land-use at the site most likely started in AD 1600 when Finnish immigrants settled down in the forest and practised a slash-and-burn agriculture where forest was burned and rye sown (Grønbech & Nesheim 1997). Later on the area was used by farmers from Ringerike which mowed the meadow and had grazing animals in the forest. The meadow is

today 16 acres large, earlier the meadow was larger and the area west of the summer-farm has overgrown with *Picea* the last 40 years (Grønbech & Nesheim 1997). Mowing occurs every year during July-August (personal communication Gjermund Andersen).

3 Material and methods

3.1 The sampling site

The core sample site was located in flat terrain, downhill from Finnerudseter, *c.* 50 m from the meadow (open vegetation) and *c.* 504 m.a.s.l. (N60˚09.064' E010˚ 32.072'). There is a ditch 10 m east from the site; which comes from earlier forestry. In the 1940s, ditching of mires and wet forests was common to increase the amount of forest producing area (G. Andersen, personal communication 2015). The forest is dominated by 40-80 years old *Picea*. The area constitutes of swampy soils with species such as *Sphagnum* sp., *Mnium* sp. (in the wetter areas with inflow/outflow water), *Equisetum sylvaticum* L., *Lycopodium annotinum* L. (in the drier and raised areas), various species of Filicateae and *Vaccinium myrtillus* L.. The soil cover was thin in some places, with presence of some sandy soils. The hollow where the core was taken was a small swampy depression (*c.* 1 m^2) dominated by *Sphagnum*-mosses (Figure 2; Figure 3).

Figure 2: The surroundings of the sampling site downhill from Finnerudseter.

3.2 Field work

Peat cores were taken in the end of August 2015 with a Russian corer (Jowsey 1966) of 5 cm in diameter and 50 cm in length. Total length of the peat cores was 149 cm. The first 4 cm were cut with a knife. Each core of 50 cm were cut in 1cm thick slices in the field and put in plastic zip-lock bags right away. The plastic bags were marked with a sample number and how many cm below the surface the sample derived from. The samples were stored in a refrigerator with 4-5 °C until preparation and analysis. Vegetation types were classified with Fremstad (2007) and vascular plant names follow nomenclature by Lid et al. (2005).

Figure 3: The sampling site.

3.3 Pollen preparation and pollen analysis

Samples were prepared in October/November in the wet chemistry laboratory at the University of Liverpool. The preparations followed a set of steps similar to those described in Fægri and Iversen (1989). As my samples consisted of peat, preparations were adjusted to their properties. Subsamples were taken every second cm from 18 cm to 59 cm below surface, and below 59 cm, subsamples were taken at every fourth cm. The subsamples were taken from the middle of the slices with a spatula. Since samples came from a small forest hollow, pollen concentrations were assumed to be high, and therefore only small samples were needed (*c.* 0.5 cm^3). Three *Lycopodium clavatum* tablets with a known concentration of spores were added in each sample,

this to enable calculations of pollen and spore concentrations (Maher Jr 1981; Stockmarr 1971). See Appendix 1 for details about preparation.

A small drop of glycerol and pollen-spore-mixture was mounted on microscope slides, covered with coverslips and sealed with nail polish. A Leica DMLB microscope with a Leica DFC320 camera was used for pollen counting at 400x magnification. A minimum of 300 pollen from tree species were counted on each slide. Fægri and Iversen (1989) was used for identification of pollen grains, supplied with pictures from Moore et al. (1991). Pictures of pollen that was difficult to identify were sent to Dr Gina Hannon and Prof Richard Bradshaw, Department of Geography and Planning, School of Environmental Sciences at the University of Liverpool. Other pollen that were difficult to identify were placed in the category UID. Pollen grains which were crumpled, in the category CRUMP. Poaceae and unidentified herbs, in the categories POACEAE UNDIFF and MIXED HERBS, respectively.

The focus in this study was to search for indications of mowing and/or grazing and cultivation. Species and families common for both mown and grazed vegetation such as *Plantago* L., *Geranium* L., Poaceae, Cyperaceae, Dipsacaceae (e.g. *Succisa* Haller or *Knautia* L.), Lactuceae (often referred to as Asteraceae Sect. Cichoriodeae), *Rumex* L., *Juniperus*, *Calluna vulgaris* (L.) Hull (cf. Gaillard et al. 1992; Loe Hjelle 1999), and species common for cultivated sites such as Chenopodiaceae and Cerealia (cf. Behre 1981), was counted. I also counted pollen from *Menyanthes trifoliata* L., *Ericaceae*, *Corylus* L./*Myrica* L., *Betula* L., *Alnus* Mill., *Pinus*, *Picea*, *Quercus* L., *Tilia cordata* Mill. and *Ulmus* L.. Spores of Lycopodiaceae and Polypodiales were included in the count. The added *Lycopodium clavatum* spores were counted to enable calculations of pollen concentration.

3.4 Radiocarbon dating

Three peat samples were sent to Beta Analytics in Miami, Florida for radiocarbon dating. The samples were dated through Accelerator Mass Spectrometry (AMS), which only need small samples (Bowman 1990). This method is based on the fact that ^{14}C is constantly formed by cosmic radiation in the atmosphere (Beta Analytic 2016b; Bowman 1990). These ^{14}C-atoms are taken up by organisms during their lifetime and makes them slightly radioactive. After death, the radioactivity of the organism gets weaker at a half-life rate of 5568 years ± 30 years. Radiocarbon dating measures the amount of ^{14}C that is left in the sample (organism), and can thus provide an estimate of the time when a given organism died.

However, AMS presupposes that ^{14}C is produced at a uniform rate and that the ^{14}C concentration in the atmosphere has been constant trough time (Bowman 1990). This is not the case and calibration of the dates is therefore necessary (Beta Analytic 2016a; Bowman 1990). Parameters to convert the results from BP (before present, 1950) to calendar years have been obtained from tree rings in old trees. INTCAL13 database was used to calibrate radiocarbon age to calendar years (Reimer et al. 2013). Beta Analytics used the methods (Pretoria Calibration Procedure program) described in Talma and Vogel (1993) to calculate the calibration curve. Excel was used for linear inter- and extrapolation of the calibrated years BP.

3.5 Data analysis and presentation of data

The results were presented in percentage pollen diagrams made with the program C^2 Version 1.7.6 (Juggins 2014). This program can import data from several formats (e.g. Excel). The percentages were calculated based on ΣP, where total terrestrial pollen (ΣP = AP + NAP + UID + CRUMP) is 100 %. ΣP does not include spores, calculations of percentage of spores are based on ΣP + spores, where the sum of these are 100 %. The filled curves in the diagram are percentage values, whereas the lines show the percentage values x10 this to be able to see also the pollen types that only occur at very low signal. The subjective methods described in Moore et al. (1991) was used for zonation in the pollen diagrams and nomenclature follows Lid et al. (2005).

Percentage values of AP (arboreal pollen) and NAP (non-arboreal pollen) were calculated based on AP plus NAP (Fægri & Iversen 1989), where % AP = (AP/AP+NAP)*100 and % NAP = (NAP/AP+NAP)*100. AP included all arboreal species, whereas NAP included all herbs (MIXED HERBS and does identified) and dwarfs-shrubs (Ericaceae, *Calluna* and *Juniperus*). UID and CRUMP pollen were not included in the calculations of % AP and % NAP because of uncertainty about whether the pollen was arboreal or non-arboreal.

The calibrated years BP (before present, 1950) were converted to calibrated years BC and AD when compared to archaeological findings and historical documentation. The Norwegian archaeological periods are given according to Østmo and Hedeager (2005), where the Bronze Age is *c.* 1800 BC – 500 BC , Early Iron Age *c.* 500 BC – AD 550, and the Late Iron Age is *c.* AD 550 – AD 1050. All dates that are from the radiocarbon dating are presented as calibrated dates, unless otherwise stated.

4   Results and discussion

Total pollen and spore count on each slide varied between 1148 and 407 and total *L. clavatum* counts varied from 2 to 784 spores. Those levels with less than 300 counted tree pollen were not included in the pollen diagram. The radiocarbon dates are presented in Table 1. The level 36-37 showed an older date, which is likely to be caused by a reversal due to in-flush of older material (see 4.3). Hard-water effect is unlikely because the geology in the area is mostly composed of granite and gneiss (cf. Overland & Hjelle 2009). The pollen source area is local, and most of the pollen derives from 20-100 m (Andersen 1970; Jacobson & Bradshaw 1981; Sugita 1994), although 20-30 m is more likely when the hollow is situated in a denser forest (Bradshaw & Hannon 1992).

Table 1: Radiocarbon dates from the peat core taken in proximity to Finnerudseter, Nordmarka. Organic sediment fractions were used for radiocarbon dating.

Lab. Ref.	Depth, cm below surface	Age ^{14}C BP	Calibrated age BP	δ^{13}C
Beta-435697	28-29	2160 ± 30	2085-2065	-27,0
Beta-433175	36-37	3090 ± 30	3375-3215	-27,0
Beta-433176	54-55	2420 ± 30	2500-2350	-27,0

4.1   The vegetation history at Finnerudseter

This study covers the vegetation history at Finnerudseter in the period *c.* cal. yr. 2587–1334 BP (cal. yr., and all following dates are also presented as cal. yr.). Based on the results from the pollen analysis, the vegetation history was divided into 4 vegetation zones; Zone I *Pinus* period, Zone II *Betula–Pinus–Alnus* period, Zone III *Betula–Pinus–Alnus–Picea* period, and Zone IV *Picea–Betula* period (Table 2). The results presented in the pollen diagram (Figure 4) covers partly the archaeological periods Bronze Age, Early Iron Age and Late Iron Age (Østmo & Hedeager 2005).

Table 2: Vegetation zones and anthropogenic indicators with their location in the stratigraphic record and in time. NAP % are average values in each vegetation period. The dotted line between Zone III and Zone II represents the possible reversal and in flush horizon at 38-39 cm.

Vegetation zones	Anthropogenic indicators	% NAP	Calibrated age BP	Below surface (cm)
Zone I ***Pinus***	*Juniperus*, *Plantago*, Lactuceae, *Rumex*	17,30	2587–2452	67-56
Zone II ***Betula–Pinus–Alnus***	Dipsacaceae, Chenopodiaceae, *Juniperus*, *Rumex*, Lactuceae, Cerealia	19,66	2425–2237	55-38
Zone III ***Betula–Pinus–Alnus–Picea***	Dipsacaceae, Chenopodiaceae, *Plantago*, *Juniperus*, Lactuceae, Cerealia	26,39	2183–1779	37-24
Zone IV ***Picea–Betula***	Dipsacaceae, *Plantago*, Lactuceae	25,93	1630–1334	23-18

4.1.1 *Zone I Pinus–Betula* period, *c.* 2587 – 2452 cal. yr. BP (67-56 cm)

This period was characterized by well-preserved pollen and high number of pollen. The time span was *c*. 2587 to 2452 BP, which covers the latter stages of the Bronze Age. *Pinus* pollen dominated in the diagram, and *Betula* and *Alnus* showed low but stable values. Other deciduous trees had low values and *Picea* started to be present, although at low values. The understory was composed of Cyperaceae, Polypodiales, Poaceae and a variety of herbaceous species. Cyperaceae started with relatively high values in the beginning of the period, but decreased gradually from the beginning towards the end, whereas Poaceae increased slightly towards the end. Herbaceous species and Polypodiales showed relatively low pollen and spore values, and a few anthropogenic indicators were present. AP was relatively high throughout the period, but was lower in the beginning of the period compared to the end. Macroscopic charcoal fragments were present in the very end of the vegetation period.

The surrounding area was probably a mixed woodland with *Pinus*, *Betula* and *Alnus*. Overland and Hjelle (2013) also recorded *Pinus*, *Betula* and *Alnus* as the dominant tree species during the Bronze Age at two sites located in the boreal forest of eastern Norway. However, the dominance of *Pinus* is also likely to reflect the abundancy of *Pinus* on a landscape level (Segerström et al. 1996) where the hollow received pollen from a larger source area (Jackson 1990). *Alnus* may represent both *Alnus incana* and *Alnus glutinosa*, however it has not been usual to separate these two in pollen diagrams from Fennoscandia (Giesecke 2005a).

The higher signals of *Alnus* and Cyperaceae in the beginning of the period (66-67 cm, Figure 4) may be the cause of paludification at the site and more light coming through (cf. Segerström et al. 1996). Later on, both species, and also Poaceae, decreased slightly as *Pinus* became more important, indicating that the site got gradually dryer and the forest slightly denser *c.* 2533 BP. After this (58-59 cm) there was a reduction in *Pinus* and subsequent increase in *Alnus* again. Occurrence of the marsh plant *Menyanthes*, as well as relatively high values of Cyperaceae and Polypodiales suggests that there were local wetter conditions again at the site (see e.g. Gunnarsdóttir 1999). However, whether the site was a swamp forest already *c.* 2600 years ago is difficult to say.

Arboreal pollen (AP) dominated the vegetation zone, with values around 83 %. Non-arboreal pollen (NAP) values were higher in the beginning of the period, which comes from the higher Cyperaceae values, but was then reduced and stayed at a low level. A relatively open forest structure led to more herbaceous species and presence of *Juniperus*. Anthropogenic indicators showed scattered presence, especially *Juniperus*, which is a species typical for post-grazing (Bradshaw & Hannon 1992; Bradshaw & Sykes 2014). A single pollen from *Plantago* was found at 62-63 cm in the profile, as well low signals from Lactuceae and *Rumex*.

Pinus often creates a more open forests structure, and this may be the reason for the scattered presence of herbaceous species in this vegetation zone. However, the AP value of 83 % and anthropogenic indicators may also signalize that the site was and open grazed woodland *c.* 2587 – 2452 BP (cf. Overland & Hjelle 2013). Low-intensity browsing by livestock is not always easy to detect in the stratigraphic record (Bradshaw & Sykes 2014).

Picea pollen was observed in this vegetation zone and reached *c.* 2 % *c.* 2479 BP. However, the signals varied between 0-2 % from *c.* 2533 – 2237 BP (Figure 4). Other studies from south-eastern Norway, and Fennoscandia, showed similar results, where *Picea* showed low signals

early in the pollen record (Bjune et al. 2009; Giesecke 2005b; Hafsten 1956; Hafsten 1992; Overland & Hjelle 2013). Overland and Hjelle (2013) and (Bjune et al. 2009) recorded low values of *Picea* early in the diagram from sites located *c.* 70 km north and 100 km north-east, and *c.* 100 km South-West from Finnerudseter, respectively. In addition, similar findings of low *Picea* signals before invasion has been recorded from Sweden (Giesecke 2005b; Segerström et al. 1996).

Whether such pollen derived from long-distance transport or not has been discussed in several papers (see e.g. Giesecke 2005b; Segerström & von Stedingk 2003), however Bjune et al. (2009) suggests that low signals of *Picea* in the diagram may indicate establishment of small local stands in the surroundings. *Picea* signals of 2 % has been associated with local establishment (Giesecke & Bennett 2004). However, the occurrence of *Picea* was rather scattered in this vegetation zone and the next (Zone II), with pollen signal varying between *c.* 0-2 %. According to Giesecke (2005a) this could be due to long-distance transport or disturbances of small stands. On the other hand, *Picea* pollen grains are relatively heavy and does not travel very far (Hicks 2001), hence long-distance transport seems unlikely.

In addition, Segerström and von Stedingk (2003) suggests that small peaks of *Picea* pollen that occur before a continuous curve may be a sign of early *Picea* presence. According to Hafsten et al. (1979) and Hafsten (1956), it is probable that the Oslo area had an earlier *Picea* establishment as compared to other parts in south-eastern Norway. Relatively high values were observed in pollen diagrams at *c.* 2650 BP and the final invasion was around *c.* 1920–1900 BP. Moreover, local establishment has shown to be quite variable even within the same (regional) area (see e.g. Hörnberg et al. 2012; Kasin et al. 2013; Segerström & von Stedingk 2003; Segerström et al. 2008; Tryterud 2003), hence the early local establishment of *Picea* at Finnerudseter predating other studies from south-eastern Norway does not seem unlikely.

It is therefore reasonable to suggest that the low signals of *Picea* early in the pollen record from Finnerudseter derived from small stands or single trees that established in the surrounding area. It is likely that *Picea* established as small stands on ecologically suitable habitats long before *Picea* spread regionally and invaded the area (cf. Hafsten et al. 1979). Giesecke and Bennett (2004) assembled pollen data from several studies performed in Fennoscandia, and their study showed that *Picea* spread into the Oslo area as early as 5000 BP.

Other tree species were also present in the record, although at low levels. Species such as *Ulmus* and *Corylus* produce much less pollen compared to *Pinus*, *Betula* and *Alnus* (Andersen 1970) and they could be more present at a site than what the diagram tell (see e.g. Gunnarsdóttir 1999). Hence, the regular low values of *Corylus* throughout the diagram from Finnerudseter suggests that there were small local stands present at the site. Low values of *Quercus* can be the cause of long-distance transported pollen or pollen from stand that were located a bit further away (Gunnarsdóttir 1999). *Quercus* produce well dispersed and relatively high amounts of pollen (Sugita et al. 1999). *Tilia* had regular low values throughout the record, which could be due to the same causes as for *Quercus*. Although, *Tilia* has a low pollen productivity compared to *Quercus* (Sugita et al. 1999), and whether this pollen came from local stands or was long-distance transported is difficult to say (cf. Giesecke 2005a).

Moreover, it is likely that the low signals of *Ulmus*, *Corylus*, *Quercus* and *Tilia* derived from single trees or stands that survived as remnants from the Holocene maximum temperature forests (see e.g. Moen et al. 1999). The declining summer temperatures that started around the late-Holocene, *c.* 4000 BP (Helama et al. 2012; Seppä & Birks 2001) led to a reduction in the representation of *Ulmus*, *Corylus*, *Quercus* and *Tilia*. Ohlson and Tryterud (1999) registered low signals of *Ulmus*, *Corylus*, *Quercus* and *Tilia* in a pollen record derived from Oppkuven, *c.* 6,5 km south of Finnerudseter.

Macroscopic charcoal was present in the end of the zone at 56-57 cm (Figure 4). The size of the fragments (> 0,5 mm) indicated that they may derive from a local fire (Ohlson & Tryterud 2000). Moreover, the changes in the pollen record that followed the charcoal finding at Finnerudseter in the next vegetation period, with reduced values of *Pinus* and increased values of light demanding pioneer trees such as *Betula* and *Alnus*, suggests that the fire had some effect on the surrounding vegetation and therefore was local (Hörnberg et al. 2012; Ohlson & Tryterud 1999; Segerström et al. 2008).

Nevertheless, it is not certain that the fire affected the on-site vegetation (Ohlson & Tryterud 2000). It is possible that there was no fire in the actual swamp forest, but just outside (cf. Ohlson & Tryterud 1999) (e.g. where the vegetation is open today, *c.* 50 m away) as only few charcoal fragments were registered. Ohlson and Tryterud (2000) found that the distance to the burned area affected the amount of registered charcoal fragments at a specific site. The results suggested that the spread of fragments was highly reduced just outside the burned area, and that

most fragments were deposited within *c.* 50 m from the fire. Furthermore, Clark et al. (1998) suggested that scattered and low occurrence may be a sign that the charcoal derived from a more distant source. Tinner et al. (2006) recorded macroscopic charcoal fragments as far as 5,3 km from a fire in the Swiss Alps, but both topography and wind conditions may have affected their results (M. Ohlson, personal communication 2016).

Moreover, the hollow was very small, and 22 macroscopic charcoal fragments is a large number for this kind of site (cf. Bradshaw & Hannon 1992). In addition, a single peat core may not register a local fire (Ohlson & Tryterud 2000; Ohlson et al. 2006), as deposition of macroscopic charcoal fragments has shown to be patchy and variable (Clark et al. 1998; Ohlson & Tryterud 2000; Ohlson et al. 2011) and with strong spatial variation (Ohlson et al. 2006). It is clear that the fire had some impact on the vegetation, as seen in the beginning of Zone II (Figure 4) and was therefore quite local. However, no charcoal bands were visible in the peat profile, so it is tempting to say that it was the vegetation just outside the wet forest that burned. Taking several peat cores would have been helpful in this matter (Ohlson & Tryterud 2000). It would also have been interesting to see if there is more charcoal further down in the profile, and if the lack or very few charcoal observations above 56 cm is due to the invasion of *Picea* and hence reduced fire regimes (cf. Ohlson et al. 2011).

4.1.2 *Zone II Betula–Pinus–Alnus* period, *c.* 2425 – 2237 cal. yr. BP (55-38 cm)

This period was characterized by well-preserved pollen and high number of pollen, except for the level 38-39 cm where the pollen content was very low. The low pollen content in the sample may be due to a flooding event, which is also indicated by the high organic material/pollen ratio with no or little visible minerogenic material (G. Hannon, personal communication 2016). Performing a loss-on-ignition (LOI) would have been useful to capture the extent of an eventual in-flush. The vegetation zone covered *c.* 2425 – 2237 BP which comprised parts of the Early Iron Age. There was a marked shift in the forest composition after the charcoal findings where *Pinus* was reduced in abundance and *Betula* and *Alnus* increased. The period was characterized of increased, but shifting, values of *Betula* and *Alnus*. Deciduous trees and *Picea* still showed low and scattered values, although *Corylus* increased a little towards the end. Poaceae increased slightly in the end, at the same time as *Alnus* values decreased and *Juniperus* increased. Herbaceous species showed relatively low values, but had a small peak in the beginning. Anthropogenic indicators showed low and scattered presence throughout the record, and a single Cerealia pollen was present in the very beginning of the period. Cyperaceae and

Polypodiales had relatively stable values the whole period. The amount of unidentified and crumpled pollen varied a lot and had relatively high values. AP values decreased slightly throughout the period, and the proportions of the different tree species changed. A few macroscopic charcoal fragments were found in the very end.

The marked increase in the more light demanding pioneer trees *Betula* and *Alnus* was probably due to a successional stage after the fire in the very end of Zone I (Figure 4). *Betula* typically grows after disturbances (Bradshaw & Lindbladh 2005) and Segerström et al. (1996) registered increased *Betula* following a fire in a swamp forest in northern Sweden. Although as discussed in the previous section, 4.1.1, it is not certain that it was an on-site fire. Similar to the results from Hörnberg et al. (2012) and Segerström et al. (2008), it may be that it was the upslope vegetation growing on the moraine that burned and not the wet forest. Whether the fire was natural or human induced may be discussed, however low signal of anthropogenic indicators was observed after the fire as well as a single pollen from Cerealia (Figure 4; Table 2). Hence, it may be that the fire was human induced.

However, it is also likely that the increase in *Betula* was due to a reduction in *Pinus* alone and that the fire was not important. It is possible that the charcoal findings at 56-57 cm derived from a single tree hit by lightning (Ohlson & Tryterud 1999). Cooling and increased precipitation rates that started during the late-Holocene (Seppä & Birks 2001) may have reduced the abundance of *Pinus*. When *Pinus* decreased trees such as *Betula* and *Alnus* became more important. According to Rasmussen (2005), Bradshaw (1992) and Bradshaw and Hannon (1992) *Betula* is favoured by a more open forest structure. It may also be that *Betula* was not that abundant, as *Betula* trees produce a lot of pollen and hence may be overrepresented in the pollen record (cf. Lagerås 2007).

Another interpretation of the sharp decline in *Pinus* pollen *c.* 2425 BP (Figure 4) is that it may have been caused by iron production in the area at that time. Iron production from the Iron Age-Medieval period has been registered next to Åbortjern 3 km away from Finnerudseter (Riksantikvaren 2015). It is likely that iron production was performed in Sinderdalen north of the lake Spålen (as mentioned in section 2.5) as well (Grimstad 2013). Solem (1991) studied the vegetation history near an iron exploitation site and found that *Pinus* pollen decreased during the Iron Age. *Pinus* was the preferred fuel for bog iron ore exploitation (Solem 1991; Stenvik 2015). However, in which extent the iron production affected the vegetation is difficult

to say, but a study from Budalen in Sør-Trøndelag suggest that an area with radius of about 1 km around the production site became completely deforested (Stenvik 2015).

However, according to Lagerås (2007), it is not an easy task to separate agricultural impact from iron production in the pollen record. Iron production led to more open landscapes which favoured more light demanding species for a period, and consequently confuses the interpreter. Nevertheless, the increase of grasses and herbaceous species at such sites may actually have led to the rise of summer farming (cf. Lagerås 2007; Stenvik 2015).

A single Cerealia pollen that was found at 54-55 cm may indicate that there was temporary small-scale cultivation at the site *c.* 2425 BP (see e.g. Hörnberg et al. 2012). The area upslope the sampling site constitutes of morainic and sandy soils (NGU 2015b) and sites for cultivation were in earlier times situated on soils with good drainage conditions, and with suitable locations and inclination (Norderhaug et al. 1999). Hence it is not unlikely that there has been some small-scale cultivation on the morainic soils at Finnerudseter as soil conditions were important properties in the traditional farming (Bele & Norderhaug 2013).

In addition, Dipsacaceae, *Rumex*, *Geranium*, *Juniperus*, Lactuceae and Chenopodiaceae were present in the same layer. Even though the signals were low, they may give indications of human activity (cf. Gunnarsdóttir 1999) and hence reinforce that the site was subjected to some kind of human land-use. There is a risk that the anthropogenic indicators derive from long-distance transport. However, long-distance transport seems unlikely as herbaceous species often does not travel very far (Overballe-Petersen & Bradshaw 2011; Vuorela 1973). As well, the inability of herbaceous pollen to disperse is further reinforced in forested areas (Bradshaw & Sykes 2014). In addition, the sampling site was a small hollow, and therefore received pollen mostly from the nearest surrounding, not more then *c.* 100 m away (Andersen 1970; Jacobson & Bradshaw 1981; Sugita 1994). According to Behre (1981), detecting small-scale land-use is difficult and it may therefore be that the sampling site has failed to register this in significant degree. Particularly since the hollow may have been surrounded by dense canopy forest when the fields where in use.

The sudden increased values of *Alnus* later in the vegetation zone, between *c.* 2317 – 2263 BP (Figure 4, 47-42 cm), may have been due to local paludification (Segerström et al. 1996), where water level changes caused a shifting *Alnus* curve (cf. Rasmussen 2005). As well, the sampling site at Finnerudseter was located *c.* 504 m.a.s.l., and the snow may have melted quite late for a

period, causing locally moister conditions (see e.g. Giesecke 2005a). The site was probably an open wet forest, with Cyperaceae and Polypodiales as the dominant understory species. The subsequent decrease in *Alnus* at 40-41 cm may have been due to dryer conditions again, as there was also a reduction in Cyperaceae and increase in Poaceae. However, there can be several interpretations of this increase and reduction.

As *Alnus* decreased, Poaceae values and *Juniperus* increased slightly, and a general increase in NAP was seen from *c.* 2290 BP (Figure 4). The increased values of Poaceae at 44-45 cm suggests that the forest was getting more open (see e.g. Segerström et al. 1996). At the same time *Corylus* showed increased values at the same time as Poaceae increased (44-45 cm). The increased values of *Corylus* may also have been due to more open conditions (Feeser & Dörfler 2014) and disturbances such as grazing by domestic livestock (cf. Molinari et al. 2005). Actually, throughout the pollen diagram, *Corylus* values increased slightly every time herbaceous species and Poaceae increased in amount (Figure 4). However, the high % AP and low % NAP in the pollen diagram indicates that the site looked more like a mixed woodland rather than large open areas (Lagerås 2007).

The combination of an increase in Poaceae, presence of several grazing indicators, and large variations in the tree pollen curves, may indicate that the site was used for small scale grazing or as a forest pastures from *c.* 2290 BP (see e.g. Segerström et al. 1994). According to Gaillard et al. (1992), Poaceae, *Juniperus* and *Rumex acetosa/acetosella* are all strong indicators of grazing pressure. Of course, there is also a risk that the increase in Poaceae and herbaceous species were due to small openings in the forest after natural disturbances (Poska et al. 2004), and thus was not the result of human impact.

The occurrence of *Juniperus* was rather scattered throughout the pollen record, and was only present at some levels – and if present, only at low signal. This may indicate that grazing was not continual (Gaillard et al. 1992) or that only small stands were present. Around 2263 BP *Juniperus* increased in presence at Finnerudseter (42-43 cm, Figure 4). *Juniperus* is a light-demanding species (Bele & Norderhaug 2013) and has a tendency to grow in cultural landscapes where livestock grazing has stopped (Bradshaw & Hannon 1992; Bradshaw & Sykes 2014) or in dry pastures and grazed forests (Behre 1981). The increased presence of *Juniperus c.* 2263 BP may indicate that the forest was used in more extent, as Poaceae showed relatively high values at the same time. The signals were still relatively low, however according to

Vuorela (1973), *Juniperus* are easily oxidised and the percentage values may therefore give false indication of its presence.

Similar to my results, Overland and Hjelle (2013) found increased amounts of grasses in the Early Iron Age and they suggested that it may be due to increased human land-use. Human land-use changed in Norway *c.* 2450 BP (500 BC) with more use of outlying areas and where grasses became more important as a fodder resource for cattle at that time (Norderhaug et al. 1999). Moreover, climate change during Iron Age – from dry and warm to humid and cold – changed the farming practices in south-east Norway, where outlying areas became used in more extent (Marstrander & Boye 1973). Several archaeological findings from the Early Iron Age and earlier has been discovered in Nordmarka over the years (Riksantikvaren 2015) and these forests were probably used for grazing livestock at this time in Nordmarka as well. The forests of Nordmarka has been important for grazing and fodder gathering quite far back in time (Blix 1952), and it is likely that farmers from Ringerike used this area even in the Early Iron Age. It is therefore tempting to suggest that small-scale or local human land-use by farmers from Ringerike (Figure 1) such as low pressure grazing or forest pastures was present at the site from *c.* 2290 BP. The increased signals of Poaceae *c.* 2290 BP at Finnerudseter may therefore be due harvesting or grazing livestock (cf. Bradshaw & Hannon 1992).

4.1.3 *Zone III Betula–Pinus–Alnus–Picea* period, *c.* 2183 – 1779 cal. yr. BP (37-24 cm)

This period was characterized by well-preserved pollen and high number of pollen. The timespan was *c.* 2183 – 1779 BP, which covers parts of the Early Iron Age. During this period the forest composition at the site changed markedly. With the increase in *Picea* there was a change in the forest floor community with increase of Cyperaceae from the beginning, and an increase in Polypodiales, *Calluna* and herbaceous species in the end. The higher values of Poaceae in the beginning (36-37 cm) and the following increase in Cyperaceae, *Calluna* and herbaceous species, suggests that there was a further opening of the forest (Segerström et al. 1996). A single pollen from Cerealia was found at 36-37 cm. In addition, *Betula*, *Pinus* and *Alnus* decreased in abundance and overall AP decreased. Deciduous species still showed low values, but *Corylus* had a little higher values than the others. A few macroscopic charcoal fragments were found, but as Segerström et al. (1996) suggests, such occurrences may be difficult to interpret. It must be noted that this zone may contain some reworked sediments between 36 and 39 cm, as seen from the reversed date at 36-37 cm (Table 1). Therefore the

interpretations of the layers in proximity to 36-37 cm must be taken with care, maybe even neglected (G. Hannon, personal communication 2016). Moreover, it is impossible to say how far up the sediment profile the reversal actually goes.

Picea started to be more present in the surroundings and probably quite near the sampling site in the beginning of this vegetation zone, *c.* 2183 BP. However, the occurrence was scattered during the whole vegetation period as seen from the oscillation in the *Picea* pollen curve. *Picea* values were shifting throughout the period, but there was a marked reduction every time *Pinus* increase in amount (Figure 4). Since the pollen data in the diagram are given in relative percentage values, it is possible that these shifts are due to the fact that an increase in one species affects the representation of other species in the pollen diagram (e.g. Hafsten et al. 1979). However, the shifting values may also be due to a larger pollen source area (Jackson 1990; Mitchell 2005) at the site if *Picea* was subjected to a disturbance and an opening of the canopy (Segerström et al. 1994) and hence, more deposition of *Pinus* pollen. Or the shifting values may be due to competition between the two tree species (M. Ohlson, personal communication 2016) and a decrease in *Pinus* due to establishment of *Picea* at the site (cf. Segerström et al. 1996).

Forest clearance may have occurred and caused local paludification, as seen from the shifting values of *Picea* and the increase and higher levels of Cyperaceae (Gunnarsdóttir 1999). However, increased signals of Cyperaceae does not only signalise paludification, but may also be caused by human land-use, as Cyperaceae strongly indicates grazing pressure or presence of meadows (Behre 1981; Gaillard et al. 1992). There has been a tradition in Norway to harvest hay from mires and other wet areas (Bele & Norderhaug 2013). Therefore, on-site harvesting may be another explanation for the increase in Cyperaceae, where harvesting favoured Cyperaceae due to changed competition between species. On the other hand, it is also likely that the high values of Cyperaceae may be due to local overrepresentation (Nielsen et al. 2012) as Cyperaceae also occur in natural communities such as bogs (Behre 1981).

Calluna is typical for open landscapes (Nielsen et al. 2012), and the slight increase at 30-31 cm may indicate that the forest was subjected to a further opening. This is further reinforced as this coincided with a slight increase in other species favoured by open vegetation such as Poaceae and herbaceous species (cf. Rasmussen 2005). In addition, but somewhat unclear, the values of *Pinus* and *Picea* decreased at this level. The presence of *Calluna* may also be a sign of long-term grazing and a subsequent exhaustion of the soils (Rasmussen 2005). Poaceae showed

relatively high values from *c.* 2290 BP and this was still the case *c.* 2102 BP (Figure 4), hence suggesting prolonged grazing by livestock at Finnerudseter, and exhaustion of the soils.

Furthermore, the increase in Lactuceae from 28-29 cm indicates that the forest got more open (see e.g. Gaillard 2007). According to Hellman et al. (2009), Lactuceae is usually under-represented due to heavy pollen grains and a low pollen production. Hence, presence of Lactuceae pollen in the pollen record is a good indicator of landscape openness on a local scale. As well, the presence of the anthropogenic indicators Chenopodiaceae, Dipsacaceae, *Juniperus* and *Plantago*, and the overall increase in NAP, further suggests that there was an opening of the canopy at Finnerudseter due to human land-use from *c.* 2183 BP (Figure 4).

Picea showed low and scattered occurrence at Finnerudseter from *c.* 2533 BP (Figure 4, Zone I), until a sudden increase to c. 14 % *c.* in the beginning of this zone (*c.* 2183 BP). If the local invasion of *Picea* was the result of natural causes such as a changed environment or human disturbance, may be questioned. However, it seems from the pollen record that the invasion happened during a period of human influence. The presence of anthropogenic indicators and reduction in AP at the same time as Cerealia, may indicate clearance for small-scale cultivation. It may be that clearing for small-scale cultivation facilitated the invasion *Picea* at Finnerudseter, as seen in the sudden increase in *Picea* from 0-2 % in Zone II to 14 % in the beginning of Zone III (36-37 cm). *Picea* was already present as small stands in the surroundings (as discussed in section 4.1.1), and human impact may have led to the sudden increase by creating clearings in the forest. Other studies suggest that human activity may have facilitated the spread of *Picea* (Bjune et al. 2009; Giesecke & Bennett 2004; Hafsten 1992; Molinari et al. 2005; Overland & Hjelle 2013). However, this interpretation may be uncertain as the Cerealia at 36-37 cm may derive from redeposited old material (G. Hannon, personal communication 2016).

The following period after small-scale cultivation was possibly characterized by further clearing of the site and livestock grazing as indicated by the shifting *Picea* curve and the increase in herbaceous species and Poaceae (see e.g. Overland & Hjelle 2013; Segerström et al. 1994). Norway does not have the right conditions for naturally occurring grasslands, therefore past and existing grasslands are mostly the product of human land-use (Steen 1980).

Furthermore, Bradshaw and Lindbladh (2005) argues that *Picea* often spread into successional *Betula* forests which had become more common because of human land-use. At Finnerudseter, *Picea* invaded a forest structure dominated by *Pinus*, *Betula* and *Alnus* (at the transition between

Zone II and this Zone), which resembles other results from Scandinavia such as Seppä et al. (2009), Ohlson and Tryterud (1999), Overland and Hjelle (2013), Hafsten (1992), Molinari et al. (2005).

The increased values of Polypodiales from 28-29 cm (Figure 4) and upwards is difficult to interpret, as ferns can grow in a divers variety of habitats. Polypodiales spores are very resistant to degradation and may signalise deterioration of other pollen species when very abundant (Jacobson & Bradshaw 1981). However, the increase may as well reflect that the site was subjected to water-level changes and local wetter conditions, as well as more open conditions (Segerström et al. 1996). Or, the increase of Polypodiales may be caused by a release of nutrients due to a fire (cf. Segerström et al. 1994). A few fragments were observed at 30-31 cm, which may indicate that fire had been present in the surroundings, but that they were rather small (e.g. ground fires) (Ohlson et al. 2011).

As well, Polypodiales increased as *Picea* increased. Segerström et al. (1994) also found increased values of Polypodiales as the amount of *Picea* increased and it may be that the increase in *Picea* at the site created a denser forest with locally wetter conditions. Polypodiales have a tendency to grow on wet soils (Hörnberg et al. 2012; Segerström et al. 2008), however Polypodiales may as well grow on dryer soils (Segerström et al. 2008).

It must be noted that the interpretations of the pollen assemblage in Zone III must be taken with care, as there are several possible explanations for the vegetation changes that are seen from the pollen diagram. For example, there may be several explanations for the shifting values of *Picea*. As well, the possible reversal and in-flush layer in the transition between Zone II and Zone III must be taken into consideration.

4.1.4 *Zone IV Picea–Betula* period, *c.* 1630 – 1334 cal. yr. BP (23-18 cm)

This period was characterized by well-preserved pollen and high number of pollen. The time covered was *c.* 1630 – 1334 BP, which covers the end of the Early Iron Age and the very beginning of the Late Iron Age. There was a further increase in *Picea* pollen, although the values were still shifting. *Alnus*, *Pinus* and *Betula* showed shifting values, with a decrease in the beginning and a slight increase in the middle before decreasing again towards the end. Other deciduous species were present at very low values, if not present at all. Herbaceous species and Poaceae showed the highest values throughout the peat profile, and Lactuceae still had

relatively high values as compared to the other anthropogenic indicators. Polypodiales continued to show high signals, but Cyperaceae decreased, as well pollen from Ericaceae and *Calluna* were present. AP continued to decrease slightly. A very few macroscopic charcoal fragments were found.

Picea showed the highest values throughout the stratigraphic record (Figure 4), and became the dominant tree species at the site. The dominance started *c.* 1630 BP, which was a little earlier than what Ohlson and Tryterud (1999) found at Oppkuven, *c.* 6,5 km south of Finnerudseter. At Oppkuven, *Picea* established locally *c.* 1700 years ago (uncalibrated), and became dominant first *c.* 450 years later. On the other hand, Hafsten (1956) found that Picea invaded and became dominant in the Oslo area *c.* 1920 – 1900 BP. These results may be a little earlier than other studies from southeast Norway (e.g. Overland & Hjelle 2013), however *Picea* most likely established and invaded the Oslo area earlier than other places in south-eastern Norway (Giesecke & Bennett 2004; Hafsten 1956; Hafsten et al. 1979; Hafsten 1992). Hence, the local dominance of *Picea* from *c.* 1630 BP at Finnerudseter does not seem unreasonable.

The further increase in Polypodiales in this vegetation zone, may indicate that the site was forming into a swamp forest dominated by *Picea*, similar to the findings of Segerström et al. (1994). *Picea* establishment may have changed the microclimate at the site due to a denser stand and therefore more humid conditions, which may be suitable for ferns (cf. Tryterud 2003). However, as discussed in section 4.1.3, the increase in Polypodiales is difficult to interpret as this group may be found in many different types of habitats.

In this zone the *Alnus* signals were very low, and *Pinus* had the lowest values throughout the stratigraphic record. *Betula* on the other hand was still well represented in the record. This may indicate that the swamp forest was dominated by *Picea* and that the transition between the open vegetation and forest was dominated by *Betula*, and with some scattered trees of *Alnus* and *Pinus*.

There was a marked increase in Poaceae and herbaceous species from 22-23 cm. As well, the presence of anthropogenic indicators such as Lactuceae, Dipsacaceae and a single pollen from *Plantago* suggests that the site was affected by human land-use (Behre 1981). The relatively high values of Lactuceae in this vegetation zone (Figure 4), suggests that the surrounding forest was subjected to further opening. In addition, while counting pollen, Zone IV was the one with most diversity in herbaceous species (although these have not been identified, but put in a

MIXED HERBS category), hence supporting the evidence of increased human land-use (see e.g. Bjune et al. 2009).

There is great evidence that some kind of human land-use, e.g. summer farming, was present at Finnerudseter *c.* 1630 BP as seen from the pollen record. The marked increase in Poaceae and herbaceous species, and the increase in NAP (cf. Solem 1991), suggest that the surrounding forest was subjected to further clearing. Increased anthropogenic activity from the Late Iron Age has been interpreted from other pollen diagrams in Scandinavia as well (Overland & Hjelle 2013; Rasmussen 2005). According to Norderhaug et al. (1999) the practice of mowing in Norway arose with the introduction of the scythe *c.* 1750 BP (AD 200). Hence, it is possible that the further opening of the canopy at Finnerudseter in the beginning of the Late Iron Age (Figure 4) may be due to the introduction of mowing at the site.

4.2   Anthropogenic indicators and NAP in the pollen record

In this section, the anthropogenic indicators and NAP (non-arboreal pollen) signals in the pollen diagram from Finnerudseter, will be discussed in relation to earlier findings on the subject. Interpretation of pollen diagrams derived from cultural sites, and therefore more open sites, is often challenging (Felde et al. 2014), as the premises are somewhat different as compared to interpretation of data from more forested sites (e.g. Bradshaw & Sykes 2014). When interpreting data from sites affected by human land-use it is important to remember that pollen no longer disperse evenly in the landscape due to opening of the canopy and patchiness (Fægri & Iversen 1989). Pollen-source area therefore becomes a uncertain factor (Gaillard et al. 1992), where treeless vegetation has a larger pollen-source area due to income of more long-distance transported pollen (Broström et al. 2005; Felde et al. 2014; Jackson 1990; Mitchell 2005).

Defining and interpreting what *type* of land-use that has been practised at Finnerudseter from *c.* 2587 to 1334 BP, is beyond the task of this thesis. Few of the counted herbaceous pollen were identified to family or genus, instead they were put in the category MIXED HERBS. Hence, the interpretations just give a clue about human land-use.

The sampling site at Finnerudseter is today situated *c.* 50 m form the meadow edge. However, if the distance between the sampling site and the open vegetation has been about the same during the whole investigated period is difficult to say. The sampling site may have been surrounded by forest the whole time, or been part of the open landscape. However, if the

sampling site was surrounded by open land species, this would have been very evident in the pollen diagram with a marked increase in NAP, e.g. reaching 50 % of total or more (cf. Fægri & Iversen 1989). The sampling site may therefore have been surrounded by forest during the whole investigated period, thus affecting the amount of NAP and anthropogenic indicators that has been deposited in the forest hollow. The % NAP stayed low throughout the pollen record from Finnerudseter (Table 2; Figure 4), although it increased slightly from *c.* 2290 BP and stayed between 20-30 % from then on.

According to Vuorela (1973) the amount of NAP is reduced already the first 10-20 m into the forest, and this is due to the fact that these pollen types does not travel very far in closed canopy forest (Bradshaw 1981). The position of the sampling site in relation to the (historical) open vegetation at Finnerudseter may therefore have affected the amount of NAP that was deposited in the hollow through time (cf. Gunnarsdóttir 1999; Hellman et al. 2009). The forest may have had a filtering effect on pollen coming from the fields at Finnerudseter when they were in use (see e.g. Gunnarsdóttir 1999; Vuorela 1973).

However, there is also a possibility that the sampling site at Finnerudseter was surrounded by open vegetation, but it should then have received more pollen from species in the NAP category (herbs, grasses and dwarf-shrubs, see 3.5) (see e.g. Fægri & Iversen 1989). However, the % NAP in the pollen record is not always a good indication on how open the landscape has been, because pollen from species in this category does not disperse easily and therefore are often under-represented compared to AP (arboreal pollen) (Gaillard et al. 1998; Hellman et al. 2009; Sugita et al. 1999). Hence, it may also be that the sampling site was surrounded by open vegetation in periods.

In addition the high AP and relatively low NAP in the pollen record form Finnerudseter may be the result of a larger pollen source area during more open conditions, where treeless vegetation received more regional pollen (as discussed in Felde et al. 2014). Broström et al. (2005) found that semi-open landscapes received pollen from a larger source area, and in general received more AP. Furthermore, the high % AP throughout the stratigraphic record from Finnerudseter could be due to the glade effect (Feeser & Dörfler 2014). Small openings in the forest may have induced a higher pollen productivity in trees that got more light (cf. Feeser & Dörfler 2014; Rasmussen 2005), and thus contributed to a higher % AP in the pollen record. However, this is a very uncertain interpretation of the high % AP, as the glade effect

stops as soon as the landscape openness gets too large and % AP decreases again (Feeser & Dörfler 2014).

AP and NAP values may therefore be difficult to use as a measurement for landscape openness, especially in semi-open landscapes (Sugita et al. 1999). Moreover, Lagerås (2007) suggests that extensive wood pasturage and herding may be present even if the pollen diagram show high AP and low NAP, and that human influence is not always easy to detect, especially not if small-scale and temporarily. It is likely that the land-use at Finnerudseter has been mostly small-scale, thus leading to less NAP reaching the hollow.

Several anthropogenic indicators were present throughout the pollen record from Finnerudseter, although scattered and only at low percentages (Table 2; Figure 4). Nevertheless, even at low signals they may give indications of human activity (cf. Gunnarsdóttir 1999). Vuorela (1973) found that important indicator species of human activity such as Chenopodiaceae and *Rumex* often showed low signals in the pollen diagram. Moreover, the occurrence of high pollen producers, such as *Betula*, may reduce the manifestation of anthropogenic indicators in the pollen assemblage (Rasmussen 2005). *Betula* was quite abundant throughout the pollen record from Finnerudseter, hence this may have watered out the anthropogenic indicator species.

A single Cerealia pollen was found in the record from Finnerudseter at 54-55, and derived from the Early Iron Age (*c.* 2425 BP). Segerström (1992) (as cited in Segerström et al. 1994) and Hörnberg et al. (2012) suggests cultivation when only single pollen of Cerealia were found in the pollen assemblage. According to pollen-analytical (Hafsten 1956) and archaeological (cf. Solheim 2012) studies, agriculture came to the Oslo area in south-eastern Norway already in the beginning of the Late Stone Age, and thus may have spread into the more unfertile areas of Nordmarka later. The single pollen from Cerealia at Finnerudseter may therefore derive from small-scale and extensive cultivation at the site (cf. Behre 1981).

Even though only one pollen grain was found, it may indicate cultivation. Cultivation in forested areas may be difficult to detect with pollen analysis (Josefsson et al. 2014) as cereals have a small pollen source area. (Bradshaw 1988 as cited in Josefsson et al. 2014). In a study where both clearance cairns and forest hollows near an archaeological site were investigated, the results showed that the hollow did not always detect cereal cultivation when the on-site clearance cairns did (Overland & Hjelle 2013). Peat profiles as near as 25 m from the clearance cairns did not record the earliest cultivation phases. Moreover, Gunnarsdóttir (1999) sampled a

stratigraphic record from a sampling site surrounded by forest, and recorded that even the activity that was present during sampling only showed low signals in the upper levels of the diagram. Human land-use may therefore be difficult to discover, even when the sampling site is situated near the fields (Behre 1981).

Josefsson et al. (2014) argues that the occurrence of single pollen from Cerealia in old stratigraphic layers, may in fact not be from Cerealia but *Glyceria*. However, the Cerealia pollen that were found in the pollen record from Finnerudseter had a wide, thick band around the single pore, where *Glyceria* have a much thinner one (G. Hannon, personal communication 2016). Hence, the single finding of Cerealia at Finnerudseter most likely derived from cultivation.

4.3 Further research and error sources

In this study, pollen and spore count varied between 1148 and 407. Counting more pollen could have been useful to capture more of the anthropogenic indicators and other herbaceous species (cf. Odgaard 2001). Moreover, a detailed land-use history may be difficult to reconstruct only on the basis of pollen analysis (Gaillard et al. 1992; Overland & Hjelle 2013). Other methods such as sampling from clearance cairns or excavating on-site soil layers to discover macrofossils can be useful to get a better picture of the land-use (cf. Overland & Hjelle 2013). Excavation for cereal macrofossils can be a way to find out, when in doubt, whether there has been cultivation or not (Bradshaw & Sykes 2014). Collecting pollen from the surface would also have been useful to see how well the sampling site records today's activity at Finnerudseter.

Moreover, there is a gap in the land-use history from *c.* 1334 BP and until the first historical documentation of land-use, which is dated to *c.* 350 BP (AD 1600). It would have been very interesting to see how the vegetation history and the extent of human land-use was during that time interval. AD 1100 to AD 1200 was a period with increased land-use in Norway (Norderhaug et al. 1999), and one could probably expect a further opening of the forest or continued land-use at the site at this time. This is also when the laws about common lands were made for Nordmarka (Holmen 1973). In addition it would have been interesting to see if and how the Black Death around AD 1300 affected the vegetation development at Finnerudseter. Most likely an increase in AP and a decrease in NAP would have been observed in the pollen diagram (see e.g. Molinari et al. 2005). Further research is therefore needed to get a more complete vegetation history at the summer farm Finnerudseter.

Furthermore, because I wanted to register vascular plants that may have been associated with cultural landscapes, sampling in proximity to the meadow was important. This of course also led to the fact that the sampling site was not optimal, and therefore a risk of the stratigraphic record not being that good – i.e. pollen content and pollen quality, and the risk of potential distortion of the stratigraphic layers. Pollen content below 67 cm and between 38-39 cm was very low, and it was therefore decided to leave these pollen data out of the pollen diagram. Moreover, there may have been a flooding and subsequent in-flush event at the site. This is shown by the high organic material/pollen ratio at 38-39 cm and the older radiocarbon dating for the level 36-37 cm. This affects the interpretation of the vegetation events and their timing due to a possible transversal (G. Hannon, personal communication 2016). It may therefore be that the interpretations of the pollen located between 39 and 36 cm should be neglected.

5 Conclusion

Throughout the investigated period (*c.* 2587 – 1334 BP), the vegetation around Finnerudseter was dominated by trees. *Pinus*, *Betula* and *Alnus* predated *Picea*, which established as small local stands *c.* 2480 BP. A fire led to a shift in the vegetation *c.* 2450 BP, where *Pinus* declined and the pioneer trees *Betula* and *Alnus* increased in abundance. *Picea* started to increase in abundance from *c.* 2180 BP, but varied in abundance until it became the clearly dominant tree species at the site from *c.* 1630 BP.

There were rather few and scattered anthropogenic indicators in the pollen record, and the NAP signals were in general relatively low. However, there was likely a small-scale cultivation at the site *c.* 2425 BP, and the area was probably subjected to extensive livestock grazing and other human land-use forms around *c.* 2290 BP. From *c.* 1630 BP, the forest got more open due to increased human land-use.

This study illustrates that human land-use at Finnerudseter was older than what the written and historical sources tell. This may also be true for other summer farms located in the forests of Nordmarka. The forests around Finnerudseter, and Nordmarka in general, are far from untouched by man, and prolonged human land-use should therefore be taken into account when managing these forests today. Contemporary cultural landscapes, such as Finnerudseter, creates variation in an otherwise forested landscape, hence creating a more diverse forest. Moreover, management should seek to maintain cultural landscapes, due to the biodiversity that is dependent on these habitats.
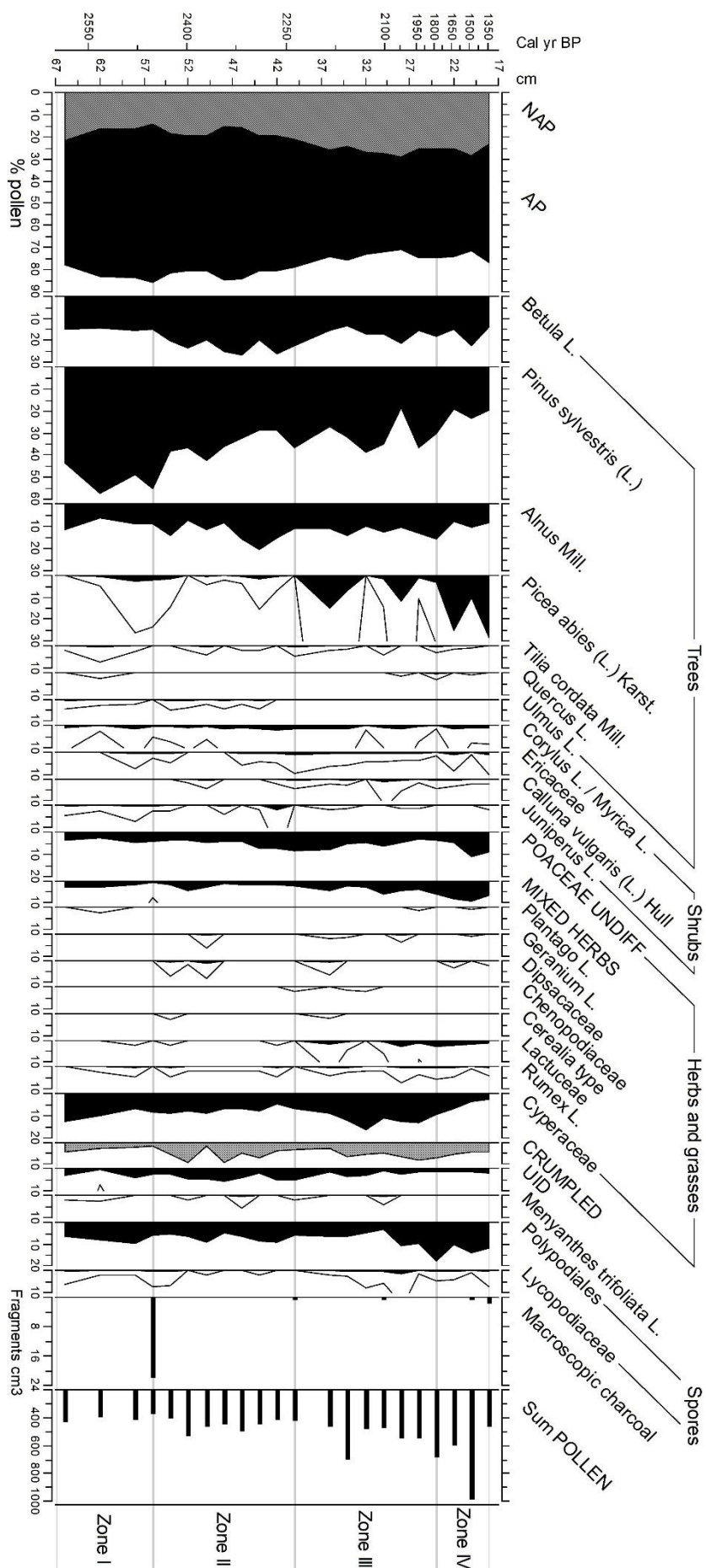
Figure 4: Pollen diagram. Finnerudseter, Nordmarka, Buskerud, Norway

Analysis: Maria K. Hertzberg 2015/2016

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Appendix 1

Pollen preparation:

1. **Sampling**:
   - Put samples of ca. 0.5-1 cm^3 in 50 mL pollen centrifuge tubes and measure exact volume by water displacement (use DD water – double distilled water).
   - Add 2-3 *Lycopodium* spore tablets to each tube, stir
2. **Hydrochloric acid treatment**:
   - Add 10 mL of 10 % HCL slowly to each tube to dissolve the *Lycopodium* tablets and remove calcareous material. All *Lycopodium* has to be dissolved at this stage
   - Equalise the liquid levels in the tubes with DD water, centrifuge and decant liquid to waste (centrifuge for 3 min. with 3000 r. p. m.)
3. **Sodium Hydroxide treatment**:
   - Add 10 mL of 10 % NaOH to each tube and place the tubes in a hot water bath (ca. 50-60 °C) for 7 min., stirring occasionally (because of peaty sediments the tubes were left in the water bath for longer than what's usual)
   - Remove from water bath, centrifuge and decant. Have DD water in each tube, and centrifuge and decant one more time. Add some DD water after this step
4. **Sieving:**
   - Fix a square of 100 µm mesh between two halves of a plastic funnel and stand each funnel in a 250 mL beaker
   - Filter the samples, washing sparingly with DD water, and collect the filtrate in the beakers
   - Transfer filtrate containing finer residue back into the respective tube, centrifuge and decant. If all the filtrate doesn't fir first time centrifuge and decant part, then add more of the filtrate until the entire finer residue is in the tube
5. **Acetolysis:**
   NB! The acetolysis procedure requires concentrated Sulphuric Acid which heats violently in contact with water. Rinsing with Glacial Acetic acid removes water from sample and is necessary before the acetolysis procedure.
   - Add 10 mL Glacial Acetic acid, stir, centrifuge and decant to waste
   - Make a mixture in the ratio of 9 mL Acetic anhydride and 1 mL Sulphuric acid, per sample, in a measuring cylinder. Prepare just enough acetolysis reagent for all samples, e.g. – 12 samples requires 108 mL Acetic anhydride in a measuring cylinder, then slowly add 12 mL Sulphuric acid. Take care, the reaction is exothermic (produces heat) and may spit (eye protection)
   - Add 10 mL of acetolysis mixture to each sample tube, stir and place in water bath (ca. 50-60 °C) for 5 min., stirring occasionally
   - Remove tubes from water bath, add Glacial Acetic acid, stir, centrifuge and decant. Repeat by adding 10 mL of Glacial Acetic acid, stir, centrifuge and decant
   - Add DD water, stir, and centrifuge and decant. Repeat this step until the solution has a neutral pH.