# Holocene forest development and tree-limit changes in Ridalen, in the Røros mountains

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## Forord

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## Abstract

Holocene forest development, tree migration and tree-line fluctuations have been reconstructed from peat sequences, derived from two study localities situated along an altitudinal transect between the north boreal and low alpine zone in the mountain region of the Røros area. The local-scaled reconstructions are based on pollen analysis, stomata and megafossil findings. Additionally, an attempt to reconstruct the climate history has been made by the use of the indicator species approach. The reconstructions have further been compared to other palaeoecological studies in adjacent regions to Ridalen, in order to deduce regional patterns for the Holocene vegetation and climate.

A pioneer flora dominated at the Lervahå mire at 770 m a.s.l. under relatively warm and dry conditions in early Holocene until ca. 10,500 cal. years BP. A rather coeval local presence of tree-birch (*Betula pubescence*) and pine (*Pinus sylvestris)* has been recorded at ca. 10,100 cal. years BP. Pine expanded rapidly thereafter, becoming the dominating tree in the Ridalen region until ca. 8,000-7,400 cal. years BP. *Alnus* grew locally in moister habitats at the Lervahå mire from ca. 9,200 cal. years BP and reached its maximum abundance around 7,400- 7,100 cal. years BP, after which a sub-alpine birch forest established at Reinskaret. In the cooler and moister period subsequent to ca. 5,000 cal. years BP the sub-alpine birch forest reached the Lervahå mire. *Picea* increased in abundance in regional forests after ca. 2,700 cal. years BP.  In the period after ca. 3,700 cal. years BP, pine only grew as scattered individuals at 770 m a.sl. Tree-birch no longer grew at the Reinskaret locality after ca. 2,000 cal. years BP.

The time of deglaciation could not be inferred for the area since the oldest layers could not be properly dated. Nevertheless, the stratigraphical sequence from the Lervahå mire is assumed to represent maximum the last ca. 11,500 years. The tree that first established in the study region is still uncertain.

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# 1 Introduction

In the Røros region, located to the east of central southern Norway, there are few studies elucidating the post-glacial vegetation and climate history (Prøsch-Danielsen, 1999; Prøsch-Danielsen and Sørensen, 2010; Thorén, 1981) and these primarily encompass the more recent anthropogenic history up to present day. Consequently, there is much information to be revealed by palaeoecological investigations regarding the vegetation and climate development in the Røros area since the last ice age.

The early Holocene (post-glacial) period in Northern Europe has been characterized by an unstable climate showing frequent and abrupt shifts (Hoek and Bos, 2007 and references therein; Nesje *et al.,* 2005; Paus, 2010). Studies on the past forest development and tree-line fluctuations could yield important indications about these climate events, as forest- and tree-line positions and structure on a regional scale are found to be highly sensitive to the prevailing climatic conditions (primarily the length of the growing season and summer temperatures) (Kullman, 1995; Kullman and Kjällgren, 2000; MacDonald *et al.,* 2008; Nesje *et al*., 2005). Traditional pollen analysis can provide information about past forest-limit fluctuations (Gunnarsdóttir, 1996). Megafossil finds together with macrofossil analysis have proven to be important complementary approaches to the study of past tree-limit positions as they are most commonly evidence of the local presence of a species (Aas and Faarlund, 1988; Bergman *et al*., 2005; Birks, 2001; Kullman, 2001).

Palaeoecological studies of the Holocene within the Scandinavian mountains have yielded ambiguous patterns regarding the time of vegetation establishment, in addition to the course of vegetation succession. Distinctly different vegetation patterns appear in studies from the alpines of central Scandinavia. To the south-west of Røros, tree-birch (*Betula pubescence*) was the first tree to establish and expand after the deglaciation (e.g. Bergman *et al.,* 2005; Gunnarsdóttir, 1996; Velle *et al*., 2005; Velle *et al*., 2010), whereas other studies both in Norway and in Sweden have recorded that pine (*Pinus sylvestris*) was the first tree to expand (e.g. Barnett *et al*., 2001; Lundquist 1969). Moreover, tree-birch and pine were already growing locally at high altitudes east in the Swedish Scandes in early late glacial periods (Kulmann, 2002; Kullman and Kjällgren, 2000). Similar records of pine have been detected west of the Røros region at Dovre (Paus *et al*.,in prep). Conversely, tree establishments and expansions are recorded much later further south in Central Norway (e.g. Barnett *et al*., 2001; Gunnarsdóttir, 1996).

The study area, Ridalen within the Røros area, is an interesting site as it lies in the middle of Scandinavian Mountains and close to the Swedish border and thus between these different early Holocene vegetation patterns.

Using pollen analysis (both percentage and influx), in addition to stomata and megafossil finds, this study primarily aims to reveal the local Holocene migration of tree-species (with focus on pine and tree-birch), forest history and tree-limit fluctuations near Ridalen, in the Røros mountain area. Small mires were chosen as sampling sites as they represent autochthonous deposits and thus reflect past local vegetation patterns (Birks and Birks, 1980; Fægri and Iversen, 1989). Further inferences will be made according to the climate development in connection to the forest-and tree-limit fluctuations since the deglaciation. In addition, it will be attempted to make deductions about the time of deglaciation; when the vegetation and the subsequent forest established in the area; which tree that first established and expanded; and how the forest developed through the Holocene. In order to infer any regional patterns in tree migration and forest establishment, the results from this study will further be compared with other palaeoecological studies in the Central Scandinavian mountain areas.

For almost a century it has been a debate whether the Last-glacial (Weichselian) Scandinavian ice-sheet was central and thick (e.g. Holtedahl, 1955; Mangerud, 2004) or thin and multidomed (e.g. Dahl *et al.,* 1997; Goehring *et al,*. 2008; Paus *et al,*. 2006). Geographically, the Røros-area is centrally positioned in this discussion (cf. Dahl *et al*. 1997). The opposing views of the ice-sheet geometry and deglaciation patterns would influence on how to interpret the vegetation development within the area, as the vegetation chronology, successions, migrational routes, and rates of change would depend on the time and patterns of deglaciation. Consequently, palaeoecological studies within the Røros area had hoped to throw some light on this controversy. However, as accurate dates of the earliest Holocene deposits could not be obtained, no exact conclusions about the ice-sheet thickness and time of deglaciation for the study area could be made.

# 2. Study area

## 2.1 Geography and topography

The study area, covering a total area approx. 10 km$^2$, includes the two coring sites the Lervahå mire and Reinskaret, which are located at different altitudes on either side of the border between Røros and Tydal municipal, in Sør-Trøndelag County, Eastern Norway. The Lervahå mire (abbr. LH) is situated in Ridalen in Røros municipal within the sub-alpine birch belt at 770 m a.s.l., and Reinskaret (abbr. RS) is located further north east at 920 m a.s.l. south in Tydalen municipal above the birch-forest (see Fig. 2.1).

***Figure 2.1:*** *A map over the study area. The study sites, the Lervahå-mire (770 m a.s.l.) and Reinskaret (920 m a.s.l., are situated on either side of the border (the purple line on the map) between Røros and Tydal municipal in Sør-Trøndelag County.*

In the investigated area, which is located around 40 km north-east of the Røros centre and around 12 km west from the Swedish border, there are only a few scattered cabins and summer houses. This remote area has not been subjected to any high levels of summer farming, and the main disturbances are considered to have been caused by low levels of either reindeer grazing or hiking and hunting activity (Paus pers. comm.2008). The study site is situated within a south Sami area, hence many sites are named in Sami and not in Norwegian.

### 2.1.1 The Lervahå mire (770 m a.s.l.)

The Lervahå mire (770 m a.s.l.) is one of two sampling sites for this study. It is located north of Lervahåen, in Ridalen, north east in Røros municipal (62° 48'N, 11° 53'E. UTM 472 660). The majority of the Lervahå mire can be classified as an intermediate to rich minerotrophic fen, whereas the smaller part (~1/3) in the east has the features of a slightly more raised ombrotrophic bog. The topogenous fen is essentially flat, but is sloping slightly in the south. It is relatively round shaped, apart from a constricted and somewhat elevated area with rich floristic hillocks in the south eastern part of the fen (see Fig. 2.2). Due to its bisected composition, it is found more convenient to use the more general and embracing term "mire" when referring to the sampling site at this location. A ca. 1 m deep stream runs along the basin margin in an eastward direction starting from the north- west part of the fen. In the middle of the basin the stream suddenly changes its direction towards south, dividing the mire into a large fen area in the west and a considerably smaller fen/bog area in the east. The fully overgrown basin measures 240 x 75 m. As it lies within a flat area, its catchment size is unknown. Based on stratigraphical transect analyses (see Appendix A), the deepest part is ca. 330 cm (coring point 2) deep.

**Figure 2.2:** *An overview picture of the Lervahå mire (770 m a.s.l.). The person in the middle shows the coring point. Photo: Aage Paus.*

### 2.1.2 Reinskaret (920 m a.s.l.)

The second sampling site is a peat profile located 3 km north east of the Lervahå mire, at 920 m a.s.l. in the mountains of southern Tydalen municipal (62° 48'N, 11° 56'E. UTM 498 674). The peat profile is a part of a soligenous fen situated in an erosion pass through a south west-facing slope (Fig. 2.3). The investigated profile had a vertical length of 241 cm, containing a high amount of birch megafossils (Fig. 2.4). The fen is approx.100x100 m, and has a catchment area of ca. 0.05 km$^2$. The fen slants towards west. However, a mountain ridge in the north shelters the locality from the prevailing winds, thus creating south-facing conditions.

**Figure 2.3:** *An overview picture of the sampling site found at Reinskaret (920 m a.s.l.). Photo: Aage Paus.*

## 2.2 Geology

Both localities belong to the Røros cover- complex formed in Cambrian to Ordovician times (NGU, 2010a). The main superficial deposit covering the area is basal till, which can coarsely be defined as unconsolidated morainic debris deposited by glaciers (Moen, 1999; NGU, 2010b).

### 2.2.1 The Lervahå mire (770 m a.s.l.)

The bedrock at the Lervahå mire locality is composed of calciferous phyllite, garnet mica schist, garbenschiefer and gneiss (NGU, 2010a).

The bedrock at the Lervahå mire consists mostly of rock types that easily weather, especially the metamorphic and porous calciferous phyllite, creating favourable growing conditions for the vegetation in terms of high quality and quantity soil production, in addition to good water and nutrient availability (Moen, 1999).

### 2.2.2 Reinskaret (920 m a.s.l.)

The bedrock at Reinskaret is composed of mainly conglomerate, but serpentinite and other rock types have a scattered distribution in the area (NGU, 2010a). In adjacent areas further north of the sampling site the bedrock is additionally comprised of augen gneiss from proterozoic times (NGU, 2010a).

***Figure 2.4:*** *A picture of the peat profile at Reinskaret, after being cut vertically with a spade. The picture shows the many birch remains found well preserved in the profile. Photo: Aage Paus*

Given that the bedrock at Reinskaret is rather resistant to weathering (i.e. has low weathering rate), one can expect the soil being thinner, coarser and poorer in nutrients (NGU, 2009), and hence less favourable for plant growth in comparison to the soil at the Lervahå mire.

In accordance with Dahl *et al*. (1997) and Paus *et al*. (2006) an early time of deglaciation (presumably around 11,500 cal. years BP) is assumed for the study area (see ch.1 and section 6.1.1).

## 2.3 Climate

The prevailing climate in the study region is transitional between sub-oceanic and sub-continental climate, experiencing rather low temperatures in the winter and somewhat high temperatures in the summer (Prösch-Danielsen and Sørensen, 1999; Moen, 1999).

Measurements from adjacent meteorological stations show that the average annual precipitation is rather low and varies between ca. 650-750 mm a year (DNMI, 2010; Moen, 1999). In addition, the region has a moderate precipitation frequency of 200-220 days of 0.1 mm or more in precipitation (Moen, 1999). Temperature inversions during winter are characteristic (Prösch-Danielsen and Sörensen, 1999; Moen, 1999). This involves very low temperatures, created as cold motionless air is being pressed down on the landscape for longer periods (DNMI, 2009).

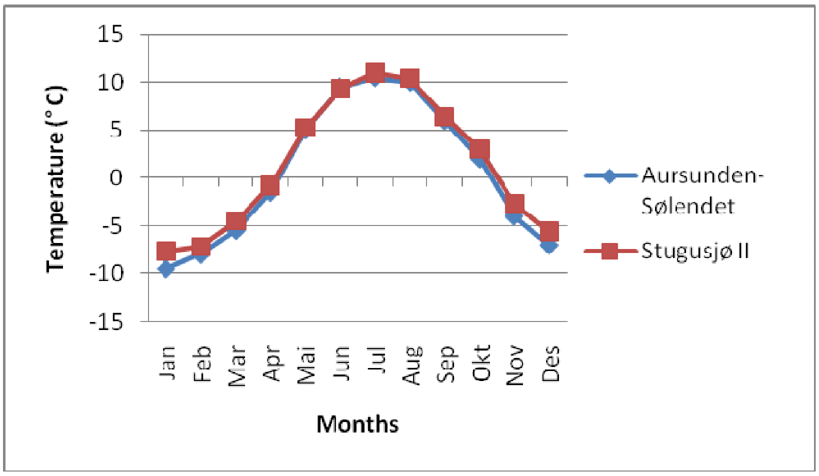


***Figure 2.5:*** *The figure displays the monthly normal temperature values for Aursunden-Sølendet and Stugusjø. The meteorological station at Stugusjø is called Stugusjø II (DNMI, 2010)*

All monthly normal temperature and precipitation values presented here refer to the period between 1961 and 1990 (DNMI, 2010).

Wind measurements in the time period between 1971 and 2000 show that moderate to fresh breezes from the north-west and south-east are dominating during the spring, whereas the summer season is mainly exposed to gentle breezes from the north-west (DNMI, 2005).

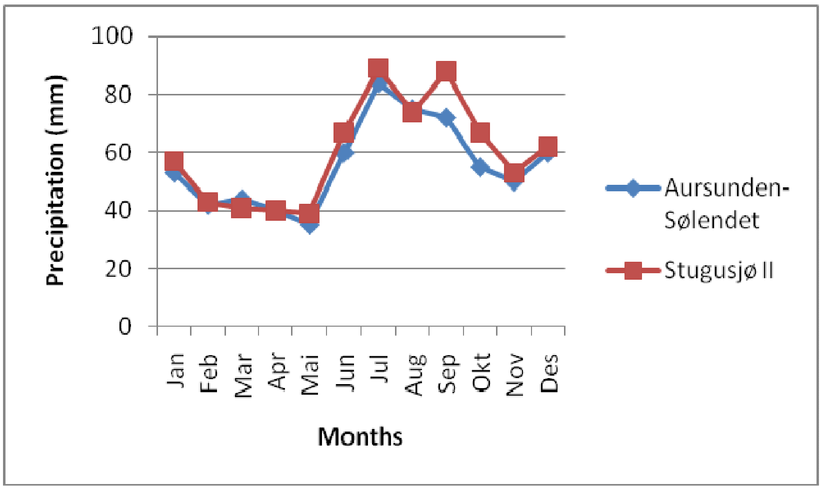


***Figure 2.6:*** *The figure displays the monthly normal precipitation values for Aursunden- Sølendet and Stugusjø (DNMI, 2010).*

### 2.3.1 The Lervahå mire (770 m a.s.l.)

The average monthly temperature values (TAM values) (Fig. 2.5) for the Lervahå mire would be similar to data from the meteorological station at Aursunden – Sølendet (750 m a.s.l.) and the lower-situated Stugusjø (615 m a.s.l.), located ca. 12 km south and 16 km north of the Lervahå mire, respectively. Their respective average annual temperatures are 0.6 °C (Aursunden-Sølendet) and 1.4 °C (Stugusjø) (DNMI, 2010).

The monthly normal precipitation values (Fig.6) are collected from the meteorological stations: Aursund- Sølendet and Stugusjø. The average annual precipitation measured at these stations is 670 mm and 720 mm, respectively. According to DNMI (2010) the lowest precipitation occurs in April or May (30- 40 mm per month). July is the month with the highest precipitation (between 80-90 mm) (DNMI, 2010).

### 2.3.2 Reinskaret (920 m a.s.l.)

One may assume that climates at the Lervhå mire and Reinskaret were similar as they are only 3 km apart. However, the altitudinal difference between Reinskaret and the Lervahå mire is ca. 150 m. Because the atmospheric temperature is negatively correlated with the increase in altitude, a correction of the mean July temperature must be carried out by the use of the lapse rate of 0.6 °C/100 m (Laaksonen, 1976). Hence, the mean July temperature is estimated to be 0.9 ° C (~1 °C) lower at Reinskaret situated at 920 m a.s.l. compared to the Lervahå mire at 770 m a.s.l.

## 2.4 Glacioisostatic uplift

After deglaciation, the earth’s surface rebounded as a result of the disappearing ice-sheet (Walcott, 1973). The rate of glacio-isostatic uplift, which has varied through the Holocene, was highest in the early post-glacial period before ca. 8,900 cal. years BP (Haftsen, 1983; Kullman, 2000). The study localities have thus increased in altitude through the post-glacial period. This must be taken into consideration as past climate temperatures for the Ridalen localities are being inferred.

## 2.5 Vegetation and flora

The study site in the Ridalen region is situated within two vegetation zones. The lowest lying Lervahå mire is situated in the northern boreal vegetation zone (i.e. northern coniferous and birch woodland zone) (Moen, 1999). This woodland zone is usually divided into an upper part dominated by *Betula* and a lower part in which *Pinus* and *Picea* occur more often. *Populus tremula*, *Sorbus aucuparia* and *Salix spp*. are more scattered within the woodland. Its flora is usually comprised of western and alpine plant species, whereas the occurrences of warmth demanding southern and south-eastern species are rare. Being located at higher altitudes Reinskaret is situated within the low alpine zone (Moen, 1999). According to Moen (1999), this zone is characterized by ridge, lee side and snow bed plant communities, in which *Vaccinium myrtillus* heath is a common vegetation feature, along with the occurrence of *Juniperus*, and dwarf shrubs such as *Betula nana* and *Salix spp.*

According to Moen (1999) the study site is located within the slightly oceanic vegetation section (O1), the growing season in the study region (measured as days with temperature above 5 °C) is rather long, 130-140 days a year.

The sub alpine-birch belt, which is situated around 850 m a.s.l. (personal observation), represents the climatic forest limit in the study area. Within the study region two stunted *Pinus sylvestris* were observed.

### 2.5.1 The Lervahå mire (770 m a.s.l.)

A tripartition of the mire into a western, eastern and central part, can be made on the basis of the plant species composition. The western part of the mire was dominated by *Carex lasiocarpa*. In the area located further north-west, lime-demanding species such as *C. buxbaumii, Juncus castaneus, Bartsia alpina*, *Trichoporum alpinum* were growing, indicating a nutrient rich flow of water to the mire from the surroundings. This high nutrient level reflects the local base-rich bedrock.
In the middle of the basin, close to the coring sites, the vegetation was domintated by species such as *Eriophorum angustifolium, Molinia caerulea, Carex rostrata* and *Trichoporum cespitosum.* In addition, rich fen indicators such as *Thalictrum alpinum* and *Parnassia palustris* (Fremstad, 1997) were growing at this location.

Low nutrient indicators such as *Sphagnum sp. and Rubus chamaemorus* (on hillocks) (Fremstad, 1997) dominate the eastern boggy part of the mire. Other dominating species were *Carex pauciflora* and *Trichoporum cespitosum.* The hillocks also contained the dwarf shrubs *Betula nana* and *Calluna vulgaris*. See Table 2.1 for plant occurrences.

### 2.5.2 Reinskaret (920 m a.s.l)

Plants which were growing within a radius of 40-50 m from the sampling site have been identified. *Betula nana* was a dominant species all around the sampling site. *Equisetum sylvaticum* was dominating in the eastern-erosional slope. *Athyrium filix-femina* snowbeds are found in the north facing slopes, whereas frequencies of *Nardus stricta*, *Eriophorum angustifolium* and *Vaccinium myrtillus* varies depending on soil mositure. Other common species were *Carex rostrata and Eriophorum angustifolium.* In relative dry areas surrounding the sampling site the species *Juniperus communis*, *Salix lapponum*, *Vaccinium spp.*and *Empetrum nigrum* were observed. The acid bedrock locally explains the lack of lime-demanding plants. Table 2.1 shows the species found at this location.

***Table 2.1:*** *The table displays all the plant species found growing at the Lervahå mire (LH) and Reinskaret (RS), September 2008. Dominating species are marked with *.*
*The table continues on the next page.*

| **Vascular plants** | **LH** | **RS** | **Vascular plants** | **LH** | **RS** |
|---|---|---|---|---|---|
| *Andromeda polifolia* | X | | *Juniperus communis* | X | X |
| *Avenella flexuosa* | | X | *Loiseleuria procumbens* | X | |
| *Bartsia alpina* | X | | *Menyanthes trifoliata* | X | |
| *Betula nana* | X | X * | *Molinia caerulea* | X* | X |
| *B. pubescens* | X | | *Nardus stricta* | | X |
| *Calluna vulgaris* | X | X | *Parnassia palustris* | X | |
| *Campanula rotundifolia* | X | | *Polytrichum sp.* | | X |
| *Carex buxbaumii* | X | | *Pedicularis palustris* | X | |
| *C. flava* | X | | *Potentilla erecta* | X | |
| *C. lasiocarpa* | X* | | *P. palustris* | X | X |
| *C. limosa* | X | | *Rubus chamaemorus* | X* | X |
| *C. nigra* | | X | *Salix herbacea* | | X |
| *C. panicea* | X | | *S. lapponum* | X | X* |
| *C. pauciflora* | X* | | *Saussurea alpina* | X | |
| *C. rostrata* | X* | X* | *Solidago virgaurea* | | X |
| *C. saxatilis* | | X | *Thalictrum alpinum* | X | |
| *Cirsium helenioides* | X | | *Tofieldia pusilla* | X | |
| *Dactylorhiza incarnata spp. cruenta* | X | | *Trichophorum alpinum* | X | |
| *Dactylorhiza incarnata ssp. incarnata* | X | | *T. cespitosum* | X* | X |
| *Deschampsia cespitosa* | X | | *Vaccinium myrtillus* | | X |
| *Empetrum nigrum* | X | X | *V. oxycoccus* | X | |
| *Eriophorum angustifolium* | X* | X | *V. uliginosum* | | X |
| *E. vaginatum* | X | | *V. vitis-idaea* | | X |
| *Filipendula ulmaria* | X | | *Valeriana sambucifolia* | X | |
| *Galium boreale* | X | | *Viola palustris* | | X |
| *Juncus castaneus* | X | | - | | |

| **Pteridophytes** | **LH** | **RS** | **Pteridophytes** | **LH** | **RS** |
|---|---|---|---|---|---|
| *Athyrium filix-femina* | | X | *Equisetum sylvaticum* | | X* |
| *Huperzia selago* | X | X | *Selaginella selaginoides* | X | |
| **Bryophytes** | **LH** | **RS** | **Bryophytes** | **LH** | **RS** |
| *Dicranum sp.* | X | | *Hylocomium splendens* | X | |
| *Drepanocladus revolvens* | X | | *Sphagnum sp.* | X* | X |
| **Lichens** | **LH** | **RS** | **Lichens** | **LH** | **RS** |
| *Cladonia arbuscula* | X | | *Thamnolia vermicularis* | X | |
| *C. gracilis* | | X | - | | |

# 3. Material and Methods

## 3.1 Fieldwork

The fieldwork was carried out in September 2008. Research material was collected and the surrounding vegetation was described at each sample site.

### 3.1.1 The Lervahå mire (770 m a.s.l.)

In order to retrieve a complete sequence of peat deposits spanning from the deglaciation to present, a north-south and east-west transect were lithostratigraphically analysed using a 54 mm Russian corer (see Fig. 3.1). A complete Holocene peat sequence was retrieved by sampling at two coring sites. These sites were selected on the basis of the 11 trial cores along the transect analysis. Peat cores were collected at both sites using a 2 m long 110 mm inner diameter PVC tube. Ditches needed to be dug around each PVC-tube in order to extract the cores from the peat.

To be able to retrieve material from the deepest part of the basin, a 110 mm diameter Russian corer was used. The PVC tubes were concealed with plastic lids, and the two other Russian cores were placed and properly concealed in plastic tubes longitudinally cut into two halves.

The Lervahå mire was also searched for megafossils. Some were found exposed near the bog surface (e.g. *in situ* stumps of roots), while others were found within the peat layers or in the stream running through the mire. Twelve megafossils of pine were found in total.

### 3.1.2 Reinskaret (920 m a.s.l.)

The 241 cm long peat profile contained large proportions of tree-birch fossils. A 57 cm long core was retrieved from the base of the deposit by using a 110 mm diameter PVC tube. The remaining sequence of the peat profile above the retrieved core was then sub sampled every 4 cm in 1 cm thick samples. The sediment samples were labelled and stored in sealable plastic bags. No tree-birch remains were found above 96 cm in the peat profile. At this stratigraphical limit, sub-sampling at higher density was carried out (every cm between 96-101 cm).

In addition to the pollen sampling, a selection of tree-birch fossils, situated within in the peat profile, were collected at regular intervals for conventional $^{14}C$ radiocarbon dating (see Table 4.3).

***Figure 3.1:*** *The figure shows the lowermost minerogenic sequence of a test core obtained with a 54 mm Russian corer at the Lervahå mire, September 2008. Photo: Vanja Haugland*

## 3.2 Laboratory work

### 3.2.1 Sediment subsampling, description and preparation

Cores were cut longitudinally into two halves. The litostratigraphical layers where then described (Troels-Smith 1955) (Table 4. 1 and 4.2). For each of the cores, only one of the two halves has been sampled for further analysis. All material has been appropriately sealed and stored in an appropriate cooling room in the Department of Biology at the University of Bergen.

1 $cm^3$ subsamples for pollen analysis were extracted. To be able to calculate pollen concentration and influx values, a known number of tablets (2-4), each containing 18,584 ± 370 *Lycopodium clavatum* spores, was added to each pollen sample (Stockmarr, 1971). All samples were then prepared by standard methods (acetolysis, HF) according to Fægri and Iversen (1989).

### 3.2.2 Microfossil analysis

The pollen analysis has been performed by the use of a Zeiss research microscope with phase contrast and oil immersion Zeiss Planapo 40/1.0, 63/1.4, Neofluar 100/1.3 objectives and 8x oculars. Pollen grains have been identified using determination keys (Fægri and Iversen, 1989; Moore and Webb, 1978), together with the modern pollen reference collection at the

Department of Biologi, University of Bergen. Special determination keys for trilete spores (Moe, 1974) have also been used in the microfossil determination.

It was attempted to distinguish *Betula nana* (dwarf birch) pollen from tree- birch pollen based on Terasmäe (1951) and the modern pollen reference material. According to Terasmäe (1951), the size of *B. nana* grains is found to be somewhat smaller, the exine is thinner, and the apertures are less protruding compared to tree birches. *Betula* pollen grains which were difficult to assign to either of the two groups have been placed in a separate group called *Betula* undetermined. All three groups have been stacked together in the diagrams (Fig. 4.3, 4.4, 4.5, and 4.6) in order to give a better picture of their proportions in relation to each other.

Stomata found in the pollen samples have been identified to the lowest possible taxonomic level and counted together with the other microfossils. The presence of stomata is shown as black dots in the percentage diagrams. Stomata that could not be identified are referred to as "stomata undetermined". Finds of stomata are important for indicating local presence of trees (Eide *et al*. 2006; Parshall, 1999; Sweeney, 2003).

### 3.2.3 Pollen diagrams and pollen sum estimates

All pollen diagrams (Figs. 4.3, 4.4, 4.5, 4.6, and.C.1, C.2 in Appendix) were constructed using the program TILIA ver. 2.0 b.4 (Grimm, 1993) and drawn using TGView ver. 2.0.2 (Grimm, 2004). Maximum probability values of the calibrated dates, depths, litostratigraphy and % LOI are shown on the left side in the diagrams. The influx diagrams (Figs 4. 4 and 4.6) only display a selected number of taxa essential for the interpretation of the palaeoecological history. The calculation of the pollen sum (ΣP) is based on identified terrestrial pollen. The calculation of a taxon X belonging to unidentified pollen grains, aquatics (*Sphagnum* included), terrestrial spores, stomata or charcoal is based on the formula ΣP + X.

In this investigation, it was aimed at analysing 500 pollen grains per sample. This was, however, not always obtainable as some pollen spectra, often deriving from more minerogenic layers or layers showing high sedimentation rates, and thus contained very low concentrations of microfossils. The pollen sum in spectra from the Lervahå mire ranged between 106-1209 (average 553), whereas the pollen sum in spectra from Reinskaret varied between 153 and 1053 pollen grains (average 575).

One pollen spectrum from Reinskaret (RS- 101 cm) showed extremely high tree birch concentrations (above 80 %), which was interpreted as a local contamination (cf. anther dropping). Assuming that the amount of tree birch pollen did not change significantly during this period, new tree-birch percentages were calculated by interpolatation between the tree-birch percentages in the adjacent pollen spectra.

The nomenclature used for higher plants and pteridophytes follows Lid and Lid (2005).

### 3.2.4 Pollen Influx

As alpine areas are characterized by low local pollen production, pollen analytical investigations in the forest line ecotone show overrepresentation of long-distance tree pollen in the pollen percentage diagrams (Aario, 1940; Eide *et al.*, 2006; Hicks, 1994; Simonsen, 1980). Hence, it is often difficult to interpret the past vegetation patterns from the pollen percentage data alone. A useful method aiding the interpretation of the pollen data is to estimate pollen influx (pollen accumulation rates (PAR)); a method independent of percentages (Birks and Birks, 1980; Fægri and Iversen, 1989). Before influx values could be estimated (TILIA ver. 2.0 b.4; Grimm 1993), an age-depth relationship had to be established by a linear interpolation between dates. The age-depth model is displayed on the left in all pollen diagrams (Figs. 4.3, 4.4, 4.5, 4.6, A C.1 and A C.2). Pollen influxes used in the interpretation have been compared to influx values from both modern pollen trap data and pollen fossil records (e.g. Gunnarsdóttir, 1996; Hicks, 1994; Jensen *et al.*, 2007; Seppä and Hicks, 2006; Vorren *et al*., 1996).

### 3.2.5 Loss on ignition (LOI)

Loss-on-ignition was measured at the same depths as the pollen analyses. The samples were first dried in a cabinet for 15-18 hours at 105 °C. Thereafter, they were put in a dessicator to cool for 30 min before they were weighed and subsequently burned at 550 °C for 6 hours. After another 30 min in the dessicator, their weight was once more measured. Based on the dry weight of each sample before and after the ignition, the percentage of organic material lost in the ignition process has been calculated. The LOI results for all analysed pollen spectra are displayed in the pollen percentage diagrams for the two localities (Fig. 4.3 and 4.5).

### 3.2.6 AMS and conventional $^{14}$C radiocarbon dates

A total of seven samples (three from Reinskaret, four from the Lervå mire) of terrestrial macrofossils were dated by Accelerator Mass Spectrometry (AMS)-dating (Table 4.3). Macrofossils were sieved (125 µm) and handpicked (see Birks (2001) for further information on macrofossil sampling and preparation methods). All terrestrial macrofossils were coarsely determined by the use of macrofossil atlas (Cappers *et al.* 2006), air dried, carefully cleaned for dust/hairs etc., and weighed before being sent to the Laboratory for Radiological Dating at NTNU in Trondheim for AMS dating. By dating terrestrial plant macrofossils, the ageing effect of “old-carbon” /hard-water is avoided (Birks, 2001; H.H. Birks, 2007; Olsson 1986).

By lithostratigraphical and biostratigraphical correlations, the dates TRa-75 (LH1-87) and TRa-78 (LH2-65) (Table 4.3) were assumed to represent the same age. Based on these two dates, a new average radiocarbon $^{14}$C date could therefore be estimated according to Olsson (1986).

Twelve megafossils of pine were found at the surface or in the deposites of the Lervahå mire. These, contained more or less intact trunk diameters and were sent to Dr. Terje Thun, NTNU in Trondheim for dendrochronological analysis. Together with seven tree-birch remains from the Reinskaret peat profile, they were dated conventionally at the Laboratory for Radiological Dating at NTNU in Trondheim

The content of the unstable $^{14}$C isotope in the atmosphere has varied through time (e.g. Stuiver and Reimer 2010). Hence, different stratigraphical intervals may contain the same $^{14}$C radiocarbon content (radiocarbon plateaux). Calibrated dates therefore often include two or more intervals of different probabilities (Stuiver and Reimer, 2010). Calibration of all the $^{14}$C radiocarbon dates has been performed by the use of CALIB 6.0 (Stuiver and Reimer, 2010). All calibrated data are presented in calibrated years before present (BP), where present time equals 1950 AD (Table 4.3 and 4.4).

### 3.2.7 Sedimentation rate estimates

For both investigated peat sequences, the sedimentation rate (cm yr $^{-1}$) has been estimated based on the AMS dates (given in cal. years BP) (Table 4.3). However, largely due to time restrictions, the number of obtained AMS dates is low. This results in a rather rough and linear age-depth relationships as displayed in Fig. 4.1 and 4.2.

As one has to expect a gradually increasing sedimentation from pioneer conditions, the depth/age relationship in the Lervahå sediments will probably show a more sigmoid than linear tendencies. Thus, a modification of the age-depth model was performed by assuming an age of 8000 years at 150 cm in order to obtain a more feasible rate of sedimentation, and hence concentration and pollen influx estimates. As an extrapolation of the calibrated ages obviously would result in a too high basal date of the sediments, it was defined to 11,500 cal. years BP (cf. Dahl *et al*., 1997; Paus *et al*., 2006). This probably represent a maximum age (see section 6.1.1). The extrapolated age-depth models for both peat sequences are based on maximum probability values of the calibrated dates (Stuiver and Reimer, 2010).

### 3.2.8 Correlation

Two correlations between cores have been carried out in order to infer the entire post-glacial vegetation history of the the Lervahå mire locality (see Fig. 3.1). The first correlation is between the PVC-cores from coring site 1 (LH1) and 2 (LH 2) and is based on stratigraphy, AMS-dates, and biostatigraphy including LOI. The second correlation has been performed between the two deepest layers of the LH1 PVC core and the LH 2 russian core retrieved from the deepest part of the basin. Due to lack of $^{14}$C radiocarbon dates, the correlation had to be carried out on the basis of lithostratigraphy and LOI (Fig 4.3).

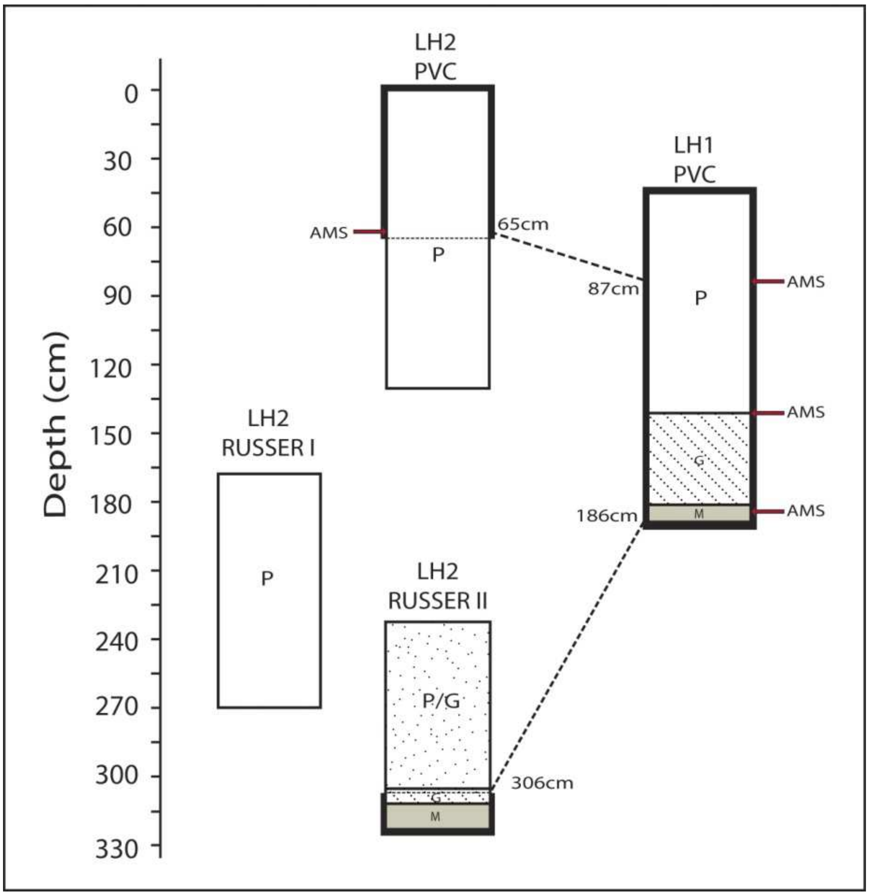


***Figure 3.2:*** *The figure displays all retrieved cores from coring site 1 and 2 (i.e. LH1 and LH2) at the Lervahå mire. The LH2 Russer I core has not been utilized for pollen analysis. The thicker lines indicate the sequences analysed for pollen. The deposits are here divided into M = minerogenic deposits, G= gyttja and P= peat. The depths from which AMS samples are obtained are shown by red arrows. The stippled lines shows the correlating depths between the cores (LH 2 PVC-65 cm = LH 1 PVC-87 cm, LH 1 PVC- 186 cm = LH 2 Russer II- 306 cm).*

In Fig. 3.1 all cores retrieved from the Lervahå mire are displayed. The LH 2 Russian core I has not been used for pollen analysis in this study as a correlation of the three other cores yielded an entire deposit sequence. The figure shows with a stippled line the correlating depths which are believed to be of the same age. The large depth gap between the PVC cores and the LH 2 Russian core II is a result of a large compression of the PVC cores during sampling (see section 4.1.1).

## 3.3 Numerical analyses

Numerical analyses in palaeoecological studies can yield many useful quantitative estimates of past vegetation patterns, which can provide vital information for the interpretation and reconstruction of the main temporal and spatial trends from complex multivariate data sets (H.J.B. Birks, 2007).

### 3.3.1 Conversion of the data files

Before the TILIA data files could be uploaded in the programs Zone 1.2 (Juggins, 1991), CANOCO (ter Braak and Šmilauer 1997-2002), and RAREPOLL 1.0 (Birks and Line, 1992), it was necessary to convert them into an appropriate file format by the computer program TRAN 1.7 (Juggins, 1993).

### 3.3.2 Zonation

Zonation identifies and delimits the different pollen assemblage zones within a diagram, and it furthermore facilitates pollen diagram descriptions and the interpretations and discussions of observed vegetational patterns (Bennett, 1996; Birks and Birks, 1980; Fægri and Iversen, 1989). Zonation is also a tool for comparing and correlating diagrams. The zonation of the diagrams from Lervahå mire and Reinskaret is based on all identified terrestrial pollen and spore taxa (*Sphagnum* included). It was carried out by an optimal partitioning of zones by the use of the sum-of-squares criterion (Birks and Gordon, 1985). This statistical and unbiased zonation method was performed with the program Zone 1.2 (Juggins, 1991). The determination of significant zones was performed by a comparison with the broken-stick model (Bennett, 1996; Birks, 1998). The results are displayed in the pollen percentage and influx diagrams (Fig. 4.3, 4.4, 4.5, 4.6, C1 and C2). The local pollen assemblage zones (LPAZ) are displayed in numerical order according to the chronology, increasing in numbers starting from the bottom. Each zone is given name on the basis of its characteristic pollen taxon/taxa observed in the percentage diagram.

### 3.3.3 Gradient analysis

Data ordination was used to detect underlying patterns in the terrestrial vegetation and palaeoecological development (H. J. B. Birks, 2007). As the Detrended Correspondence Analysis (DCA) yielded a gradient length of 1.669 (see Table 4.5), indicating linear response curves, Principal Component Analysis (PCA) was chosen as the ordination technique (see ter Braak, 1987). A united data set for both localities was subjected to ordination, and the analyses (DCA, PCA) were carried out by the ordination program CANOCO windows 4.5 (ter

Braak and Smilauer 1997-2002). The ordination plots were created in CanoDraw 4 (ter Braak and Smilauer 1997-2002). To avoid some taxa (e.g. *Pinus* and *Betula*) becoming too dominant, a square root transformation of the species data was performed. In the PCA analysis, the species and samples data were centred by species and samples, respectively. The respective DCA and PCA results are displayed in Table 4.5 and 4.6. Only identified terrestrial pollen and spores (*Sphagnum* included) were used in the indirect ordination.

### 3.3.4 Palynological Richness (PR) - Rarefaction analysis

According to Birks and Line (1992), the rarefaction analysis is a suitable and unbiased method to estimate species richness from pollen analytical data. Palynological richness (PR) is a proxy for the total floristic richness within the pollen source area. Intermediate levels of disturbance maximize richness by preventing both dominance and extinction of species (Grime, 1973). The rarefaction analysis has been performed on a combined data set for the two localities by the use of the computer program RAREPOLL 1.0 (Birks and Line, 1992). The species richness (E ($S_{392}$)) has only been estimated for the terrestrial pollen and spore taxa. The basic estimate value of *n* was 392 and equal for all pollen spectra. Three pollen spectra containing pollen and spore sums lower than 392 (LH: depth 173 and 177 cm, RS: depth 101 cm) have been removed from the total data set due to low statistical validity. The average values for the estimated species richness for the two localities are displayed on the left side in the pollen percentage diagrams Fig. 4.3 and 4.6 and further described for all local pollen assemblage zones in section 4.2.

# 4. Results

## 4.1 Peat sediments and dates

### 4.1.1 Litostratigraphical data

A brief description of the stratigraphical layers will be given in the sections underneath. More detailed descriptions (Troels-Smith, 1955) and additional descriptive comments on physical and compositional properties of the litostratigraphical sequences, which have been sampled for pollen analysis, are given in Table 4.1. The Troels-Smith (1955) descriptions are additionally displayed in Fig. 4.3, 4.4, 4.5 and 4.6.

#### 4.1.1.1 The Lervahå mire (770 m a.s.l.)

Because the correlation of the cores was carried out after the pollen analysis, the original depths of the cores have been applied in the stratigraphical descriptions (see section 3.2.8 and Fig. 3.1 for details about the correlation). The pollen spectra are later given new depths, which are displayed in brackets in Table 4.1.

**Coring site 1**

*LH-1 PVC core*

The LH-1 core retrieved by the PVC tube has a total length of 137 cm, starting from the uppermost layer at 50 cm and ending with the lowest layer at 187 cm. Given that the entire PVC tube was 2 m long, it can be estimated that the core was compacted by 63 cm during the sampling process. Since the uppermost layers are comprised of coarser and less compact *Sphagnum* peat, it seems that the highest degree of compaction occurred in this section of the core. Pollen samples have been subsampled for the entire peat sequence.

The 5 lowermost centimetres of the core were composed of minerogenic sediments, such as clay and silt. There is a gradual increase in organic material starting from 182 cm. The transition between gyttja and peat is recorded at 140 cm. The level of degradation in the subsequent *Sphagnum* peat sequence (from 140-50 cm) decreases upwards towards the uppermost layer. Rootlets and wood fragments were frequently found in the peat layers (see Table 4.1 for more details).

## Coring site 2

### *LH-2 PVC core*

The core retrieved by the PVC tube at coring site 2 experienced a more severe compaction. The peat core covers a sequence from 0 to 130 cm, in which 0 cm equals present times. This implies a compaction of 70 cm. As for the LH-1 peat core, the highest degree of compaction is assumed to have occurred in the topmost peat layers. The same compositional structures were observed for the overlapping layers of the LH 1 and LH 2 PVC cores. There are no distinct lithostratigraphical changes within the upper 65 cm of the LH 2 PVC core, which is composed mostly of coarser *Sphagnum* peat and plant fragments. More detailed stratigraphical descriptions are displayed in Table 4.1.

### *LH-2b russer core*

The russer core is retrieved from the deepest part of the basin and has a total length of 1 m. As shown in Table 4.1, minerogenic sediments are recorded in the lowest 20 cm of the core. In the layers above 311 cm, the amount of clay gradually declines and a subsequent increase in organic material is recorded. Only the sequence from 306 to 319 cm was sampled for pollen analysis (see Fig. 3.1).

***Table 4.1:*** *The table contains a stratigraphical description (Troels-Smith 1955) of the layers of the correlated litostratigraphical sequence retrieved from coring site 1 and 2 at the Lervahå mire. The description is only given for the layers which have been analysed for microfossils. * Layer 1 becomes compressed with 22 cm after the correlation of the LH 1 and LH 2 PVC cores. The table continues on the next page.*

| Core | Layer | Depth (cm) | Sediment components | Description |
|---|---|---|---|---|
| **LH2 PVC** | 1 | 0-87<br>(0- 65)* | $Ld^3 1$, $Tb^2 2$, Dh1, Dl+ | Moist *Sphagnum* peat.<br>Hardly elastic.<br>High frequency of roots and rootlets.<br>A small branch (presumably pine) recorded at 57.5 cm (0.5 m in dm, 4 cm long), in addition to another wood fragment at 71 cm. |

| | | | | |
|---|---|---|---|---|
| **LH1<br>PVC** | 2 | 87-140<br>(65- 118) | Ld$^3$4, Tb+, Th (recent) | Well degraded *Sphagnum* peat.<br>The colour is greyish-brown to reddish greyish-brown.<br>Contains a lot of organic remains.<br>Wood remains (a small fragment recorded at 102 cm, and larger between 94.5 and 97 cm). Frequent occurrences of roots and rootlets. |
| | 3 | 140-167<br>(118-145) | Ld$^2$4, Dh+, Th (recent) | Gyttja with organic remains.<br>Upwards laminated layers shifting between dark and light colour.<br>The layer between 161-163 cm is especially dark, containing a lot of downwards penetrating roots. |
| | 4 | 167-182<br>(145- 160) | Ld$^2$4, Ag+, Tb+ , Dh+ | Gyttja with organic remains.<br>The colour is brownish dark to greyish-brown.<br>Little minerogenic content. |
| | 5 | 182-185,5<br>(160-163.5) | Ld$^3$3, As1, Ag+, Dh+, Tb+ | Much clay and silt.<br>Dark colour.<br>Organic in the upper part. |
| | 6 | 185,5-187<br>(163.5-165) | As2, Ag2, Ld+ | Clay and silt.<br>Slightly organic.<br>The colour is brownish blue-grey.<br>A gradual transition to the layer above. |
| **LH2<br>Russer II** | 7 | 307-311<br>(165- 169) | Ld$^0$1, As2, Ag1 | Clay gyttja.<br>Yellow colour. |
| | 8 | 311-319<br>(169-177) | As3, Ag1 | Clay with silt |

#### 4.1.1.2 Reinskaret (920 m a.s.l.)

The PVC core collected at Reinskaret is 53.5 cm long, being compressed by 3.5 cm. Its stratigraphy is described in details in Table 4.2. The core consist of a small minerogenic layer in the bottom containing silt and gyttja. Largely decomposed peat is recorded for the first time at 221 cm. The peat becomes coarser and less degraded towards the uppermost layers. A high frequency of birch macrofossils are recorded at several depths in the peat profile between 213 and 96 cm. An increased amount of roots were recorded in the upper 36 cm of the profile.

***Table 4.2****: The table contains a stratigraphical description of the layers in the RS peat core retrieved from the peat profile at Reinskaret. The sediment composition is described and further scaled according to Troels-Smith (1955).*

| **Material origin** | **Layer** | **Depth (cm)** | **Sediment components** | **Description** |
|---|---|---|---|---|
| **Sub samples** | 1 | 0-96 | Ld$^{1}$2, Th 1, Dh1, Dl$^{+}$, Tb$^{+}$ | Coarser peat without birch megafossils. Roots and rootlets from recent vegetation, especially frequent above 36 cm. |
| | 2 | 96- 184 | Ld$^{3}$2, Dl 1, Dh1, Tb$^{+}$ | Coarser peat with birch megafossils. Roots from recent vegetation. |
| **PVC core** | 3 | 184-192 | Ld$^{3}$3, Dh1, Dl$^{+}$, Tb$^{+}$ | The layer consists of peat. Drier and coarser than layer 4. Root remains of *Equisetum.* |
| | 4 | 192-221 | Ld$^{2}$3, Dl 1, Dh$^{+}$, | Birch remains recorded at 197 cm and between 213 and 208 cm. |
| | 5 | 221-233.5 | Ld$^{3}$4 , Dl$^{+}$, Dh$^{+}$, | The layer consists mostly of degraded peat. Some plant remains and fragments. |
| | 6 | 233.5 - 235.5 | Ld$^{3}$4, Dh$^{+}$, Ag$^{+}$ | The layer is more compact and has a dark colour. Contains large amounts of degraded gyttja. |
| | 7 | 235.5-237.5 | Ld$^{1}$2, Ag2, Dh$^{+}$ | Minerogenic layer composed largely of clay and silt |

### 4.1.2 AMS and megafossil dates

The results of the AMS datings from both localities are given in Table 4.3, whereas the megafossil dates are displayed in Table 4.4. All dates are given in both uncalibrated $^{14}$C radiocarbon years BP and calibrated calendar years BP. The calibrated ages are given as intervals within one and two standard deviations.

The horizon at 65 cm in LH-2, showing a characteristic stage of the mire regrowth, is also observed in the LH 1 core at around 87 cm. As the coring sites are only 3 m apart, one may assume that these stratigraphical events are more or less simultaneous, as indicated by their overlapping dates. Using Olsson (1986) a new mean $^{14}$C radiocarbon age for the dates combined was calculated for this horizon. The results are given in Table 4.3.

***Table 4.3:*** *The table shows the results of the AMS dates from the Lervahå mire and Reinskaret. The dates are given in uncalibrated $^{14}$C years BP and calibrated calendar years intervals. The table continues on the next page.*

| **Lab. code** | **Depth (cm)$^{(I)}$** | **Uncalibrated $^{14}$C age (BP)** | **Calibrated age (BP)** | | **$\delta^{13}$C [‰]** | **Material dated** | **Purpose with dating$^{(II)}$** |
|---|---|---|---|---|---|---|---|
| | | | **[1SD]** | **[2SD]** | | | |
| **LH1 (770 m a.s.l.)** | | | | | | | |
| TRa-75 | 86.5-87 (64.5-65) | 4540± 30 | 5070-5309 | 5053-5313 | -27,4 | Seeds, needles and budscales (17.0 mg) | Believed to be the same age as TRa-78 (LH2-65). |
| TRa-76 | 139.5-140 (117.5-118) | 5720± 35 | 6450-6553 | 6413-6632 | -27,7 | Seeds, budscales and wood fragments (14.1 mg) | To date the transition between gyttja and *Sphagnum* peat |
| TRa-77 | 184-185.5 (162-163.5) | 9095± 45 | 10206-10269 | 10188-10387 | -25,8 | Seeds, budscales and wood and leaf fragments (14.3 mg) | To date the deepest part of the peat core |
| **LH2 (770 m a.s.l.)** | | | | | | | |
| TRa-78 | 64-65 | 4455± 35 | 4976-5273 | 4893-5288 | -25,9 | Pine wood fragments (16.0 mg) | The same layer/age as TRa-75 (LH1-87)? |
| TRa-75 (LH1-87) and | - | 4504 ±23 | 5056-5286 | 5049-5294 | - | - | - |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| TRa-78<br>(LH2-65)<br>combined | | | | | | | |
| **RS (920 m a.s.l.)** | | | | | | | |
| TRa-79 | 235.5-237.5 | 7815± 35 | 8552-8627 | 8481-8698 | -29,2 | Seeds, bark and wood fragments (29.1 mg) | To date the oldest layer retrieved from Reinskaret |
| TRa-80 | 184-185 | 6590± 35 | 7438-7551 | 7430-7564 | -27,0 | Seeds, needles and wood fragments (22.1 mg) | To date the upper part of the sampled core |
| TRa-81 | 100.5-101 | 4945± 35 | 5613-5713 | 5602-5738 | -25,5 | Seeds and wood fragments (24.9 mg) | The end of the megafossil layer in the peat profile |

*(I)Old depth values for the LH 1 PVC core, before any renaming of the depths. New depths are shown in brackets.*

*(II) All AMS dates are necessary for calculation of influx values*

The pine megafossil dates of the Lervahå site vary between ca. 3,700 and ca. 7,100 cal. years BP, whereas the birch dates at Reinskaret vary between ca 5,100 and ca. 8,450 cal years BP (See Table 4.4).

***Table 4.4:*** *Megafossil dating results from the Lervahå mire and Reinskaret. The dates are given in uncalibrated $^{14}$C years BP and calibrated calendar years intervals. Dates named by a depth interval (e.g. LH1-70-92), reflect the megafossil diameters.*

| **Lab.code** | **Depth (cm)** (I) | **UTM: 32V PQ** | **Uncal. $^{14}$C age** | **Cal. years BP** | |
|---|---|---|---|---|---|
| | | | | **[1 SD]** | **[ 2 SD]** |
| **Pine remains at the Lervahå mire (770 m a.s.l.)** | | | | | |
| T-19819 | | 47217-66058 | 4360 ± 45 | 4862-4968 | 4843-5044 |
| T-19820 | | 47192-66103 | 3455 ± 75 | 3639-3829 | 3485-3905 |
| T-19821 | | 47199-66097 | 6195 ± 65 | 6999-7230 | 6941-7258 |
| T-19822 | | 47218-66077 | 5040 ± 60 | 5726-5892 | 5655-5911 |
| T-19823 | | 47218-66074 | 4490 ± 55 | 5046-5286 | 4894-5313 |
| T-19824 | | 47231-66068 | 4785 ± 50 | 5472-5589 | 5328-5605 |
| T-19825 | | 47223-66043 | 5385 ± 60 | 6028-6281 | 6001-6290 |
| T-19826 | | 47229-66031 | 5180 ± 60 | 5770-5999 | 5749-6177 |
| T-19827 | | 47217 66062 | 4750 ± 55 | 5333-5584 | 5324-5590 |
| T-19835 | LH1-55<br>(33) | 47217-66058 | 4430 ± 55 | 4879-5265 | 4867-5285 |
| T-19837 | LH1-70-92<br>(48-70) | 47217-66058 | 4940 ± 60 | 5605-5721 | 5586-5887 |
| T-19836 | LH2- 69 | 47217-66058 | 4180 ± 50 | 4628-4830 | 4570-4844 |
| **Birch remains at Reinskaret (920 m a.s.l.)** | | | | | |
| T-19828 | RS-211 | 49895-67446 | 7675 ± 55 | 8412-8536 | 8386-8580 |
| T-19829 | RS- 184 | 49895-67446 | 6310 ± 55 | 7168-7287 | 7029-7416 |
| T-19830 | RS-152-159 | 49895-67446 | 6130 ± 65 | 6945-7156 | 6799-7236 |
| T-19831 | RS-136-140 | 49895-67446 | 5765 ± 50 | 6501-6633 | 6441-6672 |
| T-19832 | RS-109 | 49895-67446 | 5165 ± 60 | 5768-5993 | 5745-6174 |
| T-19833 | RS-82-85 | 49895-67446 | 4450 ± 95 | 4893-5284 | 4853-5314 |
| T-19834 | RS-77-79 | 49895-67446 | 4585 ± 95 | 5053-5451 | 4971-5580 |

(I) *The cells without content equal 0 cm. Depths in brackets are the new depths after the correlation of the Lervahå mire cores*

### 4.1.3 Calibration and sedimentation rates

The calibration of the dates was carried out in CALIB 6.0 (Stuiver and Reimer, 2010) and the results are displayed in Table 4.3 and 4.4. The program calculates the calendar years in which it is probable to find the true age of the sample (Stuiver and Reimer, 2010). The number of age-intervals varied for the different dates. Some dates were given two or more intervals for the calibrated ages. In these situations the calibrated ages are defined within a new interval, which is comprised of the two extreme values.

For both localities the AMS dates (in cal. years. BP) are displayed in a depth/age plot (see Fig. 4.1 and 4.2). In both plots all dates are given in 2 SD intervals. The AMS dates are marked with an M. The other intervals are dated megafossils from the localities. The intervals are shown with a thicker line than the macrofossil dates. The thinner lines which are intercepting the AMS dates in both plots represent the sedimentation rate for the two localities.

#### ***4.1.3.1 The Lervahå mire (770 m a.s.l.)***

The relationship between the calibrated ages and the depths are displayed in Fig. 4.1. For this locality, the calculation of the sedimentation rate is based on the three AMS dates obtained from the different layers in the peat sequence. However, due to the low amount of dates, the influx and sedimentation rate estimates are inaccurate. As one has to expect a gradually increasing sedimentation from pioneer conditions, the depth/age relationship in the Lervahå sediments will probably show a more sigmoid than a linear tendency. So, the depth/age relationship was modified as displayed in Fig. 4.1, and thus thought to more reliably reflect the regrowth of the Lervahå mire. Nevertheless, these are only assumptions and not reliable dates, which make the chronology for the locality highly tentative. This highlights the importance of the need for dense dates in order to obtain a high quality chronology and absolute pollen estimates.

The megafossil LH2-69 was found at 69 cm in the peat profile at the second coring site. The calibrated age of the megafossil has been added in the plot in addition to the AMS dates. As shown in Fig. 4.1, the date of the megafossil yielded an older age than the AMS dates. This underlines that megafossils may not be situated *in situ*, and therefore they might not be contemporary with their surrounding sediment (cf. downwards penetrating root, upwards pointing branches from fallen stems).

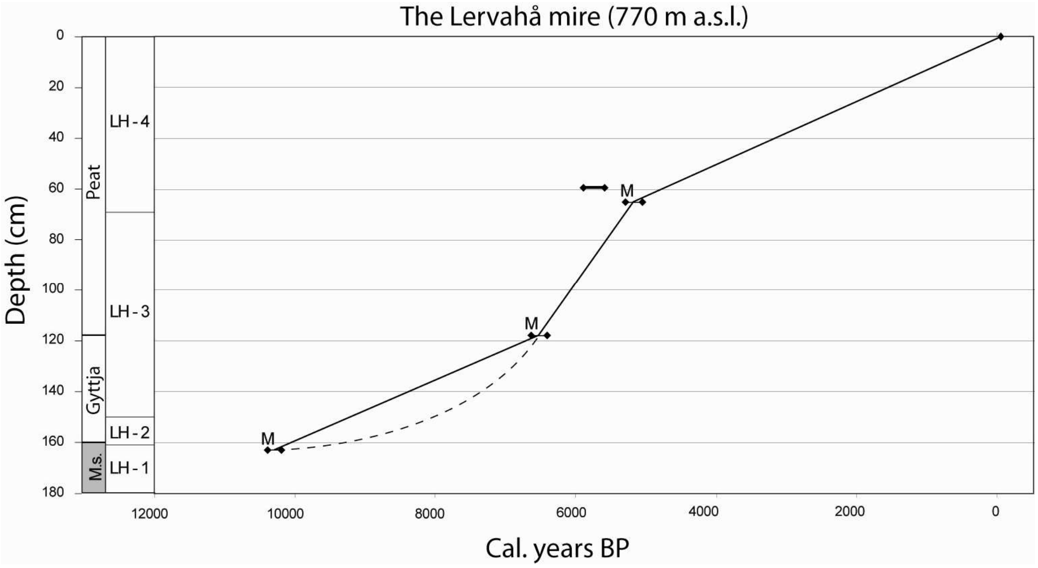


*Figure 4.1: A depth/age plot showing the relationship between the age and depths in the sediments of the Lervahå mire.*

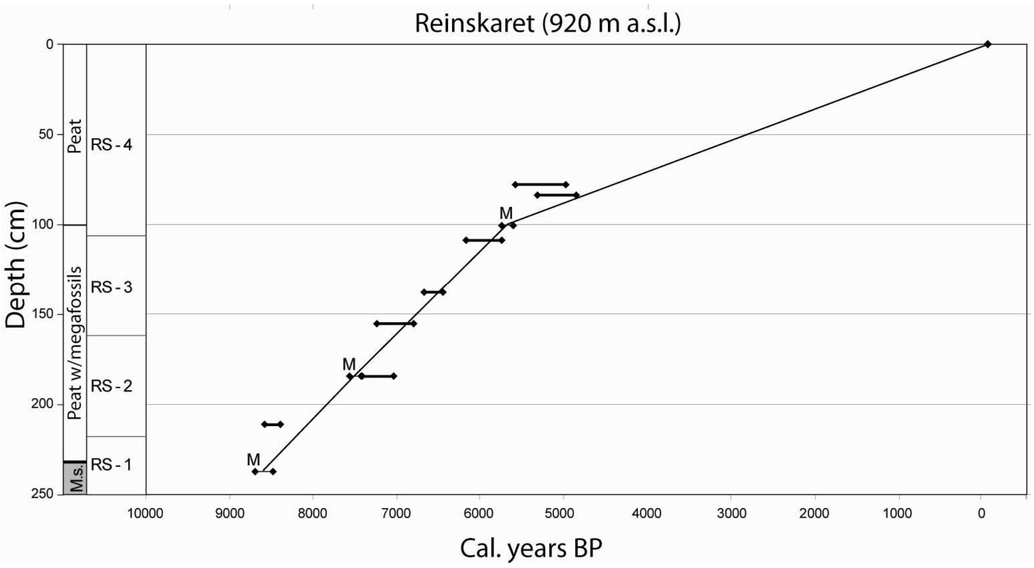


*Figure 4.2: A depth/age plot showing the relationship between the age and depths in the sediments of Reinskaret*

### 4.1.3.2 Reinskaret (920 m a.s.l.)

All AMS and birch megafossil dates, which are found within the depth/age plot (Fig. 4.2) of the investigated peat sequence from Reinskaret, are showing a more or less linear sedimentation rate. The rate decreases when birch megafossils disappear from the profile. Birch megafossils seem to give reliable dates, though, as also pointed out for pine megafossils (see above), megafossils may not been found in their primary deposition (cf. downwards penetrating roots etc.).

## 4.2 Pollen diagrams and the local pollen assemblage zones (LPAZ)

The pollen percentage and influx diagrams for each study locality will be described in the forthcoming section. The dates are given in calibrated years BP and are maximum probability values (Stuiver and Reimer, 2010).

As the *Betula* undetermined pollen grain records are not included in the LPAZ descriptions, all tree-birch or *Betula nana* percentages or influxes which are given in the results and interpretations are minimum values.

It must additionally be mentioned that the pollen concentration and influx records from Reinskaret show unusually high values than what is commonly estimated in previous palynological research (cf. Hicks, 1994; Hättestrand *et al.*, 2008; Jensen et al. 2007; Seppä and Hicks, 2006). The estimated total pollen influx within the section range in values between ca.1,200 and 54,400 grains cm$^{-2}$ yr$^{-1}$. The influx records for all pollen spectra show similar elevated levels (see Fig. 4.6). Due to the overall consistency of the influx estimates, errors caused by incorrect preparation or incorrect number of *Lycopodium* tablets added, cannot explain such high influx values. One might assume it to be a local effect caused by (1) a prevailing wind pattern which creates high levels of pollen falling on the fen, or (2) water currents or streams which concentrates pollen locally. These situations either alone or combined are only assumptions of what may be the causative factors for the anomalous influx values from this locality.

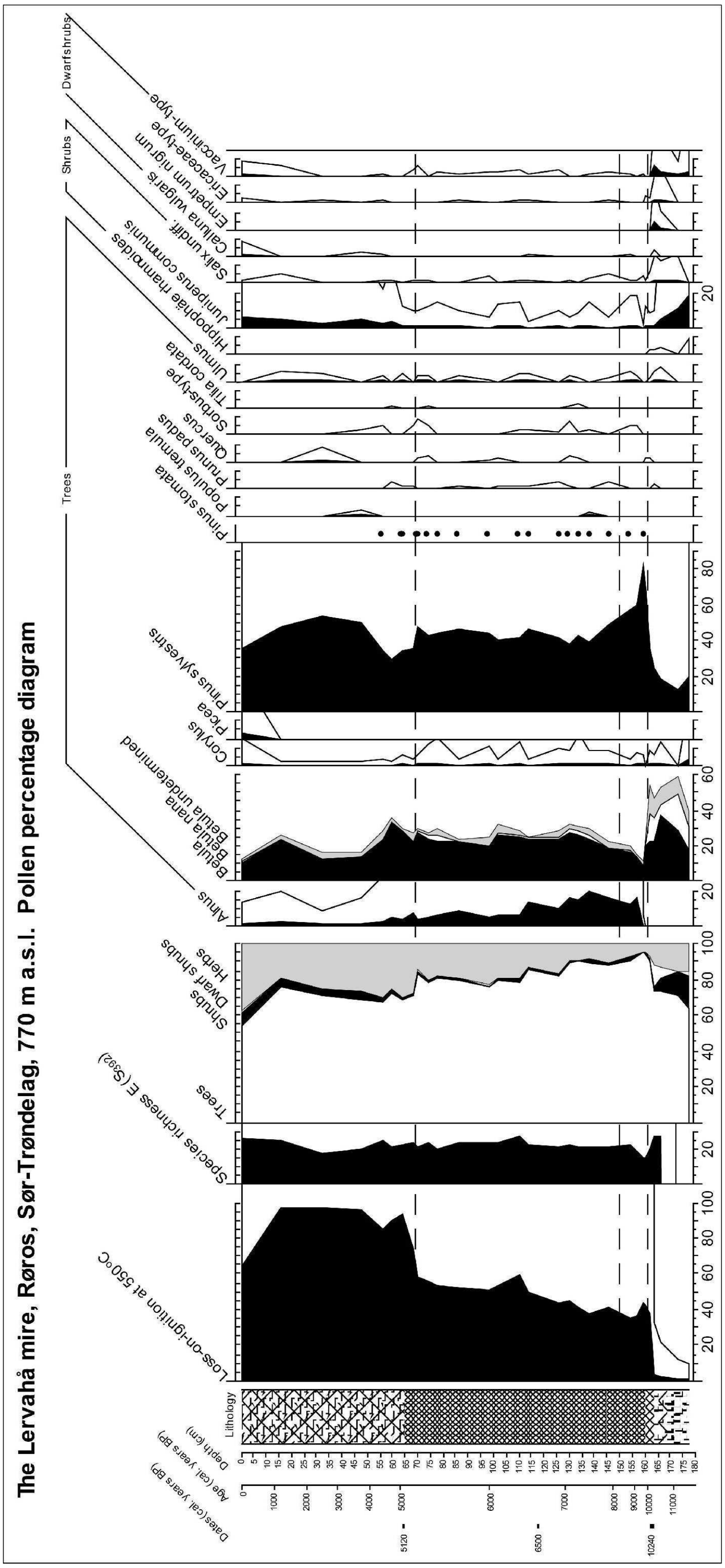


***Figure 4.3:*** *The pollen percentage diagram for the Lervahå mire. A selection of pollen taxa are represented in the diagram. Maximum probability values of the calibrated dates, litostratigraphy, LOI and palynological richness (PR) values are displayed furthest to the left. The solid curves in the diagrams represents the percentage values, whereas the hollow silhouettes denotes the same values exaggerated by a factor of 10.Stomata are presented as presence/absence. Local pollen assemblage zones are denoted by the stippled line (see Fig. 4.4 continued for the LPAZ names). A total percentage diagram for the Lervahå mire is given in Appendix C.*

***Figure 4.3** continued*

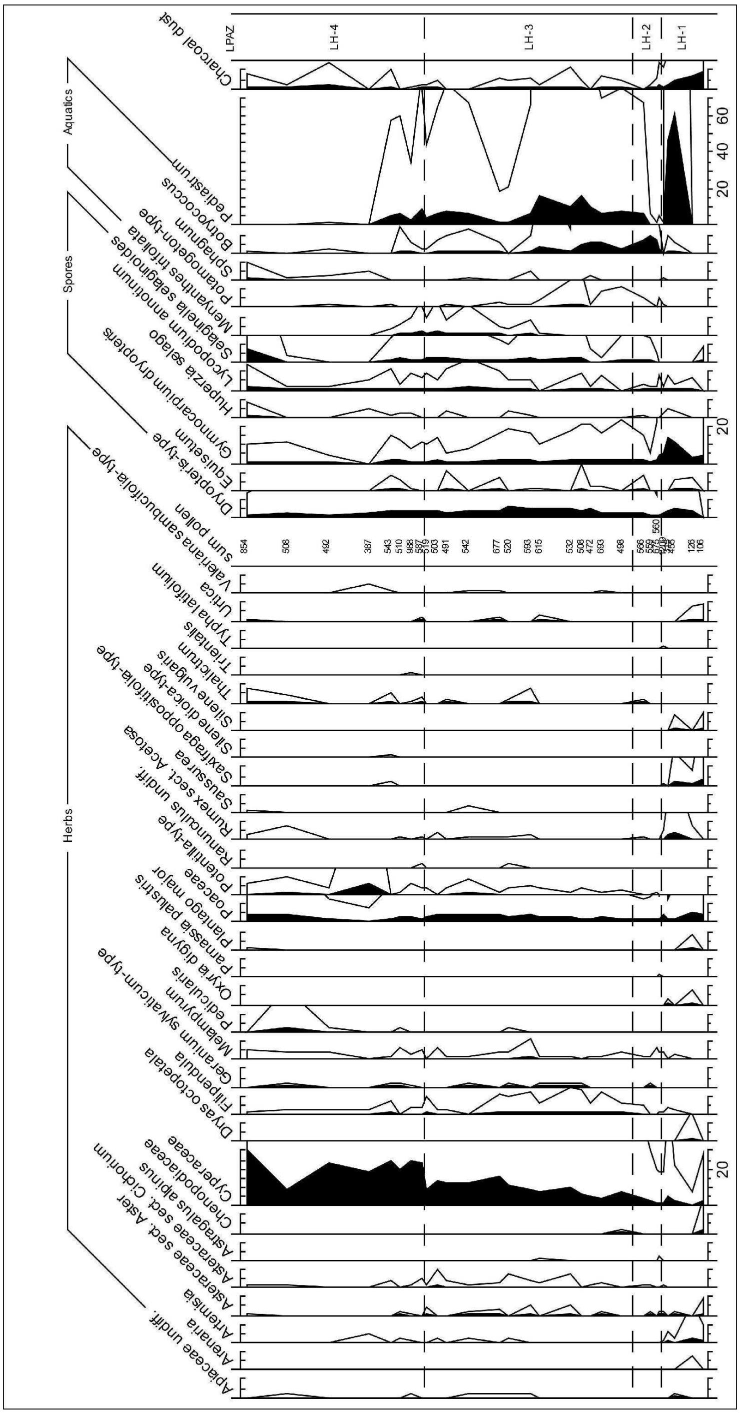
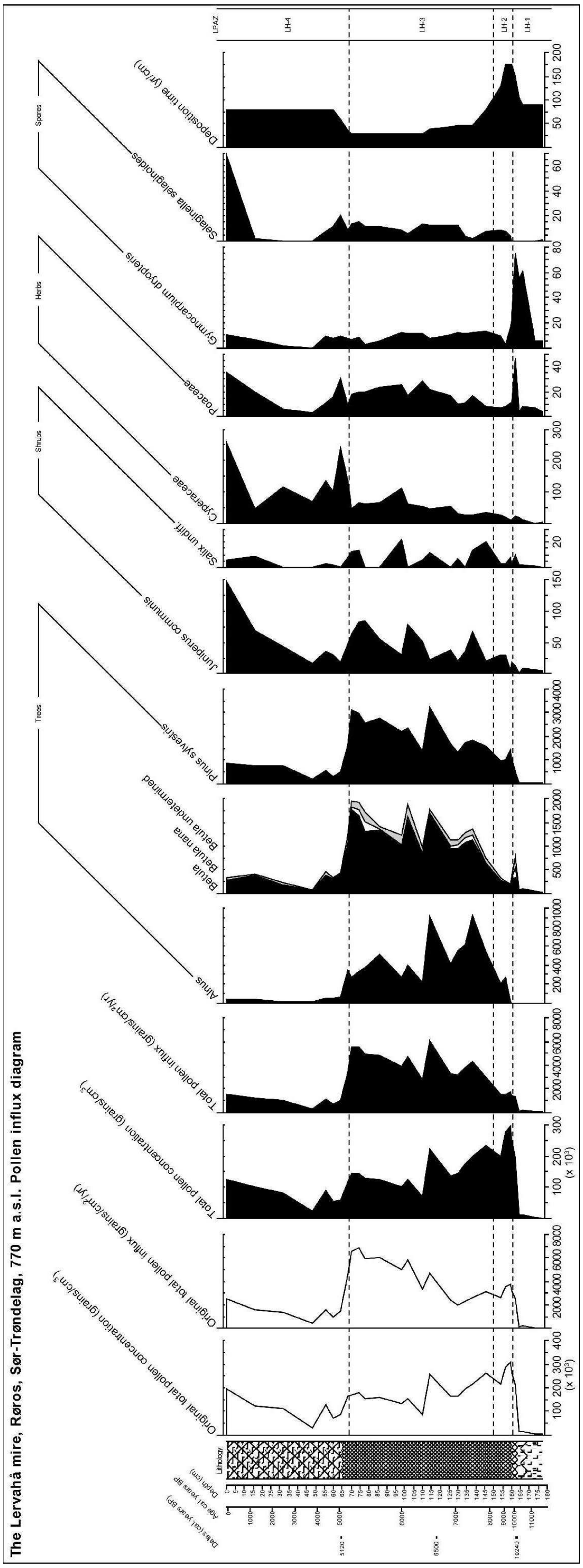


***Figure 4.4:*** *The pollen influx diagram for the Lervahå mire. A selection of pollen taxa are represented in the diagram. Maximum probability values of the calibrated dates, litostratigraphy, original and modified total pollen influx and concentration curves are displayed furthest to the left. The solid curves in the diagrams represent the pollen influx values. Local pollen assemblage zones are denoted by the stippled line and their names are displayed furthest to the right.*



### 4.2.1 The Lervahå mire (770 m a.s.l.)

**LPAZ LH- 1 (*Betula – Hippophäe – Juniperus* zone, 177 – 161 cm, ca. 11,500 – ca. 10,000 cal. years BP)**

The five lowermost pollen spectra are included in this zone. LOI values are low throughout the zone, except for the rapid increase from 3 to ca. 40 % in the upper part. The zone is characterized by the high percentage values of tree- birch, which maximum value of nearly 40 % is recorded at 166 cm. This, on the other hand, is not recorded in the influx values. They show stable low values varying between 2 and 10 pollen grains cm $^{-2}$ year $^{-1}$, except for an increase to180 pollen grains cm $^{-2}$ year $^{-1}$ at 162 cm. *Corylus* reaches its maximum value of 4 % in the lower most sample but decreases in value upwards in the zone. The pine percentage and influx values are low and show a similar pattern except for a dramatic increase towards the upper zone boundary.

The only occurrence (less than 1 %) of the pioneer shrub *Hippophäe* is recorded in this zone. According to the percentage diagram all shrubs (*Salix*, *Juniperus* and *Hippophäe*) and dwarf shrubs (*Betula nana*, Ericaceae, *Vaccinium* and *Empetrum*) have their maximum values in this zone. However, their values suddenly decrease to very low values and/or disappear towards the zone boundary. This trend is clearly recorded for *Juniperus* in the percentage diagram, which peaks with 18 % in the lower most sample, but falls markedly to 1 % in the end of the zone. Though, the influx values do not show the same pattern for light-demanding shrub as its lowest values for the entire Holocene period is recorded in this zone. *Betula nana* is present throughout and has a maximum percentage value of 20 % in the beginning of the zone. This maximum is, on the other hand, not recorded in the influx diagram. A Poaceae maximum of 6 % is detected in the lower part of this zone at 173 cm. Nor this corresponds with the influx diagram, which shows low values of Poaceae except for in the very end of the zone. In brief, the total pollen concentration and influxes are recorded at their lowest values within this zone.

The pioneers *Arenaria*, *Dryas octopetala*, *Plantago major* and *Silene vulgaris* and *Sedum* are all characteristic pioneer taxa that only occur in this zone. A single pollen tetrad of *Typha latifolium* is recorded in the uppermost spectrum. The maxima of *Artemisia*, Chenopodiaceae, *Rumex sect. Acetosa*, *Saxifraga oppositifolia*, *Urtica*, *Gymnocarpium dryopteris* and the green algae *Pediastrum* are recorded within this zone.

The Holocene species richness maximum occurs in this zone (27). However, a distinct fall in the species richness occurs towards the upper zone boundary.

### LPAZ LH- 2 (*Alnus* - *Pinus* zone, 161-150 cm, ca. 10,000 – ca. 8,000 cal. years BP)

The lower part of the zone is characterized by a maximum peak in tree-pollen (AP), which at 159.5 cm makes up as much as 95 % of the pollen sum. At the same time, the total pollen concentration reaches its maximum value for the entire Holocene period.

The first occurrence of *Alnus* is recorded at 159.5 cm in this zone (ca. 9,700 cal. years BP). However, its values increase from nearly1 to 16 % around 9,200 cal years BP (157 cm). Another characteristic feature for the zone is a major increase in pine pollen percentage exceeding 80 % around 9,700 cal. years BP. This is the maximum recorded value for pine throughout the percentage diagram. Its influx values show similar trends but maximum values are reached in the next zone. Pine stomata are recorded for the first time in this zone at 159.5 cm. As pine rises, both percentage and influx values of tree-birch decreases.

Poaceae has a stable value around 2 %, whereas the values of Cyperaceae show a stable, although small, increase towards the zone boundary. *Botryococcus* increases quickly from 2 % to its maximum value of 9 % in the lower parts of the zone.

In correspondence to the strong increase in AP, an equivalent decrease in species richness is recorded in the lowest part of the zone. This is the lowest value of species richness recorded for the entire diagram. Towards the zone boundary, the species richness increases to higher values.

### LPAZ LH- 3 (*Alnus*- *Betula*- *Pinus* zone, 150-69 cm, ca. 8,000 – 5,200 cal. years BP)

This zone is characterized by minimum values of shrubs and dwarf shrubs throughout. *Alnus* maximum (20 %) is recorded in the lower part at 138 cm (ca. 7,400 cal. years BP), after which it gradually decreases to about 4 % in the last part of the zone. Similar patterns are recorded for tree-birch and pine in the influx diagram, in which both taxa have their maxima. Tree-birch reaches the highest value at 70 cm with 1,800 pollen grains cm $^{-2}$ year $^{-1}$and pine with 3,200 pollen grains cm $^{-2}$ year $^{-1}$ at 114 cm. High stable values for both taxa are also recorded in the percentage diagram. Pine stomata are found in all zone spectra except for 102 and 68 cm depth.

*Betula nana* increase in value in both the percentage and influx diagram in the lower and upper part of the zone. The influx diagram shows a *B. nana* maximum with ca. 200 grains cm $^{-2}$ yr$^{-1}$ at 78 cm.

The percentage and influx diagrams both show increasing values in both Poaceae and Cyperaceae. Apposed to the percentage diagram, Poaceae has its maximum influx value in this zone. *Asteraceae* sect. *Cichorium*, *Filipendula*, *Melampyrum* and *Saussurea* all reach their maximum value in this zone. Together with Cyperaceae and Poaceae, these constitute the main herb taxa in this time period.

All aquatic taxa are represented in this zone. *Potamogeton*-type reaches its maximum value in the beginning of the zone. *Menyanthes trifoliata* occurs for the first time and is present in the entire zone starting from the middle at 114 cm. Around the same time, the *Dryopteris*-type reaches its maximum values with nearly 40 %.While *Gymnocarpium dryopteris* and *Selaginella selaginoides* show more or less stable values for the whole zone.

The species richness value is relatively stable throughout the zone, with the exception of a small peak of nearly 27 at 110 cm. At about the same time, the percentage diagram records a slight drop in AP with ca. 7 %.

### LPAZ LH- 4 (*Betula- Pinus-Juniperus-Cyperaceae* zone) 69-0 cm, 5,200 cal. years BP – present)

A strong increase in LOI from around 60 and up to ca. 90 % occurs in the lowest part of the zone. LOI are maintained at high levels until a distinct decrease in the uppermost spectrum, going from ca. 95 to ca. 65 % at present times. The percentage diagram shows the highest value of herbs in this zone in comparison to any of the previous ones. However, the overall pattern for the zone is a gradual increase in trees and shrubs from the zone boundary and up to 16 cm. Thereafter trees decline with 20 %, whilst shrubs and dwarf shrubs continue to increase towards present times. Pine stomata are not recorded after 56 cm (ca. 4,400 cal. years BP).

The lowest values of *Alnus* are recorded in this zone as it reaches 1 % in the upper part. The lower part of the zone is characterized by a 10 % increase in tree-birch and a correspondingly 5 % decrease in pine. Apart from this, a strong dominance in pine is recorded in the percentage diagram. In addition, pine stomata are recorded at both 64 and 56 cm. Both tree-birch and pine show a decrease towards present times. Their influx values do not reveal the same trend as they are significantly lower in this zone compared to the previous local assemblage zone. *Picea* is for the first time recorded in the uppermost spectrum with 4 %.

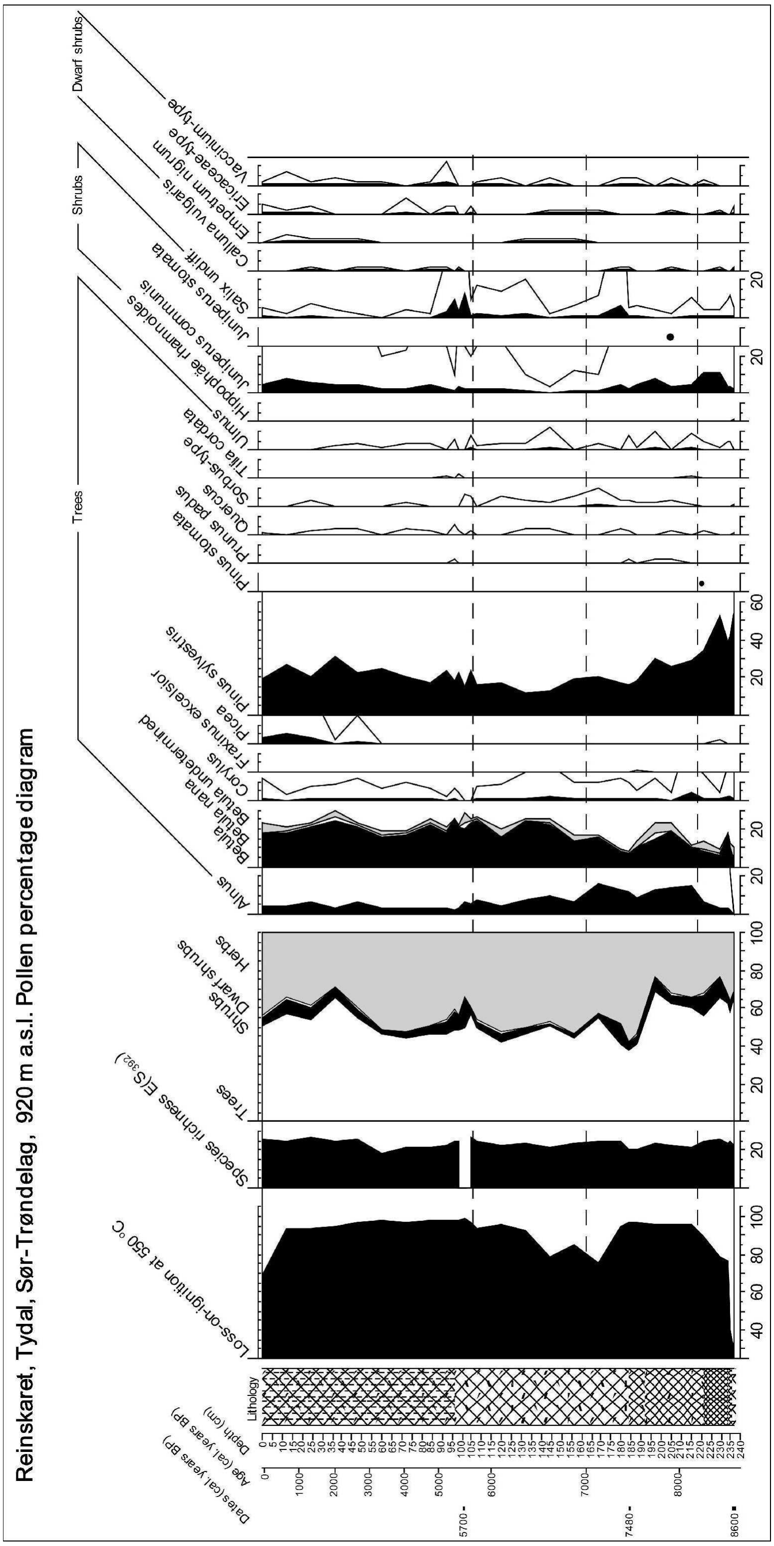
A gradual increase in *Juniperus* from the lower part of the zone and up to present times is recorded in both the percentage and influx diagrams. At the zone boundary, Cyperaceae increases with nearly 15 % compared to zone below. Apart from a sharp decline with 15 % at 16 cm, the highest values for Cyperaceae are recorded in this zone in the percentage diagram. This trend is, however, not recorded in the influx diagram as the overall recorded influx values for Cyperaceae (with the exception of a Cyperaceae maximum at 68 cm) are higher in the previous local assemblage zone.

Other characteristic features for this zone are the maxima of *Potentilla*, *Pedicularis* and *Valeriana.* A *Selaginella selaginoides* maximum at present times is recorded in both the percentage and influx diagram.

All aquatic taxa disappear in the upper part of the zone, except from *Sphagnum*, which increases to maximum values.

At 32 and 48 cm the species richness decreases compared to the other spectra within the zone. The highest value in species richness is recorded in the uppermost spectrum. Apart from this, there are no dramatic changes in the estimated values of species richness in this zone.

***Figure 4.5:*** *The pollen percentage diagram for Reinskaret. A selection of pollen taxa are represented in the diagram. Maximum probability values of the calibrated dates, litostratigraphy, LOI and palynological richness valyes are displayed furthest to the left. The solid curves in the diagrams represents the percentage values, whereas the hollow silhouettes denotes the same values exaggerated by a factor of 10.Stomata are presented as presence/absence. Local pollen assemblage zones are denoted by the stippled line (see Fig. 4.5 continued for the LPAZ names). A total percentage diagram for Reinskaret is given in Appendix C.*



***Figur 4.5** continued*

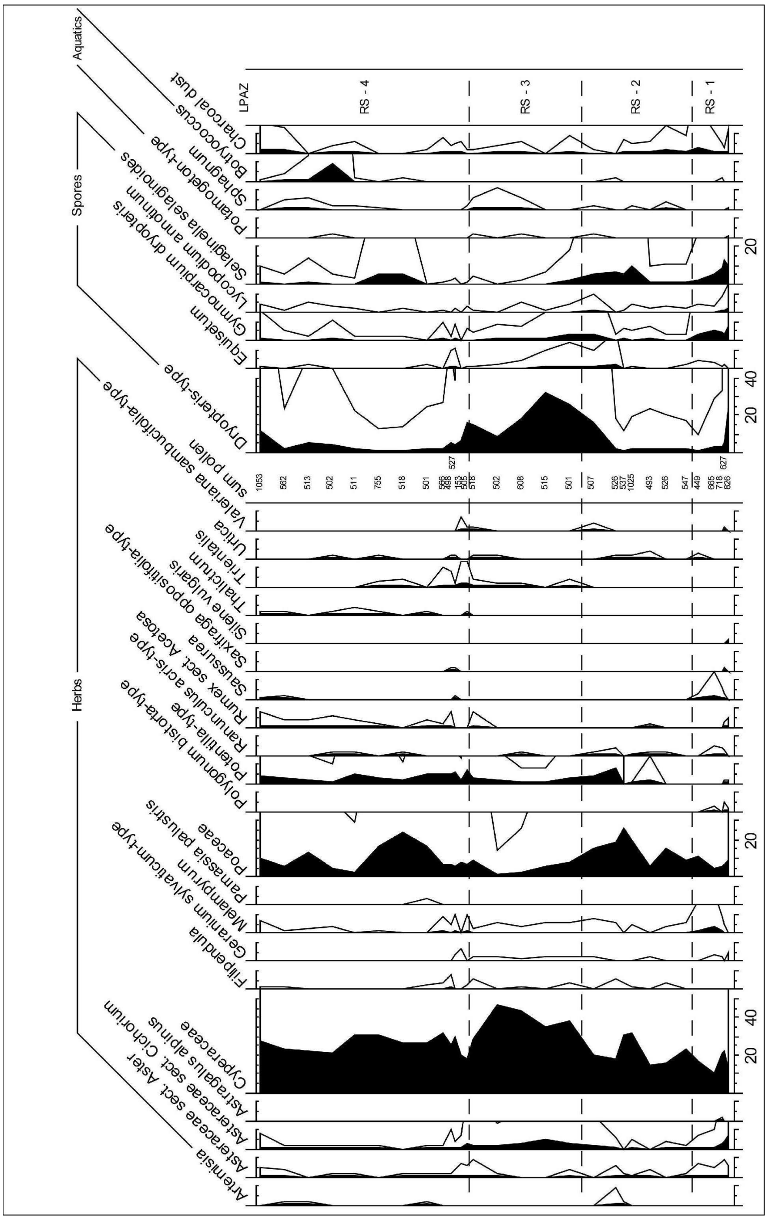
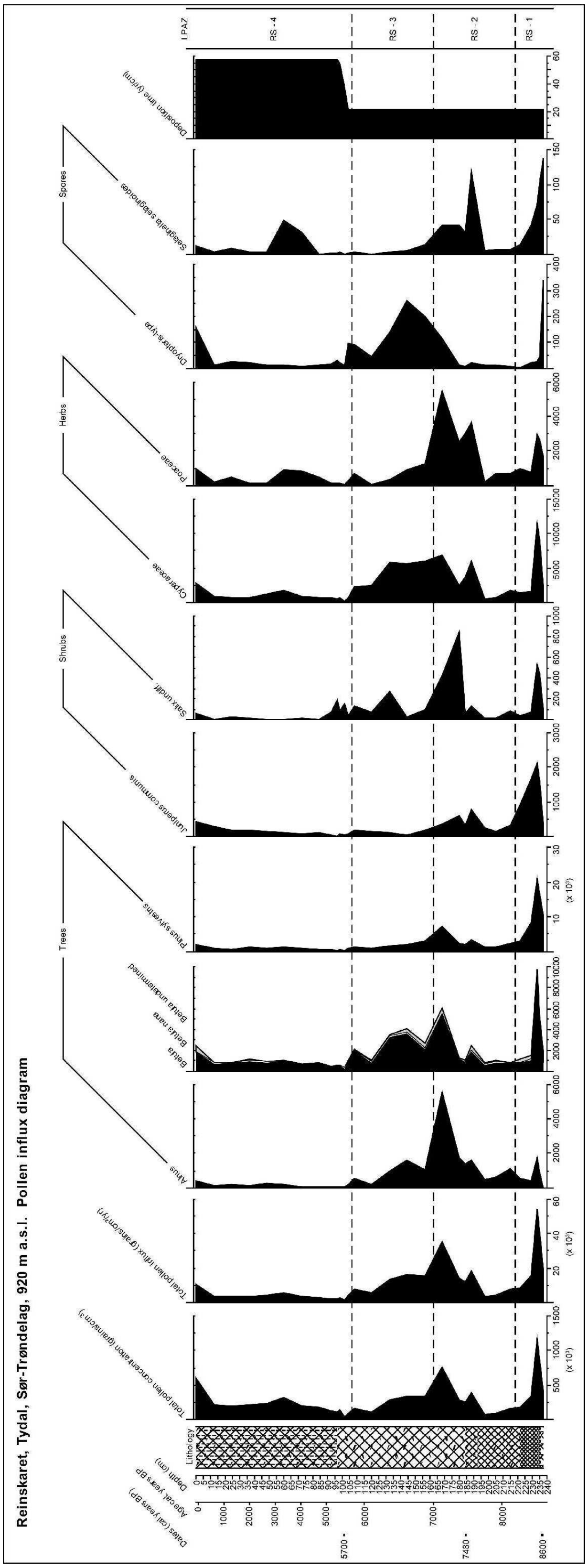


**Figure 4.6:** *The pollen influx diagram for Reinskaret. A selection of pollen taxa are represented. Maximum probability values of the calibrated dates, litostratigraphy, original and modified total pollen influx and concentration curves are displayed furthest to the left. The solid curves in the diagrams denote the pollen influx values. Local pollen assemblage zones are denoted by the stippled line and their names are displayed furthest to the right.*



### 4.2.2 Reinskaret (920 m a.s.l.)

**LPAZ RS - 1 *Pinus- Juniperus* zone, 237-218 cm, 8,600- 8,200 cal. years BP)**

This zone is characterized by a strong LOI increase from 60 to 90 % at the end of the zone. *Alnus* is for the first time recorded at 235 cm (around 8,600 cal. years BP). According to the percentage diagram, pine is the dominating tree in this zone and its maximum value (55 %) is recorded in the lowermost sample. At the same time as tree-birch peaks to 16 %, pine percentages decreases. This decrease is rapidly followed by a new peak in pine at 229 cm. The only Holocene occurrences of pine stomata at Reinskaret are recorded in this zone at 221 cm (ca. 8,300 cal years BP). In contrast to the percentages, the tree-birch influx reaches a maximum value in the peak at 233 cm. In addition, the maximum influx value of pine is not recorded before the second peak at 229 cm. At the same depth, *Picea* is present by a single pollen grain.

*Hippophäe* is as well present just by a single grain in the lowermost sample in this zone. *Juniperus* reaches maximum values (11 %) in the upper part, although the maximum is recorded earlier in the influx diagram compared to the percentage diagram. Cyperceae and Pocaeae are found at relatively low percentages in this zone compared to the other zones in the diagram. On the contrary to the percentage records, Cyperaceae influx values reach a maximum in the early phase of the zone.

*Polygonum bistorta*-type, *Silene vulgaris* and *Astragalus alpinus* are not recorded in any other zone but this one. *Melampyrum, Saussurea* reach their highest values in the middle of the zone. *Gymnocarpium dryopteris, Dryopteris*-type and *Selaginella selaginoides* are all abundant in the early part, but decreases towards the zone boundary.

The species richness values show no major changes within this zone.

**LPAZ RS - 2 (*Alnus-Pinus*-Poaceae zone, 218-162 cm, 8,200- 7,000 cal. years BP)**

LOI values are stable around 96 % until a sudden decrease to 75 % in the upper part of the zone. The beginning of the zone is further characterized by the highest recorded AP percentages throughout the diagram, in addition to a *Corylus* maximum of 4 %. *Alnus* strongly increases starting from the zone boundary and reaches its maximum of 16 % at 168 cm. The percentage diagram shows an increase in tree-birch compared to the previous zone. Pine has a general decreasing trend towards the end of the zone. The values for *Juniperus* are lower in this zone compared to LPAZ RS-1. However, one *Juniperus* stomate is recorded at 205 cm.

A marked fall in AP from 60 to 40 % (ca. 7,500 cal. years BP) is recorded in the middle of the zone. Just before the tree-birch falls to its lowest values within the entire diagram, *Betula nana* reaches its maximum value of 3 %. Simultaneously with the drop in AP, Cyperaceae increases together with Poaceae which reaches its maximum value in this zone. *Salix, Artemisia* and *Potentilla*- type peak slightly after, but decreases or disappear towards the zone boundary. *Equisetum, Gymnocarpium dryopteris, Lycopodium annotinum, Dryopteris*-type and *Selaginella selaginoides* all increase in the upper part of the zone.

The peak in *Salix* in the upper part of the zone is recorded as a *Salix* maximum in the influx diagram. This is however not in correspondence with the percentage diagram. Additionally, the influx diagram has higher values of tree-birch and pine in the upper part of the zone, which is the opposite of what is recorded in the percentage diagram. Apart from these exceptions, the overall vegetation patterns recorded for this zone in the influx diagram coincide with those recorded in the percentage diagram.

Apart from a slight decrease at the same time as the AP decreases, the species richness curve has an upward increasing trend in this zone.

### LPAZ RS - 3 (*Betula – Cyperaceae – Dryopteris*-type zone, 162-106 cm, 7,000- 5,800 cal. years BP)

The LOI varies between ca. 75 and 96 %, but stabilizes around 90 % towards the upper boundary. This zone contains the maximum values of herbs, which in some parts reach values slightly above 50 %. Shrubs are found at low values throughout the zone, and especially in the lower part. The zone is further characterized by a gradual decrease in *Alnus*. Tree-birch increases upwards to about 20 % and is the overall dominating tree species in the zone, whereas pine varies between values of 12 and 19 %. These are the lowest values recorded for pine in the entire diagram. Except for tree-birch having lower values in the upper part of the zone, similar trends for tree-birch, pine and *Alnus* are recorded in the influx diagram.

*Juniperus* has low values throughout (1-2 %), and almost disappears in the middle of zone. *Salix* shows a similar pattern. *Asteraceae* sect. *Cichorium* is recorded at relatively high percentages throughout the zone, and reaches its maximum value of 5 % at 144 cm. A maximum in *Dryopteris*-type is recorded for the same depth.

In contrast to the influx diagram, Cyperaceae is recorded at its maximum value (47 %) in the percentage diagram at 120 cm in this zone. Poaceae reaches at the same time its lowest Holocene values.

There are no major changes in species richness in this zone, except for a slight decrease in value (24-21) at 144 cm.

**LPAZ RS - 4 (*Betula* – *Pinus* – *Cyperaceae*, 106-0 cm, 5,800 cal. years BP- present)**
The zone is characterized by a high and stable LOI, except in the uppermost part of the zone, showing a decrease from ca. 90 to 70 %. AP percentages reach between 66 and 45 % in this zone. Both influx and percentage values show similar trends throughout the zone for tree-birch and pine. There is, however, a lack of correspondence between the influx and percentage diagrams in regard to the abundance of the two tree species in the zone. According to the influx diagram, this zone contains the lowest values in the entire diagram for tree-birch and pine. Conversely, the percentage diagram s records high values for both taxa more or less through the whole zone. *Picea* is recorded continuously up to present times starting from 48 cm (ca. 2,700 cal. years BP).

The highest values of shrubs (16 %) and dwarf shrubs (2 %) in the entire diagram are recorded within this zone at 101 and 92 cm, respectively. *Juniperus* increases upwards in the zone, but has a slight decrease in percentages towards present times. The influx diagram, on the other hand, shows a continuous increase in *Juniperus* throughout the zone. A *Salix* maximum is recorded in the beginning of the zone in percentage diagram. Poaceae and *Selaginella selaginoides* peaks around 72 cm, followed by a sudden peak in *Botryococcus* at 36 cm. Except for a decrease at the lower zone boundary, Cyperaceae is recorded at stable values around 20-30 %.

The largest difference in species richness is recorded within this zone, ranging in average values between 18 and 24.

## 4.3 Gradient analysis by indirect ordination

### 4.3.1 Detrended Correspondence Analysis (DCA)

The results from the DCA analysis are shown in Table 4.5. As the gradient length (1.669) is less than 2 SD the DCA results reveal a linear response of the plant species to the environmental gradients (ter Braak, 1987; ter Braak and Prentice, 1988). Based on these results it was decided to analyse the data set by PCA.

***Table 4.5**: The results of the DCA analysis performed on a total data set*

| **Axes** | **1** | **2** | **3** | **4** |
|---|---|---|---|---|
| **Eigenvalues** | 0.147 | 0.064 | 0.052 | 0.038 |
| **Lengths of gradient** | 1.669 | 1.225 | 0.914 | 1.122 |
| **Cumulative % variance of species data** | 12.9 | 18.5 | 23.1 | 26.4 |

### 4.3.2 Principal component analysis (PCA)

The PCA results are shown in Table 4.6. The composite information within a species data set contains a lot of variation between the variables (i.e. pollen and spore taxa). In ordination, the aim is to capture as much of the variance as possible along a few ordination axes (ter Braak, 1987). The eigenvalues express the amount of variation which is being intercepted by the different axes. The values are given in a number between 0 and 1, in which values above 0.5 are considered significant, whereas values below 0.1 hardly explains any of the data set variation (ter Braak, 1987). The axis which captures the maximum variation from the species data set is called the first ordination axis.

According to Table 4.6, the PCA results show that the first ordination axis explains 27.6 % of the total variation within the data set. Together with the second ordination axis, 44.1 % of the variance can be explained. Since the last two axes together only explain another 18 % of the variation, the interpretation of the PCA results will be based only on the first two ordination axes. It was found most convenient to give a sub interpretation of the PCA species plot in this section together with its description.

***Table 4.6****: The results of the PCA analysis performed on a total data set*

| **Axes** | **1** | **2** | **3** | **4** |
|---|---|---|---|---|
| **Eigenvalues** | 0.276 | 0.164 | 0.102 | 0.080 |
| **Cumulative % variance of species data** | 27.6 | 44.1 | 54.2 | 62.2 |

Fig. 4.7 shows the species distribution along the PCA ordination axes. Species with long vectors are assumed to represent high proportions of the variation within the plot. The directions of the vectors indicate the correlation between the species. Species which are placed in the same direction show similar patterns in the diagram and correlate with each other, whereas species placed in opposite directions are negatively correlated.

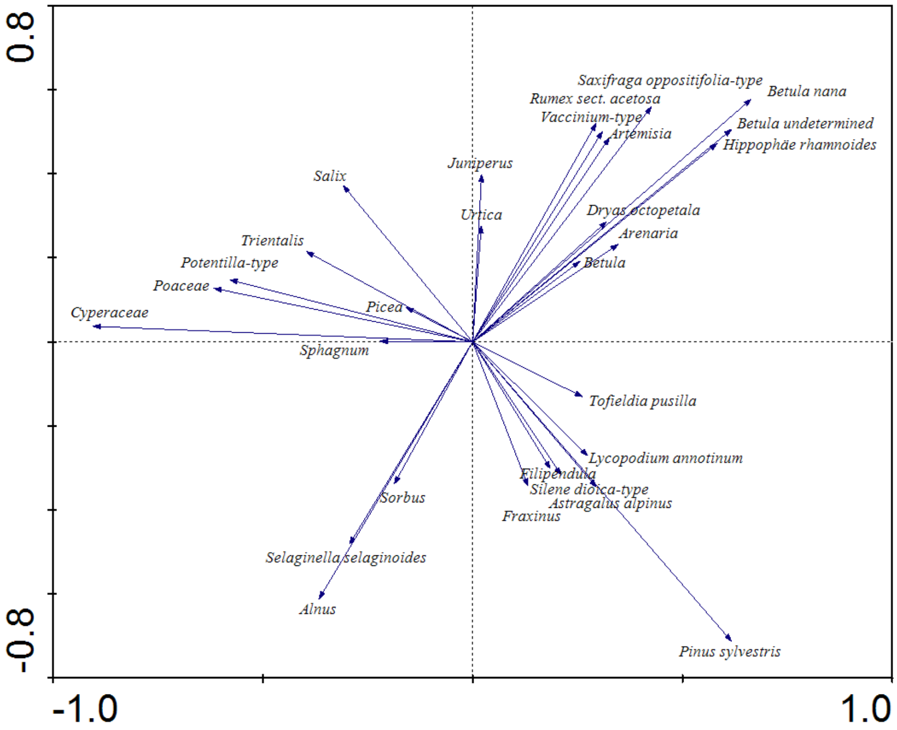


***Figure 4.7****: Results of the PCA ordination analysis performed on the total data set. The PCA plot shows the species distribution along the two gradient axes.*

The upper right corner of the PCA species plot (Fig. 4.7) is characterized by an assemblage of light-demanding pioneer taxa (e.g. *Rumex sect. Acetosa*, *Artemisia*, *Oxyria*, *Hippophäe*) which thrives on poor developed and minerogenic soils (Lid and Lid, 2005). *Pinus*, *Fraxinus* and *Silene dioica* which are often found in more closed, competitive and forested environments are placed further down on the right side of the plot. *Alnus*, *Selaginella selaginoides* and *Sorbus* are assembled together on the lower left side of the first axis. These commonly grow in more open and moist environments. The assemblage of e.g. *Dryopteris*-type, Cyperaceae, *Salix*, *Picea* and *Potentilla*-type seems to reflect a moister and more open environment.

Based on the species distribution within the PCA plot, the horizontal first axis might reflect a moisture gradient. The more moist demanding species seem to gather on the left side of the axis, whereas species growing under drier conditions are placed further to the right. The vertical second axis, on the other hand, appears to represent a gradient of vegetation density. The most open conditions seem to be represented by the shadow intolerant pioneer species congregated in the upper part of the plot. Hence, the degree of vegetation density increases downwards along the axis.

Fig. 4.8 and 4.9 show the pollen sample distribution along the PCA ordinations axes. As for the species distribution, the position of pollen spectra can be interpreted in terms of the same environmental gradients. The age of the pollen spectra increases with the numbers, meaning that pollen sample 1 in Fig. 4.8 represents present times. See the local pollen assemblage zone descriptions (section 4.2) for a more thorough interpretation of the PCA sample plots.

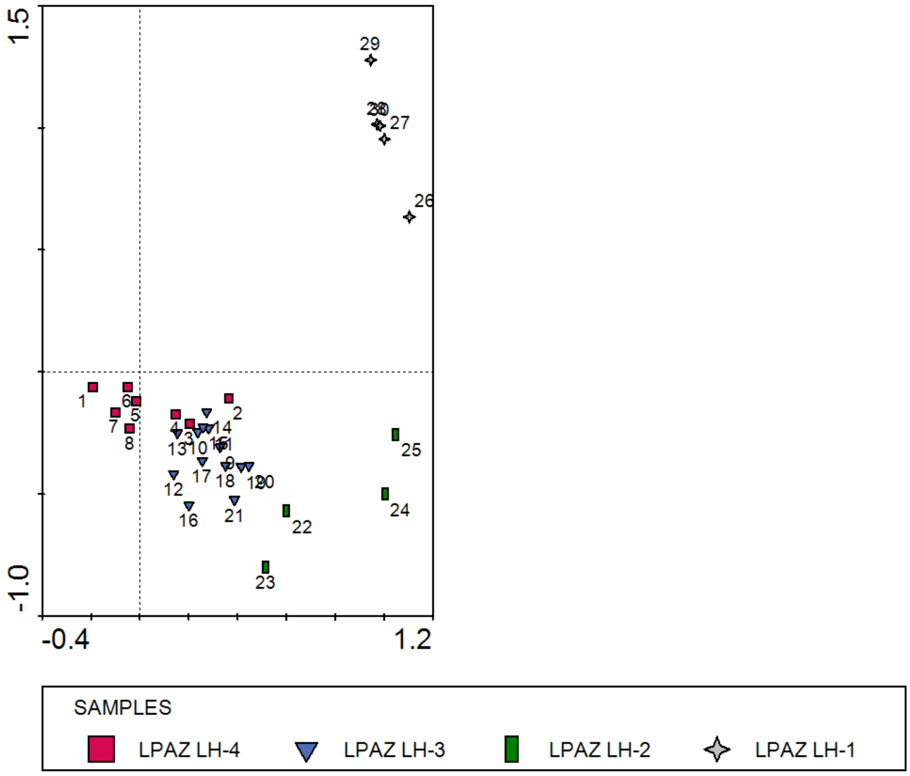


***Figure 4.8**: PCA analysis plot of the pollen spectra from the Lervahå mire. Each local pollen assemblage zone has been given an own symbol. The pollen spectra are numbered from 1 to 30, in which 1equals present times and 30 the oldest analysed spectrum.*

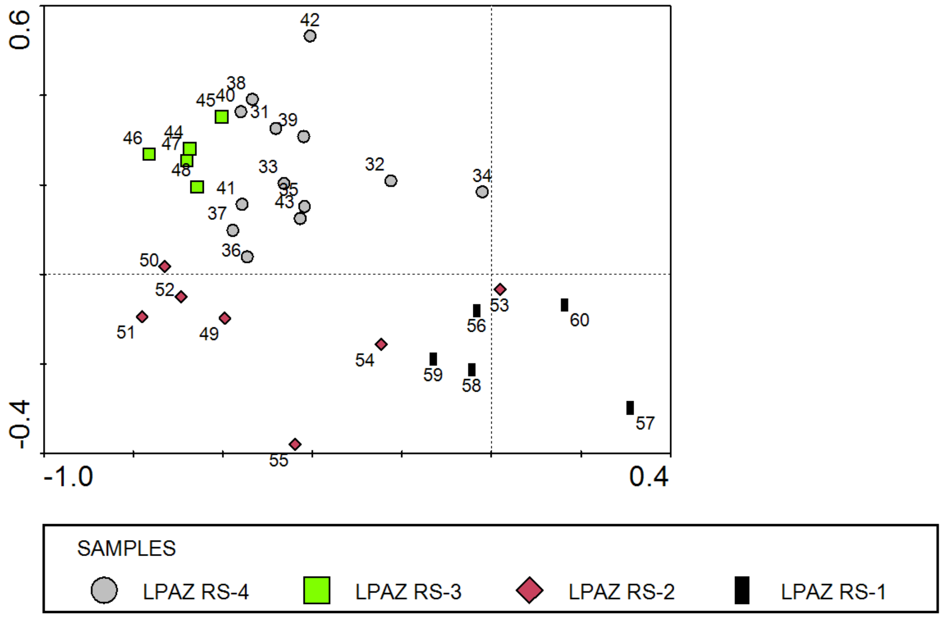


***Figure 1.9**: PCA analysis plot of the pollen spectra from Reinskaret. Each local pollen assemblage zone has been given an own symbol. The pollen spectra are numbered from 31 to 60, in which 31 equals present times and 60 the oldest analysed spectrum.*

# 5 Interpretation

The paleoecological records from the study site are being interpreted based on the pollen percentage and influx diagrams, total concentration data, dates of megafossil finds of birch and pine, and the statistical results provided by the gradient and palynological richness (PR) analyses. The interpretations and reconstructions of past vegetation are inferred by reconstructing pollen assemblages, which may further be interpreted into past plant communities (Janssen, 1967). The ordination of data facilitates the expression of underlying vegetational patterns and ecological gradients.

To infer the climate history at each site (more detailed in ch. 6.2) the indicator species approach is used (Iversen 1954). Assuming that the climate requirements of plants have not changed within the Holocene, the presence of certain indicator species can indicate minimum values of mean July temperatures in the past. Pollen analyses in peat sequences provide records of the local vegetation and climate conditions of the study sites. Nevertheless, entomophilous herbs and aquatic plants are considered to signal local features than anemophilous trees and shrubs, which may represent more regional climate conditions (Iversen, 1954). However, local climate reconstructions are vulnerable to long-dispersal pollen transportation when the local presence of an indicator species cannot be accounted as certain (Birks, 1993). The main focus of the Holocene climate reconstructions will be on temporal changes in temperature and humidity.

The high influx values at Reinskaret prevent the use of threshold influx values differentiating between major vegetation types within Fennoscandia (e.g. Hicks, 1994; Jensen et al. 2007; Seppä and Hicks, 2006). Hence, to avoid any misinterpretations of the influx estimations, I have chosen not to include the influx records in the interpretation of the past local vegetation at the Reinskaret locality. Consequently, the interpretation of the Reinskaret records will exclusively be based on the pollen percentages, stomata and megafossil records.

As for the Lervahå mire sequence, the statistical validity of two lowermost analysed spectra may be disputable as their pollen sums are less than 150 pollen grains. Nevertheless, these are merely meant to be “snapshots” of the first establishing vegetation at the locality after the withdrawal of the ice sheet.

## 5.1 The Lervahå mire (770 m a.s.l.)

### LPAZ LH– 1 (*Betula – Hippophäe – Juniperus* zone, 177 – 161 cm, ca. 11,500 – ca. 10,000 cal. years BP)

The highly minerogenic sediments (Table.4.1) seem to reflect an early Holocene pioneer stage on unstable, mineral and alkaline soils (cf. glacial deposits), which gradually became eroded and washed into the basins. A total pollen influx less than 120 grains $cm^{-2}$ $yr^{-1}$, indicates a sparse vegetation cover. The plant community was dominated by pioneers such as *Artemisia, Arenaria, Rumex* sect. *Acetosa* and *Plantago major*. Dwarf willows (presumably *Salix herbaceae*) were growing in snow beds together with the other pioneers *Saxifraga oppositifolia* and *Oxyria* (Lid and Lid, 2005). Whereas *Betula nana* and *Vaccinium* spp. were present further up in the leesides. In the early pioneer stages, the lime-demanding *Dryas* was presumably growing on exposed ridges (Lid and Lid, 2005). As the soils on the ridges became richer in humic acids, a subsequent rise in the acidiophilic *Empetrum* occurred (Lid and Lid, 2005). The recorded increase in the more humus demanding *Ericaceae* taxa, in addition to the increase in organic soil content in the last part of the zone may thus be an indication of the successional stage towards productive and developed soils (Gunnarsdóttir, 1996).

The heliophilous pioneer shrub *Hippophäe rhamnoides* is commonly regarded as a relict of the incipient post glacial period (Gunnarsdóttir and Høeg, 2000; Hafsten, 1966) and a local indicator of the successive pioneer stages towards forested conditions (Paus, 2010). With its low pollen dispersal abilities, percentages of 0.5-1% may indicate that *Hippophäe* grew locally at the Lervahå mire in this period (Haftsen, 1966; Paus, 2010). In addition, *Juniperus* was most likely a common shrub which occurred locally in light-open areas on well-drained soils.

As the local pollen production was low, the high percentages of both tree-birch and pine were most likely a result of long distance dispersed pollen from adjacent areas in the region (Aario, 1940; Simonsen, 1980). Tree-birch and especially pine are known for their high pollen production and good dispersal abilities (Fægri and Iversen, 1989). As a result, they are commonly over-represented in the local pollen rain in low productive areas, such as the artic/alpine areas (e.g. Aario, 1940; Gajewski 1995; Hicks, 1994; Paus, 2000). Tree-birch reached the highest percentages in the early Holocene period, with nearly 40 % at ca. 10,500 cal. years BP. Pine, on the other hand, nearly reached 20 % within the same period. As indicated, for instance, by the presence of the green algae *Pediastrum*, the Lervahå mire was a small lake in the earliest period after the deglaciation. Lake sediments reflect more regional vegetation patterns compared to peat deposits (Fægri and Iversen, 1989; Birks and Birks, 1980). Hence, the high tree-birch percentages might suggest that tree-birch was the first tree to establish within the region of the Lervahå mire locality.

At the depth of 162 cm, the LOI increases from 3 to nearly 40 % and the sediments shift from clay/silt to gyttja. This occurs at ca. 10,200 cal. years BP (see Table 4.4). Although arctic-alpine areas may show long-distance pollen of tree-birch between 250 and 600 grains $cm^{-2}yr^{-1}$ (Hicks, 1994), a tree-birch influx around 300 grains $cm^{-2}yr^{-1}$ and a pine influx of nearly 500 grains $cm^{-2}yr^{-1}$ could indicate the first local establishment of the trees in the Lervahå area ca.10,100 cal years BP (Hicks, 1994; Jensen et al. 2007; Seppä and Hicks, 2006).

However, the analysed peat sequence contains large annual gaps as a result of the low number of analysed pollen spectra (only 30 spectra in total). An age gap of 300 years between the last two spectra in the LPAZ LH-1 therefore hardens the certainty of the inferred time period in which trees established at the Lervahå mire locality. In addition, there are no stomata or megafossil finds that can indicate any local presence of tree birch or pine at the locality within this period. The low resolution and tentative chronology impede the possibility of making any firm conclusions about the exact period in which the trees established at the Lervahå mire locality. A rather simultaneous establishment of birch and pine at the site around 10,100 cal. years BP could be interpreted from the pollen influx record (Fig. 4.5).

The increased influxes of both tree-birch and pine (Fig. 4.6) after ca. 10,100 cal years BP, together with the disappearance of the pioneer herbs, *Hippophäe*, *Juniperus* and Poaceae indicates a succession from late pioneer stages towards forested conditions. As the soils became more stable, less material was washed out into the basin, presumably causing improved light transparency in the water and favourable conditions for the growth of *Pediastrum* and *Botryococcus* (Fig. 4.3).

The PCA spectra are positioned in the right upper region characterized by the open pioneer vegetation on immature, minerogenic soils (Fig. 4.8). However, the spectra seem to represent a temporal change towards a denser and darker vegetation cover. The PR values reflect a similar trend as the earliest period was characterized by low interspecific competition causing a maximum in the PR values. However, the PR decreases towards the zone boundary, which might indicate a development towards denser vegetation and a higher degree of competition.

**LPAZ LH- 2 (*Alnus* - *Pinus* zone, 161-150 cm, ca. 10,000 – ca. 8,000 cal. years BP)**
The increased organic content including high frequencies of plant fragments in the soils (Table 4.1) suggests improved conditions and increased terrestrial and limnic organic production. The conditions seem to have become moister, as the field layer changed to dominant Cyperaceae, *Dryopteris*-type and *Gymnocarpium dryopteris*. The green algae *Pediastrum* and *Botryococcus* indicate the establishment of a basin with nutrient rich and open water. The regression of *Juniperus* could also indicate moister conditions, in addition to increasing shade.

The AP percentages in the early part of the zone indicate that trees established locally. Around 9,800 cal. years BP pine exceeded a 1,000 grains grains cm$^{-2}$ yr$^{-1}$, which in accordance to Vorren *et al*. (1996) suggests the presence of a local pine forest. Pine expands and becomes the dominant tree growing at the locality, causing more shade and interspecific competition within the forest. Stomata finds reflect the local presence of pine at ca. 9,700 and ca. 8,700 cal. years BP. Though, one cannot entirely rule out the probability long dispersal of smaller objects such as needles (Bergman *et al.*, 2005). The oldest pine megafossil found in eastern Jotunheimen by Lie and Sandvold (1997) was dated to ca. 10,200 cal. years BP. Hence, the stomata findings at ca. 9,700 cal. years BP from the Lervahå mire locality can therefore be assumed to be one of the oldest local indications of pine in Norway.

Ca. 9,700 cal. years BP the pine forest was at its maximum recorded density. This is indicated by the especially high pine values (%, influx), and lowest value of species richness recorded for the entire Holocene period at the Lervahå mire. However, the chronological uncertainty, and hence influx estimations, makes it difficult to infer an exact time period for the pine optimum at this locality. Nevertheless, around 9,200 cal. years BP pine had already become less dominant in the forest landscape and it never reached the same dominating position in the forest as previously recorded. This might suggest that pine had reached its highest level of forest dominance at the Lervahå mire locality in period between ca. 10,000 and ca. 9,200 cal. years BP. A decrease in ferns, Poaceae, Cyperaceae and the algae *Pediastrum* and *Botryococcus,* might indicate that conditions were drier between ca. 9,700 and 8,700 cal. years BP.

The earliest *Alnus* pollen grains are recorded ca. 9,700 cal. years BP. This was presumably the less warmth-demanding *Alnus incana,* which likely migrated into the region from the east

(Giesecke, 2005b; Tallantire, 1974; Paus, 2010). Alnus probably grew locally at the Lervahå mire at ca. 9200 cal. years BP (> 250 grains $cm^{-2}yr^{-1}$: Vorren et al. 1996).

The shift between darker and lighter layers in the forthcoming stratigraphical section indicates occurrences of erosion and soil disturbances in the subsequent period starting from about 9,200 cal.years BP. The recommenced occurrence of *Pediastrum* and *Botryococcus* around 8,700 cal. years BP, may suggest a rise in the water table, creating more open and favourable conditions for algae growth in the water basin. *Potamogeton*- type probably grew along the basin margin.

A simultaneous increase in Cyperaceae and *Selaginella*, may be additional indications of a shift to more humid conditions. The increased humidity, in addition to possible soil disturbances and erosions, made conditions less favourable for pine. The climatic and edaphic shifts made it possible for tree-birch and *Alnus* to expand their distributional limits within the region. An increase in *Juniperus* and the slight decrease in AP might thus indicate an opening of the vegetation, which perhaps was a result of the compositional shift from a closed pine forest to a more open mixed forest of *Alnus*, pine and tree- birch. *Melampyrum* and the nutrient and nitrogen demanding *Filipendula* were commonly growing on deeper and fertile soils in the forest openings.

The positioning of the pollen spectra within the PCA plot (Fig. 4.8) yields consistent patterns. Here, the positions of first spectra within the local pollen assemblage zone reflect the development into a dense pine forest on well-drained soils. The youngest spectra are positioned along the gradient axes reflecting a change into lighter and slightly more humid conditions.

The increased vegetation density is also reflected by the quickly decreasing PR values, reaching its minimum in this period and showing increasing interspecific competition (Fig. 4.3). The increase towards the end of the zone might indicate a thinning of the local forest canopy, enabling the re-establishment of more light demanding species at the Lervahå mire site.

### LPAZ LH- 3 (*Alnus- Betula- Pinus* zone, 150-69 cm, ca. 8,000 –ca. 5,200 cal. years BP)

An increased sedimentation and overall high pollen accumulation rate in Fig. 4.4 reflects a high local production and accumulation of organic material. The LOI (Fig. 4.3) shows a gradual increase in soil stability, although some fluctuations occur within the period.

At ca. 7,800 cal. years BP, the pine influx values above 2,200 grains cm$^{-2}$ yr$^{-1}$ indicate that pine is still the dominating tree in the forest landscape (Hicks, 1994; Jensen *et al*., 2007; Seppä and Hicks, 2006). Tree-birch and *Alnus* influx values of 1,200 grains cm$^{-2}$yr$^{-1}$ and nearly 500 grains cm$^{-2}$yr$^{-1}$, respectively, indicate an increasing representation of the trees within forest (Hicks, 1994; Jensen *et al.,* 2007; Seppä and Hicks, 2006; Vorren *et al*., 1996). The frequently recorded megafossil finds (see Table 4.7) and stomata findings also show the local occurrence of pine within this period. The oldest recorded pine megafossil on the Lervahå bog surface is dated to approx. 7,100 cal. years BP (Table 4.4).

Ca. 7,400 years ago, *Alnus* reached its maximum influx value of about 900 cm$^{-2}$ yr$^{-1}$. As tree-birch and pine were respectively represented by 1,100 and 1,800 grains cm$^{-2}$yr$^{-1}$, the forest had now become mixed showing a more even representation of tree species than previously (Hicks, 1994; Jensen et al. 2007; Seppä and Hicks, 2006). According to Hicks (1994), this reflects a forest composition at the transition to a birch forest with pine.

The thermophile *Corylus* and *Ulmus* were regionally present throughout the period. The broadleaved trees were most likely not growing locally at the site as their values are less than 2 % (cf. Prösch-Danielsen, 1999). However, their stable appearances in the pollen records are often considered as a regional signal of favourable climatic and edaphic conditions (Prösch-Danielsen, 1999; Paus, 2010).

*Betula nana* fluctuates in abundance within the zone, and is more frequently occurring near both zone boundaries. It is commonly found growing in snow beds, but might also grow on heaths and drier hummocks at the mire surface (Lid and Lid, 2005). Its presence might be reflecting higher amounts of snow or possibly the occurrence of more light-open areas. Except for *B.nana*, the shrubs and dwarf shrubs are hardly represented within this zone. On the other hand, herbs such as Poaceae, *Filipendula, Melampyrum, Asteraceae* sect. *Cichorium* (perhaps *Cicerbita alpina*) , *Valeriana, Apiaceae, Urtica* and the pteridophytes *Dryopteris*-type and *Selaginella selaginoides* increased in abundance within this period. This suggests a development towards a more humid and open forest landscape, with a nitrophilous tall-ferns and herbs field layer.

Conversely, the total pollen influx, as well as pine and tree-birch influx records are increasing compared to the previous periods. There is a decrease in the concentration around 6,300 cal. years BP, most likely as a result of the strong increase in sedimentation rate from ca. 6,500 to ca. 5,100 cal. years BP (AMS dates; Fig. 4.1). This increase might have affected the influx values. Nevertheless, the pollen records suggest an opening of the forest canopy, as signalled by the previously mentioned increase in e.g. *Juniperus,* Poaceae and Cyperaceae, along with the gradual decrease in AP. Although the local presence of pine is frequently recorded, the increase in tree-birch and *Alnus,* in addition to the moist and nutrient demanding herbs and pteridophytes, suggest less favourable conditions for pine growth at the Lervahå mire in this period.

After *Alnus* reached its maximum at ca. 7,400 cal. years BP, it gradually retreated to lower altitudes. *Menyanthes trifoliata* is often an indicator of swampy conditions (Paus *et al*., 1987) and increased in frequency around 6,300 cal. years BP. The additional increase in Cyperaceae and *Pediastrum* might also be indicating moister conditions, probably caused by increased precipitation and or/lower temperatures causing decreased evapotranspiration. Moreover, at ca. 6,300 cal. years BP the percentage value of 6 % (Vorren *et al*., 1996) indicates that *Alnus* had lost its local position and fully retreated from the Lervahå mire, making pine and tree-birch the two main constituents of the gradually retreating mixed forest.

In the PCA plot (Fig 4.8), the pollen spectra are still clustered in the area which indicates an open and moister forest. There are no large reductions in the species richness, which also may indicate stable forest vegetation in this period.

### LPAZ LH- 4 (*Betula- Pinus-Juniperus-Cyperaceae* zone) 69-0 cm, ca. 5,200 cal. years BP – present)

The last AMS date for the Lervahå mire locality suggests a sudden shift to more humid and coarser *Sphagnum* peat occurring at ca. 5,100 cal. years BP (see Table 4.1). In addition to the litostratigraphic observations, the high LOI values and the increased presence of *Sphagnum* indicate a period with highly organic and quickly accumulating *Sphagnum* peat.

The last ca. 5,200 years are however largely characterized by a reduced abundance of tree-birch and pine and increased presence of lower growing shrubs and dwarf shrubs (Fig. 4.3 and 4.4). This compositional change may indicate a change towards unfavourable climatic conditions forcing the tree taxa down to lower elevations. In the last ca. 5,000 years, the influx values of tree-birch and pine are varying between 400 and 60 grains $cm^{-2}yr^{-1}$ and 870 and 200 grains $cm^{-2}yr^{-1}$, respectively (Fig. 4.6). Although these values are not in total agreement with the mountain-birch woodland analogue presented in Hicks (1994) the values may indicate the establishment of the local sub- alpine birch woodland and at the Lervahå mire locality after ca. 5,000 cal. years BP. Similar influx values for sub-alpine birch woodland have been recorded in Smådalen, in eastern Jotunheimen (Gunnarsdóttir, 1996). The gradual retreat of the forest landscape (especially pine) and increase in open growing vegetation might be interpreted as the shift towards more open, harsher and less productive alpine conditions. However, the lack of dates after ca. 5,100 cal. years BP, results in an abrupt lowering of the sedimentation rate. This change might deviate from the authentic rate of sedimentation. Hence, the pollen influx estimates for this zone might not be completely reliable and need to be interpreted with caution.

At about 3,800 cal years BP, there is a distinct decrease in total pollen influx from ca. 1,000 to 300 grains $cm^{-2}yr^{-1}$. Again, it is important to take unreliability of the influx estimations into consideration. In addition, the low resolution pollen records for the period from ca. 3,800 cal. years BP to present times are based on four analysed pollen spectra (Fig. 4.3). Nevertheless, it might suggest a period of lower pollen producing plant community at the Lervahå mire.

From ca. 3,800 to 2,500 cal. years BP, a decrease in PR might indicate a reduced number of species growing at the locality within this period. Around the same time, there is a marked increase in *Potentilla*-type, whereas the aquatics *Menyanthes trifoliata*, *Potamogeton*- type, *Pediastrum* and *Botryococcus* are virtually disappearing. *Potentilla* –type often thrives in swamp-like conditions (Paus *et al.,* 1987). These changes might therefore reflect a fully closure of mire basin.

Pine shows stable high percentages around 50 % in the period from ca. 3,800 to ca. 1,200 cal. years BP. The influx values on the other hand, are decreasing for the same period. The most probable cause for the large increase in pine must be an increased magnitude of long-distance transported pine pollen in the percentage diagram due to the lower pollen producing conditions (Aario, 1940; Fægri and Iversen, 1989; Simonsen, 1980). Pine is no longer locally recorded (i.e. megafossils and stomata) after ca.3,700 cal. years BP (Table 4.4 and Fig. 4.3). All records thus suggest that subsequent to ca. 3,700 cal. years BP, the local growth of pine at the Lervahå mire was restricted even more.

The Lervahå locality has always been situated within the sub-alpine birch forest. However, an increase in tree-birch percentages and decrease in influx values might suggest a higher level of long-dispersal tree-birch pollen, presumably due a sparse and open forest landscape. The marked increase in *Juniperus* and *Poaceae* enhance the signal of open conditions. High levels of e.g. Cyperaceae, *Dryopteris*-type and *Selaginella selaginoides* and increased *Sphagnum* accumulation suggest a humid environment and especially towards present times (Fig. 4.3).

There has been a decline in the organic content in the soils compared to ca. 1,200 years ago. This might be explained by an increase in anthropogenic activities such increased number of summer houses and thus hiking. Except for the slight increase in *Rumex* sect. *Acetosa*, *Thalictrum* and *Urtica* (Lid and Lid, 2005), there are few anthropogenic indicator species recorded for the last spectrum. *Picea* is not recorded at the locality before the last spectrum presenting the present conditions. It has an influx value of 90 grains cm$^{-2}$ yr$^{-1}$ and a percentage nearly reaching 4 %. This possibly indicates local *Picea* trees growing adjadent to the Lervahå locality. The pollen record accords well with the precedent incidence of *Picea* planting in the region (Paus, pers.comm. 2010).

Except for the distinct decline in species richness in the period between ca. 3,800 and 2,500 cal. years BP, the increased PR values towards present times may also indicate more open conditions, and thus less competition for light and space.

The overall pattern of the PCA analysis (Fig. 4.8), show a marked change to more humid and open conditions, as the majority of spectra is placed on the left side of the first axes. According to the characteristic species composition (e.g. *Alnus*, *Sorbus*, *Melampyrum*), this shift in position indicates less shaded and moister areas, possibly with good nutrient availability (cf. lime-rich bedrock).

## 5.2 Reinskaret (920 m a.s.l.)

### LPAZ RS - 1 *Pinus- Juniperus* zone, 237-218 cm, 8,600- 8,200 cal. years BP)

The lowermost layer of the zone has been dated to be around 8,600 cal. years BP. The peat sequence is thus of a younger age than the Lervahå locality (see above). According to high percentages and presence of stomata, pine was already locally present throughout the zone. Furthermore, pine megafossils dated to ca. 9,500 cal. years BP are found ca. 200 m away from the Reinskaret locality at the same altitude (Paus, pers.comm., 2010). So, local pine forests were probably present from the early Holocene.

Tree-birch was present from ca. 8,600 to ca. 8,200 cal. years BP with an average of 9 %. The tree-birch megafossils (Table 4.4) show that some pollen derives from local tree-birch. The percentage values for tree-birch are most likely suppressed by the high pine percentages within the zone, which thus creates a false impression of a rather low presence of tree-birch. It is therefore interpreted that tree birches were occurring locally in more humid and less exposed areas.

*Alnus* was first recorded at 920 m a.s.l. at ca. 8,560 cal. years BP. An average value of 3 % might indicate a local presence at Reinskaret in this period (Huntley and Birks, 1983).

The single *Picea* pollen grain recorded at 229 cm (ca. 8,500 cal. years BP), is unlikely to represent local presence of the tree at Reinskaret (Hafsten, 1992). The recorded grain is interpreted as long – distance dispersal perhaps from Stugudalen (approx. 10 km north of the Lervahå mire) or east in the Swedish Scandes Mountains, where spruce has been recorded present already in the late glacial and early Holocene (Kullman, 1996;2000;2001;2002; Segerström and Stedingk, 2003) (see ch. 6.1.3).

The occurrence of tree-birch megafossils, the pioneer shrub *Hippophäe,* herbs such as *Silene vulgaris Polygonum bistorta*-type, *Astragalus alpinus, Asteraceae* sect. *Cichorium, Saussurea* and high pine percentages suggest the first recorded period at Reinskaret to be characterized as a late forest succession towards a pine dominated woodland (Gunnarsdóttir and Høeg, 2000; Paus, 2010). However, the end of the period contains relatively high PR values and increased presence of light-demanding taxa such as *Juniperus* and Poaceae. This might be an indication of a change in the forest composition towards a more light-open conditions. Relatively high levels of *Salix,* Cyperceae, *Dryopteris*-type, *Selaginella selaginoides, Gymnocarpium dryopteris, Saussurea* and *Asteraceae* sect. *Cichorium* suggest the presence of moist and fertile soils. Thus, within the forest grew thus a rich field layer dominated by grasses, sedges, taller ferns and lime-demanding herbs. As the bedrock at the locality is considered acidic and slow weathered, one would not expect the local growth of lime-demanding herbs. A feasible explanation for this might be the presence of lime-rich morainic deposits favouring plant growth. Peat accumulation or totally eroded deposits may be possible reasons for the reduced supply of calciferous deposits for the later plant communities at the locality.

The positioning of the pollen spectra for this period within the PCA plot (Fig. 4.9) indicates moderately dark and dry vegetation at the site. There is an observed trend in the arrangement of the spectra towards more humid conditions.

### LPAZ RS - 2 (*Alnus-Pinus*-Poaceae zone, 218-162 cm, 8,200- 7,000 cal. years BP)

High values of LOI above 90 %, indicate well-developed soils. Pine became less dominant compared to the previous period. Relatively high pollen percentages indicate that tree-birch and *Alnus* were important constituents of the forest. Two birch megafossil finds have been dated to ca.7,260 and 7,000 cal. years BP, representing the local growth of tree birch at the time. The nitrogen-fixating root noodles of *Alnus* (see e.g. Johnsrud, 1978) resulted in an increase in soil fertility. Within the period *Alnus* and tree-birch grew on the well-developed and moist soils, whereas pine was constrained to more dry and nutrient poor areas. Slightly elevated values of the thermophilous *Corylus* and *Ulmus* occurring in the same period might be interpreted as a regional signal of warmer summers and favourable soil conditions (Paus, 2010; Prösch-Danielsen, 1999).

The increase in tree pollen, together with the decreasing *Juniperus* and PR values might indicate a well-developed forest canopy, in which more shade intolerant species were outcompeted by the dominating trees. At around 7,600 cal. years BP, there is a shift in the vegetation including distinctly decreasing pine and increasing Poaceae. A simultaneous shift is observed in the sediment composition at ca. 184 cm, in which coarser and less degraded peat was observed (Table. 4.2). This compositional shift has been dated to ca. 7,500 cal. years BP (see Table. 4.6). A fall in total pollen concentration, AP percentages and species richness suggest disturbances occurring locally at Reinskaret around 7,600 cal. years BP, causing an opening of the forest. This presumably led to increased soil instability and erosion which is reflected by an increase in minerogenic deposition in the soils during the subsequent period.

As a result of the forest retreat, pioneer herbs such as Poaceae and *Dryopteris*- type, received the opportunity to occupy open areas with unstable and less developed soil conditions, in which they are often found to grow (Lid and Lid, 2005). *Alnus* benefitted from the open conditions and was the first tree to increase from about 7,600 cal. years BP. It reached a maximum at ca. 7,100 cal. years BP. A further decrease in *Juniperus*, together with an increase in the several moisture indicating taxa such as *Salix*, Cyperaceae, Poaceace, *Potentilla*-type, *Equisetum*, *Gymnocarpium dryopteris*, *Selgainella selaginoides* and *Dryopteris*-type suggest a period of prevalent humid conditions within the rather open forest (cf. low AP) including *Betula, Alnus, Prunus* and *Sorbus*. The disappearance of the water-consuming pine forest possibly caused changes in the water balance in the local soils (Kaland, 1986). In addition, precipitation might have increased. The presence of the nitrophilous herbs *Filipendula*, *Geranium*, *Valeriana*, *Asteraceae* sect. *Cichorium* (perhaps *Cicerbita alpina* ) and the pteridophytes *Dryopteris*-type and *Selaginella selaginoides* might suggest an establishment of a tall-fern and tall- herb woodland from about 7,300 cal. years BP (Fremstad, 1997; Paus *et al*., 1987).

In line with this, the late pollen assemblage zone spectra are positioned in an area in the PCA plot (Fig.4.9), indicating moister soils.

### LPAZ RS - 3 (*Betula – Cyperaceae – Dryopteris*-type zone, 162-106 cm, 7,000- 5,800 cal. years BP)

After its peak at ca. 7,100 cal. years BP, *Alnus* showed a gradual retreat from Reinskaret. Pine decreased as well. Tree-birch percentages, on the other hand, showed a gradual increase throughout the period. These records, together with birch megafossil findings (Table 4.4), might suggest the establishment of a sparser sub-alpine birch dominated forest with clustered occurrences of pine, *Alnus* and *Sorbus*. The relatively stable values of *Dryopteris*-type, *Filipendula* and *Asteraceae* sect. *Cichorium* (perhaps *Cicerbita alpina*) and PR, indicate a continuous presence of a tall-fern and tall-herb dominated field layer. *Ulmus* and *Corylus* had a stable presence throughout the period (Fig. 4.5). Similarly to the Lervahå mire, their overall percentages are too low to indicate a local presence at Reinskaret (Prösch-Danielsen, 1999).

Around 6,400 cal. years BP, elevated levels LOI reflect a higher rate of organic accumulation (e.g. *Sphagnum* peat) and perhaps more stabile soil conditions. *Alnus* disappeared from Reinskaret in the period between ca. 6,400 and ca. 6,300 cal. years BP. About 200 years later, a strong increase in Cyperaceae together with maximum values of *Sphagnum* might suggest increased precipitation and an elevation of the water table at the locality (Gunnarsdóttir, 1996). The described vegetation changes occurring within this period might reflect a gradual shift towards sub-alpine conditions at Reinskaret.

The arrangement of all the pollen spectra for this period in the PCA plot reflects past conditions of high moisture and openness (Fig. 4.9).

### LPAZ RS - 4 (*Betula – Pinus – Cyperaceae*, 106-0 cm, 5,800 cal. years BP- present)

The first period from ca. 5,800 cal. years BP was dominated by an open sub-alpine birch forest. The open conditions made it possible for the growth of Poaceae and herbs (e.g. *Melampyrum*, *Trientalis*) in the field layer. The continuous presence of *Salix*, Cyperaceae and *Dryopteris*-type indicate moist conditions.

Around 5,700 cal. years BP, the peat sediments became coarser and the presence of macrofossils scarce (Table 4.3 and 4.4). The last local record of tree-birch at the locality was at ca.5,100 cal. years BP. The AP minimum in the following period between ca. 4,700 – 3,400 cal. years BP together with a large peak in Poaceae, might indicate a forest-line situation (Ario, 1940; Simonsen, 1980). Subsequent to ca. 3,400 cal. years BP, AP and *Juniperus* increase quickly, which presumably was a result of a further opening of the vegetation. Consequently a larger portion of long-distance transported AP is recorded in the percentage diagram (Fægri and Iversen, 1989). However, the local south-facing conditions (see section 2.1) might have created favourable growing conditions for a small tree-birch population at the locality in the period after ca. 3,400 cal. years BP.

At ca. 2,700 cal. years BP, *Picea* rapidly increased in percentages. The increase was most likely caused by an increased abundance of *Picea* in regions of lower altitudes adjacent to the Reinskaret locality (see section 6.1.3).

After ca. 2,000 cal. years BP, a decrease in AP is recorded. This might be a reduction in long-distance transported pollen due to anthropogenic deforestation activities in adjacent regions (e.g. Paus *et al*.,1987). However, a simultaneous increase is recorded for *Botryococcus* (Fig. 4.5). These events might as well indicate the final retreat of the local sub-alpine birch population from Reinskaret. The disappearance of trees probably resulted in an increase in water content (Kaland, 1986) and increased nutrient availability through unstable soil conditions which made conditions more favourable for algae growth (cf. Paus, 2010). The presence of *Potentilla*-type, Cyperaceae, *Dryopteris*-type, *Juniperus*, Poaceae and *Sphagnum*, indicate moist and light-open conditions at Reinskaret after the disappearance of the local forest. The herb composition and relatively low levels of microscopic charcoal indicate low levels of anthropogenic activities at the locality (Fig. 4.5).

The increase in PR towards present times is an additional signal of a thin vegetation cover with reduced levels of interspecific competition. The positioning of the pollen spectra for this pollen assemblage zone within the PCA plot indicates conditions of high moisture and openness (Fig. 4.9).

# 6 Discussion

In the discussion, the vegetation and climate reconstructions of the study sites (ch.5) are being compared, and the results further discussed and compared with similar forest dynamics and tree-line studies within the region.

## 6.1 The vegetation history

### 6.1.1 The early Holocene pioneer vegetation (ca. 11,500- ca. 10,000 cal. years BP)

This phase is only recorded from the sediments at the Lervahå mire. The oldest AMS sample that could be obtained from the peat sequence yielded an age of ca. 10,200 cal. years BP (Table 4.4). Since the basal minerogenic layer below did not contain sufficient organic remains for dating, the start of the constructed pollen diagram was defined to ca. 11,500 cal. years BP in accordance with pollen analytical similarities with Dovre (Paus 2010, Paus *et al.* in prep.) and the assumed early deglaciation of the alpines in central Norway (cf. “minimum ice model”; Dahl *et al.*, (1997), Paus *et al.* (2006)). A more precise date can not be suggested as an exact deglacial chronology based on accurate $^{14}$C dates of terrestrial plant remains is not yet established for central Norway.

The first period from ca. 11,500 to ca.10,300 cal. years BP was characterized by low LOI and total pollen concentration and influx values. Low influx and concentration values might be caused by a rather quick accumulation of minerogenic sediments in the early post-glacial period (cf. heavy erosion and outwash) which has a diluting effect on the pollen grains accumulating in the deposits (Paus, pers. comm., 2010). A second source of error might be the unknown ages of the lowermost layers. Incorrect extrapolated ages can result in too low estimates of pollen influxes and concentrations. Hence, there are large uncertainties regarding the authenticity of the pollen influx and concentration estimates for the early Holocene at the Lervahå locality.

The rather early presence of the more humus-demanding species (e.g. Ericaceae, *Empetrum, Vaccinium*-type.*)* indicate that the deepest sediments retrieved from the locality have had time to mature and thus become more favourable for plant growth (Fig.4.3). This was additionally indicated by the record of small amount of organic material in the sediment composition and loss-on-ignition values (Table 4.1). Consequently, it is assumed that the entire post-glacial period has not been fully covered by the obtained peat sequence. Besides, with its relatively high tree-birch and low pine percentages, along with the moderate abundance of pioneer species *(e.g. Artemisia, Dryas, Rumex* sect. *Acetosa*), this early Holocene vegetation at the Lervahå mire resembles the recorded vegetation which existed in Rødalen, between ca. 11,600 and ca. 9,900 cal. years BP and Dovre between ca. 11,200 and ca. 10,300 cal. years BP, in Central Norway (Paus, 2010; Paus *et al.*, in prep.). Although, there might be local differences in time of deglaciation between the compared sites, the similarities might signal that the Levahå mire experienced an early deglaciation as proposed by Dahl *et al*. (1997) and Paus et al. (2006). However, the lack of dates makes it impossible to give any exact conclusions about the past ice-sheet structure and time of deglaciation at the locality.

Based on the influx values, the local establishment of the rapid migrating pine and tree-birch seemed to occur somewhat simultaneously at the Lervahå mire around 10,100 cal. years BP. Both pine and tree-birch are regarded as climatically sensitive and thus thought to respond quickly to temporal changes in climate (Kullman, 2002). In other words, tree migration is most likely a rapid and fine-scaled process. Hence, a synchronized occurrence at the Lervahå mire can not be judged as certain, as the resolution of the analysis is low. Additional uncertainties are created by the tripartation of the *Betula* pollen grains. The method decreases the level of exactness of the tree-birch records as the undetermined *Betula* grains have been excluded. A macrofossil analysis, by which *Betula* macrofossils (e.g. fruits, bud scales) can be identified down to species level (cf. van Dinter and Birks, 1996), could have been an alternative complementary method and would have likely yielded valuable and more exact information about the local presence and abundance of *Betula* taxa (Birks and Birks, 2000; Birks, 2001; Eide et al., 2006). Such an analysis could, however, not be performed in this study due to time restrictions. Consequently, the study has not yielded any concrete evidence on the successional sequence of local tree establishment in the studied region.

In Rødalen, Tynset, ca. 100 km SW of the Ridalen region, tree-birch became established at ca. 10,300 cal. years BP (Paus, 2010). This pattern is also recorded for other alpine sites in mid-Scandinavia (cf. Bergman *et al*., 2005; Velle *et al*., 2005; 2010). The Rødalen pine rise occurs slightly later at ca. 10,150 cal. years BP. At Västerbotten in northern Sweden, high percentages of both tree-birch and pine were recorded at ca. 10,000 cal. years BP (Barnekow *et al*., 2008). These records reflect rather synchronous patterns and chronology for the first tree establishment in mid-Scandinavia. Pine and birch megafossil evidences from the Swedish Scandes (Kullman, 2002; Kullman and Kjällgren, 2000), and pine stomata findings at Dovre (Paus *et al.*, in prep) suggest the local growth of pine and tree-birch in favourable sites at high altitudinal mountain peaks (nunataks) during the late glacial. Pine and tree-birch might thus have rapidly migrated from higher elevations to lower altitudes in Scandinavian Mountain region as a response to the improved climatic conditions in the early Holocene (Kullman, 2002; Kullman and Kjällgren, 2000; Paus *et al*., 2006). However, further SW in Norway, in eastern and Central Jotunheimen, pine established about 300 years later (e.g. Gunnarsdóttir, 1996; Barnett *et al*., 2001). A later dated deglaciation occurrence in the Jotunheimen region (see e.g. Barnett *et al*., 2001; Gunnarsdóttir, 1996; Nesje and Rye, 1990) might be a possible explanation for the recorded delay in tree migration.

Based on the similar patterns of tree migration recorded both east and west of the Ridalen region, it seems likely that pine and tree-birch grew locally at the Lervahå mire around 10,100 cal. years BP.

### 6.1.2 The local pine forest (ca. 10,000 – ca. 9,200 cal. years BP)

Pine was present not later than ca. 9,500 cal. years BP at Reinskaret and from ca. 10,100 cal. years BP at the Lervahå mire. Dating uncertainties (ch. 3.2.7) give no precise dates for the pine optimum in the Ridalen region. However, based on the pollen analytical records for the Lervahå locality, pine seems to have reached its highest distribution in the region within the period between ca. 10,000 and 9,200 cal. years BP. As the peat sequence only dates back to ca. 8,600 cal. years BP, no inferences about the maximum abundance of pine at Reinskaret can be made. Furthermore, an exact altitudinal distribution of the tree taxa cannot be inferred by this study, as no pollen analytical and megafossil records are recorded for altitudes above the Reinskaret locality. A more thorough search for megafossils and/or a sampling site at higher altitudes could be alternative approaches to obtain more information about their maximum distributions. Nevertheless, both pine and birch have been recorded at much higher altitudes in adjacent areas to the Ridalen region during the Holocene (e.g. Aas and Faarlund, 1988; Gunnarsdóttir, 1996; Kullman, 2004; Kullman and Kjällgren, 2000; Paus, 2010; Velle *et al*., 2010). It is thus likely to assume that they both occurred above 920 m a.s.l. within this period.

A decline in pine seemed to occur around 9,200 cal. years BP, and its dominance ended around 8,000 cal. years BP at higher altitudes at Reinskaret and ca. 7,400 cal. in the lower lying Lervahå mire. The lag of ca 600 years at the Lervahå site could result from a low chronological resolution in both peat sequences. However, the altitudinal differences between the localities (150 m), reflecting a temperature difference of almost 1 ° C (Laaksonen 1976), might have been an important factor for causing differences in forest composition between the sites, as today.

Regions located both east and south south-west of Ridalen show similar patterns in of the local occurrence and expansion of the pine forest. Pollen and macrofossil records show a similar time interval for pine dominance at both Lake Holtjärn and Abborrtjärnen in the Central Scandes Mountains (Giesecke, 2005a,b). Furthermore, pine was recorded as dominant between 9,900 and 8,500 cal. years BP in Rødalen, in southern Central Norway (Paus, 2010). The fact that Flåfattjønna is located at 1,110 m a.s.l. might be contributing factor for the more rapid loss in pine dominance in Rødalen. This implies a temperature difference of at least 1.2 ° C (glacio-isostatic rebound not included) compared to the localities in Ridalen. At Brurskardtjørni, located in eastern Jotunheimen, pine reached its highest altitudes in the Holocene around 9,000 cal. years BP, after which it retreated (Velle *et al.*, 2010). A gradual decline of pine since ca. 9,500 cal. years BP has also been recorded by pine megafossil finds both east and west of the study site (south-central Norway and the Swedish Scandes) (Kullman, 1995; Kullman and Kjällgren, 2006; Paus, 2010).

Though the pollen analytical data suggests that pine was no longer dominant in the region after ca. 7,400 cal. years BP, the first recorded megafossil of pine was dated to ca. 7,100 cal. years BP (Table 4.4). Megafossils, which provide reliable evidence of local tree occurrences (Aas and Faarlund, 1988; Birks, 2001; Kullman, 1998), only give a fragmented picture of the vegetation in space and time (Aas and Faarlund, 1988; Bergman *et al.*, 2005; Gunnarsdóttir, 1996; Paus, 2010). It is for instance unknown if the megafossil has been growing within a forest or by itself due to favourable microhabitat conditions (Bergman *et al.*, 2005; Gunnarsdóttir, 1996). In addition, one can not be certain if the lack of megafossils is actually a result of local absence (due to i.e. climatic changes) or i.e. poor and/or selective preservation conditions (Aas and Faarlund, 1988; Bergman *et al.*, 2005; Eide *et al.*, 2006; Gunnarsdóttir, 1996; Kullman, 2000). The reason for the absence of megafossils at the study site before ca. 7,100 cal. years BP is thus uncertain. Perhaps the localities at the time did not contain appropriate environmental conditions for megafossil preservation. Nonetheless, the local presence of pine is frequently recorded within the entire period by the stomata findings starting from ca. 9,700 cal. years BP.

### 6.1.3 The history of *Picea*

The first record of spruce in Ridalen is the single pollen grain recorded at Reinskaret ca. 8,500 cal. years BP. Similar finds of single grains have been considered to reflect long-distance transport (Hafsten, 1992). It has generally been believed that spruce migrated from Central Russia in the east to the Scandes Mountains at around 3,500 cal. years BP (e.g. Tallantire, 1977; Hafsten, 1992). However, recent megafossil studies by Kullman (e.g. 1995; 1996; 2001) show that spruce was present in the Scandes Mountains already from ca. 12,850 cal. years BP. Kullman (2001) has also found megafossils showing the presence of spruce in Stugudalen, ca 10 km north of the study site at regular intervals between ca. 9,300 and 2,500 cal. years BP Furthermore, pollen analytical data show evidence of local spruce establishment in the early Holocene, ca. 9,000 cal. years BP, in west Central Sweden (Segerström and von Stedingk, 2003). So, a much earlier immigration of spruce to the Central Scandes than previously thought is visualised. Hence, it seems likely that spruce was growing in adjacent regions both north and south-east of Reinskaret around 8,500 cal. years BP. It cannot be discounted that spruce was present at this time in Ridalen either.

### 6.1.4 The rise and expansion of *Alnus* (ca. 9,200- ca. 6,300 cal. years BP)

The tentative chronology suggest that *Alnus*, most probably *A. incana* (see section 5.1), rises at the Lervahå mire around 9,200 cal years BP. This correlates well with other studied regions in Central Scandinavia (Giesecke, 2005a; Paus, 2010; Segerström and von Stedingk, 2003). At Reinskaret, *Alnus* is lacking in the lowermost spectrum, but is frequent from ca. 8,600 cal. years BP. It is a question of whether this pattern is accidental or reflects an extremely rapid *Alnus* rise. This probably reflects that *Alnus* was less common at Reinskaret than at the Lervahå mire in the early stages of its Ridalen occurrence. Disregarding the uncertain chronology at each sampling site (cf. low amount of dates), a possible explanation of the different pattern in *Alnus*, might be a result of differences in local factors such as soil moisture, topography, sloping etc. Besides, soil and humidity conditions (as well as growing season length and summer temperatures) seem to be an important factor for the growth of *Alnus incana* in high elevations (Moe, 1998). Accurate AMS dates of the local establishment and expansion of *Alnus* could not be obtained due to time restrictions.

After the *Alnus* expansion, pine gradually lost in competition to the more moist demanding *Alnus* and tree-birch. The local forest changed in composition, to a more mixed pine, tree-birch and *Alnus* forest, with a rich field layer of tall-ferns and nitrophilous herbs. After its maximum at ca. 7,400 and ca. 7,100 cal. years BP, at the Lervahå mire and Reinskaret, respectively, *Alnus* had a gradual decline towards present times.

An *Alnus* maximum was similarly recorded at ca. 7,600 cal. years at Lake Stentjärn (Bergman *et al*., 2005) and ca. 100 years later at Lake Spåime (Hammarlund *et al*., 2004) in the Scandes Mountains, in west-central Sweden. Further south in Central Norway in eastern Jotunheimen, *Alnus* shows a maximum abundance around the same period (Velle *et al*., 2010; Gunnarsdóttir, 1996). *Alnus,* however, shows a different migration pattern for the Leirdalen 5 mire, in Central Jotunheimen, as its local expansion is first recorded around 6,800 cal. years BP (Barnett *et al*., 2001). This is nearly 400 years later than what Gunnarsdóttir (1996) and Velle *et al*. (2010) recorded for eastern Jotunheimen. The time of deglaciation is of similar dates between Smådalen and Leirdalen 5 (Gunnarsdóttir, 1996; Nesje and Rye, 1990). As Leirdalen 5 is a relatively small mire (Barnett *et al*., 2001) its records reflect local vegetation patterns (Birks and Birks, 1980; Fægri and Iversen, 1989). It might be possible that the late rise in *Alnus* at the Leirdalen 5 mire has been a local effect created by differences in local site conditions.

In the subsequent period after the maximum in *Alnus*, the sub-alpine birch belt established at the Reinskaret locality, whereas pine re-established on drier soils within the local forest of the Lervahå mire. The change into more alpine conditions at the Reinskaret was likely the reason why pine did not succeed to regain its previous position within the local forest. A tree-birch forest establishment has also been recorded at similar periods both in southern, central and western regions of Norway (e.g. Bjune *et al*., 2005; Paus, 2010; Velle *et al*., 2010) and in the east in the Swedish Scandes (e.g. Bergman *et al*., 2005; Barnekow *et al*., 2008). Around 6,300 cal. years BP, *Alnus* no longer grew within the local forests in the Ridalen region.

### 6.1.5 The retreat of the local forest (ca. 6,300- ca. 3,700 cal. years BP)

The forests in the Ridalen region showed a gradual retreat in the subsequent period after *Alnus* receded to lower elevations. After ca. 5,100 cal. years BP, birch megafossils were no longer recorded at Reinskaret. A similar trend is seen for the pine megafossils and stomata at the Lervahå mire, which declined in frequency in the following period. The sub-alpine birch belt seemed to establish at the Lervahå mire around 5,000 cal. years BP. Around the same time, the forest landscape at higher elevations developed into a forest-line situation.

In the period around 5,500 – 5,000 cal. years BP, the rate of sedimentation decreases (Fig. 4.1 and 4.2). This is assumed to be a result of the absence of dates in the subsequent period (Table

4.3). One could probably expect a more gradual decline in sedimentation rate (i.e. a more sigmoid shaped sedimentation curve) for the last Holocene period than what is estimated by the available dates. An argument might thus be that a similar age modification should have also been performed for the uppermost layer for the Lervahå locality (Fig.4.1). The dated megafossil T-19837 which is displayed in Fig. 4.1 might represent an accurate date for the period. However, as several of the dated megafossils at Reinskaret reveal a different age than the surrounding peat sediments (Fig. 4.2), I chose not to include any megafossil dates in the sediment rate estimations. The vague chronology thus creates uncertain sedimentation and influx estimates for the period.

In the period after ca. 4,700 cal years BP, a forest-line situation was recorded at 920 m. a.s.l. in the study area. At the same time, pine declined in abundance at the Lervahå mire. After ca. 3,700 cal. years BP pine the local record of pine ceased, implying a sparse representation of pine in the study area in the subsequent period.

Compatible forest dynamics to the Ridalen region have been recorded for sites located both east and south of the study site. At Lake Stentjärn in west-central Sweden, trees gradually declined after ca. 6,000 cal. years BP, and disappeared around ca. 3,500-2,000 cal. years BP (Bergman *et al*., 2005). This accords well with the deforestation pattern at Lake Spåime in the same region (Hammarlund *et al*., 2004). Current megafossil records in the Scandes, show a general retreat of tree-lines after ca. 6,300-5,700 cal. years BP (Kullman, 1995). In the central mountains of Norway, further south of Ridalen, a pine recession in the period between ca. 4,400 and 4,000 cal. years BP, and tree-birch around 3,200 cal. years BP (Velle *et al*., 2005). Also in eastern Jotunheimen a general change towards more open conditions is recorded around 5,000 cal. years BP (Gunnarsdóttir, 1996; Velle *et al*., 2010).

### 6.1.6 Late Holocene forest dynamics (ca. 3,700 cal. years BP - present)

Pine receded even more after ca. 3,700 cal. years BP, leaving only scattered individuals within the sub-alpine birch forest. The sub-alpine birch belt had more or less retreated from Reinskaret, possibly leaving only a small population of tree-birch growing in favourable microhabitats at higher altitudes. After ca.2,000 cal. years BP, forests were no longer growing at 920 m a.s.l. in the study area. At the same time the region experienced a distinct decline in tree pollen towards present times, most likely as a result of regional deforestations, e.g. south-west in Innerdalen (Paus *et al*., 1987). None of the Ridalen localities seem to have been exposed to any wide-spread summer-farm activity. Charcoal values are increasing slightly, but this could be interpreted as long distance transport. Small increases in e.g. *Thalictrum* and *Rumex* sect. *Acetosa*, both which can be components of a cultivated landscape (Lid and Lid, 2005), might be the result of increased hiking and summer house activities in the area. The sub-alpine birch forests show stable values at the Lervahå mire towards present times, whereas pine seems to increase slightly. This accords with the records of Kullman (2010) explaining the rise in the tree-line towards present times as a result of climate warming. However, *Picea* and *Pinus* sp. have been planted during the last 40-50 years close to the Lervahå mire. Their presence is most probably reflected as increases in the pollen diagram tops. Also at Reinskaret, the high *Picea* percentages can be interpreted as representing planted populations at lower elevations such as the Lervahåen populations.

It must however be emphasized, that the pollen analytical records for the last period, especially for the Lervahå mire sequence (Fig. 4.3) are based on considerably fewer pollen spectra. Hence, the period of lowest resolution stretches from about 3,700 cal. years BP to present times. The vegetation reconstructions of this period thus represent rather large-scaled changes.

## 6. 2 Climate history

One has to keep in mind the altitudinal difference between the Lervahå mire (770 m a.s.l.) and Reinskaret (920 m a.s.l.). Consequently, temperatures at Reinskaret have been approx. 1 ° C lower, compared to the Lervahå mire, at any given time (ch. 2.3).

### 6.2.1 The early Holocene pioneer vegetation (ca. 11,500- 10,000 cal. years BP)

The *Juniperus* dominance in the early Holocene, suggests dry conditions (Lid and Lid, 2005) from ca. 11,500- ca. 10,500 cal. years BP. Locally present *Selaginella selaginoides* indicates a July mean temperature of at least 7 ° C at ca. 11,500 cal. years BP, whereas *Hippophäe* suggests that the July mean was at least 11 °C for the whole period. A single tetrad of *Typha latifolium* was recorded at the Lervahå mire at ca. 10,100 cal. years BP. As the *Typha* tetrads are wind dispersed (Lid and Lid, 2005), *Typha* may not have been locally present. Nevertheless, it might be an important regional indicator of high temperatures, as *T. latifolium* requires at least a July mean of 12° C (Kolstrup, 1979). In continental areas, the birch-forest line correlates with the 10 °C July isotherm (Odland, 1996), whereas pine requires a mean July temperature of 11°C to develop forests (Paus, 2010). Based on these indications, the July mean temperature in the early Holocene at the Lervahå mire seems to have been at least 11 ° C.

To compare past and present regional temperatures at similar altitudes, one has to take into account the glaciostatic uplift. According to Hafsten (1983), the land uplift during the last 10,000 years has been ca. 90 m. By using a lapse rate of 0.6 °C/ 100 m (Laaksonen, 1976) the corrected minimum mean July temperature at the Lervahå mire was at least 10.5 ° C in the interval 11,000-10,000 cal. years BP. This is close to present summer temperatures (Fig. 2.5).

An increase in Salix, *Dryopteris*-type and *Gymnocarpium dryopteris* from ca.10,500 cal. years BP might reflect more moist conditions at the end of the pioneer stage. This trend towards humid conditions seems to be in agreement with a manifold of palaeoclimatological reconstructions from the Nordic region (i.e. Fennoscandia and the northern Europe) (Seppä *et al.,* 2010).

The early Holocene summers in the Ridalen region seemed therefore to be rather dry and warm (cf. Velle *et al*., 2010; Paus, 2010). The palynological records further suggest a change towards moister conditions in the late pioneer stages.

### 6.2.2 The local pine forest (ca. 10,000- ca. 9,200 cal. years BP)

According to the temperature requirements of pine, the local pine forest establishment in this period suggests July mean temperature of at least 11 ° C in the study region (Paus, 2010). Allowing for the glacio-isostatic rebound (ca. 70 m, ~ 0.4 ° C), the temperatures were at least 0.5 ° C higher within this period compared to present times (Fig. 2.5). Conditions seemed to become drier during the local pine expansion between ca. 9,700 and 8,700 cal. years BP.

This temperature trend seems to concur well with climate reconstructions from the Nordic region (Seppä *et al*., 2010). Besides, temperature reconstructions within the same period in adjacent regions in the Central Scandinavian Mountains suggest temperatures being 1.5-2 ° C higher than present times (Barnett *et al*., 2001; Bjune *et al.*, 2005; Gunnarsdóttir, 1996; Velle *et al*., 2005). The rise and expansion of pine has thus been suggested to be a result of a more continental climate and less snow cover during the winter (Velle *et al*., 2005).

From about 9,200 cal. years BP, pine declined in abundance and *Alnus* expanded at the Lervahå locality and changes in the vegetational composition suggest a change to more local humid conditions. The humidity might have resulted in a local restriction of pine to drier sites.

### 6.2.3 The rise and expansion of *Alnus* (ca. 9,200- ca. 6,300 cal. years BP)

The *Alnus* period seems to have been rather warm and moist. *Alnus*, tree-birch and pine have a tetraterm (June-Sept.) of 7.7, 7.5 and 8.4 ° C, respectively (Helland, 1912). Compared to the minimum July mean requirements of tree-birch and pine (ca. 10 and 11 °C: Odland, 1996; Paus, 2010), it is reasonable to believe that the establishment of *Alnus* requires a minimum July mean slightly above 10 °C. Although *Ulmus* and *Corylus* were most likely a regional feature, their respective tetraterms of 11.2 and 12.5°C (Helland, 1912), would imply regionally occurring high July mean temperatures possibly between 12 and 14 °C. As pine grew abundantly within the local forested landscape, the minimum July mean was presumably not less than 11 ° C. The glacio-isostatic uplift (ca. 40 m: Haftsen, 1983) only accounted for a rise in temperature of about 0.2 °C.

The cooling event around 8,200 cal. years BP ("the 8.2 ka event" or "Finse event"), which was detected for the first time by Dahl and Nesje (1994; 1996), at Finse in southern Central Mountains of Norway, could not be observed in the pollen analysis record from either of the two study sites in the Ridalen region. The study area might not have been affected by this short-lasting climatic event due to local site conditions. Yet again, the most plausible explanation would be the low resolution of the pollen analysis, in which short- lasting climatic shifts, such as the "8.2 ka event," may be undetected (Seppä *et al*., 2010).

The occurrence of the Holocene Thermal Maximum (HTM) from the Nordic region appears to differ slightly between previously undertaken palaeoclimatological investigations. Seppä *et al*. (2008) records the Holocene Thermal Maximum (HTM) within northern Europe from ca. 7,500- 6,500 cal. years BP, in which the summer temperatures were inferred to be 1.5 °C higher than modern times. On a lower scale, Bjune *et al*. (2005) found similar HTM in western Norway, ending ca. 4000 cal. yr BP and reaching July mean temperatures above 12 ° C, i.e. 2 °C warmer than today. Conversely, chironomid temperature reconstructions performed in the Central Scandinavian mountains indicate a HTM from ca. 11,500- 10,500 cal. years BP (Hammarlund *et al*., 2004; Velle *et al*., 2005; Velle *et al.*, 2010).

All the same, the maximum altitudinal distribution of pine in the Scandinavian Mountains is found to be closely linked to maximum Holocene temperature records (Kullman and Kjällgren, 2006; Paus, 2010). The highest altitudinal distribution of the local pine forest in the Ridalen region is not known. In addition, no distinct changes in the early Holocene temperature can be detected in the pollen analytical data. Hence, the beginning of the HTM and the exact time period in which the highest temperatures were reached in the investigated region cannot be deduced in this study. The records however suggest an end of the high summer temperatures around 5,000 cal. years BP (cf. Velle *et al*., 2010).

### 6.2.4 The retreat of the local forest (ca. 6,300- ca. 3,700 cal. years BP)

Indicated by the presence of pine within the local forest, the July mean temperatures were probably around 11 ° C at the Lervahå mire around 6,300 cal. years BP (Odland, 1996; Paus, 2010). The July mean was probably closer to 10 ° C at Reinskaret (cf. height difference and few occurrences of pine within the forest).

In the following period the forest landscape became sparser in the Ridalen region, and a high abundance of Cyperaceae, *Selaginella, Potentilla* og Dryopteris type indicates a trend towards cooler and moister conditions. Less tree-birch occurrences after ca. 4,700 cal. years BP at Reinskaret indicate further temperature decreases. After ca. 2,000 cal. years BP, July mean temperatures were not adequate to sustain tree-birch growth at 920 m a.s.l. in the study region. The record of *Calluna* and *Selaginella selaginoides* indicates a minimum July mean temperature of 7 ° C towards present times (Kolstrup, 1979).

In Scandinavia, neoglaciation occurrences (i.e. advancement of glaciers) have been recorded for the period after ca. 6,000 cal. years BP (Nesje, 2009) and a temperature decreases were recorded in the mountain regions in Central Norway (Paus, 2010). Similarly to the study area in Ridalen, a distinct decrease in temperature occurred around 5,500 cal. years BP in south-central Norway (Velle *et al.,* 2010). A further lowering of temperatures is recorded within the same region after 4,400 cal. years BP (Velle *et al.,* 2005). Low temperatures together with increased humidity are also recorded in central Sweden, and suggested to be the causative factors for the disorganisation and retreat of the forested landscape at higher altitudes (Hammarlund *et al*., 2004).

The change to cooler and moister conditions, which has been recorded for the study area in the Ridalen region, seems thus to be an overall trend in the Scandinavian Mountains. In fact, this climatic pattern is recorded in most palaeoclimatological investigations in the Nordic region (Seppä *et al*., 2010).

### 6.2.5 Late Holocene dynamics (ca. 3,700 – present)

The period from about 3,500 cal years BP is characterized by a cooler and moister climate resulting in paludification (Barnekow *et al*., 2008). The retreat of forests and, thus, the reduction in the evaporation could be an additional explanation for the moister soils. In line with this, both localities experience an increase in Cyperaceae, ferns and *Sphagnum*. As the Lervahå mire is situated about 80 m below the present sub-alpine birch-forest line, and has been situated within the birch-belt since continuous pine-forests retreated from the site after ca. 3,700 years ago, the minimum mean July temperature may have been constantly between 10 and 11 ° C (Odland, 1996; Paus, 2010) since then. *Selaginella selaginoides* is present at Reinskaret, which thus implies a minimum mean July of 7 ° C (Kolstrup, 1979). However, as the Lervahå mire has a minimum mean July around 10-11 ° C, it would be reasonable to assume that Reinskaret, situated 150 m higher, has a minimum mean July around 9-10 ° C.

Summer temperatures are generally believed to be the most important parameter for forest-lines (Odland, 1996). The present summer temperatures are similar to the temperatures inferred for the early Holocene. Even so, pine and birch reached higher altitudes in the early Holocene than today. This can partly be explained by the fact that inferred temperatures are minimum estimates and that land uplift has occurred. Also, Paus (2010) and Kullman (2010) highlight the importance of winter conditions, such as wind exposure and snow cover, in shaping the tree-line and forest positions on a regional scale in the Central Scandes Mountains.

# 7 Conclusion

Pioneer herbs, *Betula nana* and *Juniperus* dominated the vegetation cover in the early Holocene at the Lervahå mire until ca. 10,500 cal. years BP. Tree-birch was most likely the first tree to establish on a regional scale, but seemed to migrate rather synchronously with pine to the Ridalen region around 10,100 cal. years BP. Late-glacial megafossil and stomata findings of pine and tree-birch in nearby regions of Ridalen might suggest that pine and tree-birch migrated to the Ridalen region from small local growing populations on ice-free nunataks in the Mid-Scandinavian mountains. Shortly after its arrival pine expanded and dominated the local forested landscape in the study area until the ca. 8,000- 7,400 cal. years BP. Stomata findings represent the first local presence of pine at the Lervahå mire at ca. 9,700 cal. years BP.

*Alnus* (presumably *A. incana*) was first locally present in the Ridalen region at 770 m a.s.l. around 9,200 cal. years BP, and formed together with pine and tree-birch a tall-rich and tall-fern woodland until about 7,400-7,100 cal. years BP. After the decline in *Alnus*, a sub-alpine birch forest established at the Reinskaret locality, whereas a mixed pine and tree-birch formed the forests at lower altitudes.

No local evidence of tree-birch at Reinskaret was recorded after ca. 5,100 cal. years BP and around the same time, the sub-alpine birch belt established at the Lervahå mire. *Picea* increased in regions near to Ridalen at ca. 2,700 cal. years BP. After ca. 2,000 cal. years BP, tree-birch was no longer capable of growing in the low alpine conditions at 920 m a.s.l. Today, the forest at the Lervahå mire is mainly comprised of tree- birch, although scattered individuals of pine and *Picea* are to be found.

Climate reconstructions indicate relatively warm and dry conditions at the onset of the Holocene at the Lervahå mire, followed by moister conditions after ca. 10,500 cal. years BP. Except for a dry period between ca. 9,700- 8,700 cal. years BP, the local conditions have shown a temporal trend towards increased humidity. The study area had July mean temperatures of at least 11 ° C until ca. 8,000-7,400 cal. years BP, and at least 10 -11° C and 9-10 ° C until present times at the Lervahå mire and Reinskaret, respectively.

Due to inadequate amounts of terrestrial plant macrofossils, the basal sediment layers could not be accurately dated. Thus, an exact time of deglaciation could not be deducted for the study area. However, in conformity to central mountain areas situated south-west of Ridalen, the reconstructed plant communities might suggest an early deglaciation at the Lervahå mire and thus the past existence of a thin and multidomed ice-sheet in the Ridalen region.

This study was unfortunately not able to detect which tree that was to establish first in the study area. This could presumably have been solved by performing a higher resolution pollen analysis, preferably in combination with macrofossil analysis and/or thorough search for megafossils.

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# Appendix

## Appendix A: Litostratigraphical transect at the Lervahå mire

Figure A.1 and A2 gives a coarse overview over the sequences, in which the test corings were performed.

**WSW 10 ----- 3 -----LH2 ----- LH1 ----- 11 ENE**

***Figure A.1:*** *The cores in the west south-west (WSW) to east south-east (ESE) were cored in the sequence*

**NNW 6 ----- 7 ----- 8 ----- 5 ----- LH2 ----- 4 ----- 9 SSE**

***Figure A.2:*** *The cores in the north north-west (NNW) to south south-east (SSE) were cored in the sequence:*

Coarse descriptions of the test cores are displayed in Table A1.1

***Table A1.1:*** *Test cores in a west south-west (WSW) to east north- east (ENE) transect*

| **Coring site number** | **Depth (cm)** | **Core description** |
|---|---|---|
| **1 (LH 1)** | 127 -220 | Peat |
| | 220- 225 | Peat/gyttja phase |
| | 225- 227 | Clay and silt layer |
| | | |
| **2 (LH 2)**<br>(3 m west of coring site 1) | 230-313 | Peat/gyttja phase |
| | 313-315 | A bright layer with clay and silt |
| | 315-317 | Highly organic layer |
| | 317- 318 | Peat/gyttja phase |
| | 318-330 | Blue-grey clay and silt layer |
| | | |
| **3**<br>(3 m west of coring site 2) | 210-276 | Organic peat layer |
| | 276-305 | Peat/gyttja phase |
| | 305-310 | Grey-blue clay and silt layer |
| | | |
| **10**<br>(6m west of coring site 2 | 195-265 | Peat layer |
| | 265-293 | Peat/gyttja layer |
| | 293-295 | Blue-green clay and silt layer |
| | | |
| **11**<br>(6 m east of coring site 2) | 100-194 | Peat layer |
| | 194-197 | Minerogenic gyttja layer |
| | 197-200 | Blue green clay and silt layer |

***Table A1.2**: Test cores in a north north-west (NNW) transect to south south-east (SSE) transect. The LH 2 test core is shown in Table A1.1.*

| | | |
|---|---|---|
| **4**<br>(3 m south of coring site 2) | 200–297 | Laminated, dark and light layers. Contains much macrofossils |
| | 297 –300 | Clay and silt layer |
| | | |
| **5**<br>( 3m north of coring site 2) | 170-253 | Peat/gyttja phase |
| | 267-270 | Blue-grey clay and silt layer.Upwards laminated |
| | | |
| **6**<br>(13 m north north-west of coring site 2) | 170-255 | Peat layer |
| | 255-267 | Peat/gyttja phase |
| | 267-270 | Blue-grey clay and silt layer |
| | | |
| **7**<br>(6.5 m north north- west of coring site 2) | 140-235 | Peat layer |
| | 235-239 | Peat/gyttja phase |
| | 239-240 | Blue green clay and silt layer |
| | | |
| **8**<br>(6m north of coring site 2) | 165-245 | Peat layer |
| | 245-255 | Peat/gyttja layer |
| | 255-265 | Blue-grey clay and silt layer |
| | | |
| **9**<br>(6 m south of coring site 2) | 185-245 | Peat layer |
| | 245-285 | Peat/gyttja phase |

## Appendix B: Palynological richness (PR)- Rarefaction analysis

*Table B 1: The main results of the rarefaction analysis on a total dataset.*

| **The Lervahå mire** | | | **Reinskaret** | | |
|---|---|---|---|---|---|
| **Zone** | **Range in $E(S_{392})$** | **Average value of $E(S_{392})$.** | **Zone** | **Range in $E(S_{392})$** | **Average value of $E(S_{392})$** |
| **LH-4** | **17.5 - 26** | **22,4** | **RS-4** | **18.6- 27.1** | **23.9** |
| **LH-3** | **19.7- 26.6** | **22.3** | **RS-3** | **21.1- 24.9** | **23.2** |
| **LH-2** | **15.2- 21.8** | **17.8** | **RS-2** | **20.3- 25.1** | **22.6** |
| **LH-1** | **19.7- 27.4** | **24.7** | **RS-1** | **22.6- 25.8** | **24.3** |

# Appendix C: Pollen percentage diagrams for the Lervahå mire and Reinskaret