Early Maglemosian culture in the Preboreal landscape: Archaeology and vegetation from the earliest Mesolithic site in Denmark at Lundby Mose, Sjælland

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A B S T R A C T

The transition from Late Palaeolithic to early Mesolithic cultures is strongly associated with the major environmental and climatic changes occurring with the shift from the Younger Dryas to the Holocene in northern Europe. In this paper, we present an interdisciplinary study combining archaeological and palaeoenvironmental research in an attempt to examine the relationship between environment and culture during this transition. Lundby Mose is a former kettle hole lake in southern Denmark where the earliest Danish human traces of the Holocene were excavated. Two types of bone deposits were found, 1) ritual offerings of worked, marrow-split elk bones and antler and 2) settlement waste with multiple species. These date to the early Holocene and are affiliated to the early Maglemose culture. The modelled 14C ages suggest that the bones were deposited in four phases. A pollen based palaeoenvironmental reconstruction suggests that the ritual offerings were deposited in an environment of limited, underdeveloped forest with unstable soils and areas of open grassland. The settlement waste deposit is associated with a more developed Preboreal forest type. This forest type was not fully established until c. 11,250 cal BP and if substantiated by further evidence, may be one of the reasons why there are no known early Maglemose/Preboreal settlement sites in southern Scandinavia.

1. Introduction

The Pleistocene–Holocene transition is one of the most abrupt climatic changes in the history of the human settlement of northern Europe. It marks the cultural transition from the Palaeolithic to the Mesolithic culture (Petersen, 1973) and dates to 11,703 b2k (c. 11,653 cal BP) in the Greenland ice core data (Rasmussen et al., 2006). The vegetational landscape is thought to have responded to this shift within a very short time period and understanding its development is pertinent to any associated archaeology, as certain types of vegetation supply certain food resources for humans and thus have a strong influence on the material culture retrieved. Direct correlations between the climatic impact, the vegetational response and the human response are challenging due to the lack of well dated archaeological sites on both sides of the transition (Brinch Petersen, 2009; Tolksdorf et al., 2009). Sites allowing an integrated approach combining these different data are rare but can aid our understanding of both the cultural and the environmental responses to the Holocene shift.

Our knowledge of landscape change in southern Scandinavia is built upon numerous studies stretching back to the pioneer phase of vegetational reconstructions (von Post, 1916; Jessen, 1935; Nilsson, 1935; Iversen, 1942, 1946, 1947; Mikkelsen, 1949; Iversen, 1960). Many of these studies were carried out prior to the development of radiocarbon dating and often served a double function by also supplying a relative date to archaeological sites (Iversen, 1946; Jørgensen, 1954). Very few of these earlier studies systematically analysed plant macrofossils or calculated pollen influx but recent work is now showing a more nuanced vegetational development with differences in small-scale vegetation patterns over relatively short distances and significant time delays during periods of climatic transitions (Mortensen et al., 2011; Fischer et al., 2013; Mortensen et al., 2014a). The distinctive shift from the late Palaeolithic Ahrensburg cultural material of the Younger Dryas to that of
the Mesolithic Maglemose culture of the Holocene on the northern European plain is clearly observed on a large scale. Seen in more detail there is an evident chronological gap between the two cultures but due to the limited number of known settlement sites, and the few reliable radiocarbon ages available, it is difficult to be more precise as to how long this gap lasts (Hansen et al., 2004).

Modern agriculture with intensive ploughing and drainage has strongly degraded Late Palaeolithic and early Mesolithic sites and the loss of potential prehistoric hunter–gatherer sites is very evident in the east Danish bogs. Nonetheless in 1999 a group of students from a local agricultural college (Lundby Landbrugsskole) dug into a kettle hole and discovered well preserved, worked elk (Alces alces) bones and antler. The subsequent excavation revealed a series of bundled, marrow-split elk bones deposited around the edge of a small ancient lake and has proved to be the earliest Holocene site with human traces found in Denmark so far. In this paper we present the excavation and the different types of bone deposits together with a palynological vegetational reconstruction. Lundby Mose is a unique site and key in the understanding of how humans adapted to the environmental changes at the beginning of the Holocene and offers the exceptional opportunity to apply an integrated palaeoenvironmental and archaeological approach and consider the relationship between environment and culture in the early Mesolithic.

2. Background

2.1. Palaeoclimatic and environmental context

The start of rapid Holocene warming at 11,703 b2k (c. 11,653 cal BP) (Rasmussen et al., 2006) initiated a complex series of climatic responses in northern Europe with associated responses in biological systems and their ecology. The late Glacial succession of vegetational immigration has been well described in northern Europe over many years (Jessen, 1935; Iversen, 1954, 1967). These studies were mostly based on pollen analyses and much of the biostatigraphic zonation was determined from southern Scandinavian sites (von Post, 1916). They also detected hitherto undocumented rapid climatic changes during the early Holocene (c. 11,653–8000 cal BP) (Iversen, 1973). These events, recorded in correlated relative chronologies, have since been shown in many palaeoclimatic indicators from the northern hemisphere within absolute chronologies (Alley and Ágústsdóttir, 2005; Jessen et al., 2008; Blockley et al., 2012 and references therein). The events, which are often suggested to be associated with meltwater pulses into the North Atlantic Ocean (Teller et al., 2002; Jessen, 2006), were part of an early Holocene dynamic climate with rapidly changing temperatures and precipitation regimes, possibly impacting the developing landscapes and the large scale migrations of the associated flora and fauna. Disentangling this complex mixture of responses to early Holocene climatic change with all their associated time delays can be aided by sites with secure stratigraphic contexts and the integration of different scientific disciplines.

2.2. Archaeological and cultural context

The bog sites of eastern Denmark have played an important role in establishing and developing Mesolithic archaeology in Europe (Fig. 1). The first investigation was at Mullerup in western Zealand (Sarauw, 1903) and the name of the bog, ‘Maglemosen’, later gave its name to the early Mesolithic of southern Scandinavia: the Maglemose culture (c. 11,600–8400 cal BP) (Brinch Petersen, 1993). The characteristic microlith flint technology and big game forest hunting distinguish it from the preceding late Palaeolithic hunters of the northern European plain. During the 20th century many Danish bog excavations defined and described the Maglemosian and became a frame of reference for early Mesolithic research in northern Europe. These Maglemose sites are positioned in the Preboreal, Boreal and the early Atlantic biostratigraphic zones.

![Fig. 1. A) Map of Denmark with the sites mentioned in the text. B) LIDAR map of Køng Sværdborg bog with early Mesolithic sites. LM: Lundby Mose, L: Lundby, S: Sværdborg, H: Hasbjerg, KF: Køng Flaskholm.](image-url)
though most date to the Boreal and no occupation sites are found until around the middle of the Preboreal. Amongst the best studied are Klosterlund (Mattiassen and Iversen, 1937; Brinch Petersen, 1966), Sværdborg (Friis Johansen, 1919; Broholm, 1924; Henriksen et al., 1976), Holmegård I, IV, V, VI (Broholm, 1924; Becker, 1945), Ulkestrup I & II (Andersen, 1951; Andersen et al., 1982), Barmosen (Johannson, 1990) and Lundby I & II (Henriksen, 1980; Hansen, 1995).

The Lundby Mose site lies close to the large Køng Sværdborg Bog which contains several well-known early Mesolithic sites. The best preserved are found on islets in the former lake, for example, the Boreal site Sværdborg I, which covers an area of 1.5 ha and the slightly younger sites on the Lundby Islet (Lundby I – III) (Brinch Petersen, 1972; Henriksen, 1980; Hansen, 1995).

3. Methods

After the initial discovery of worked elk bones, large trenches were opened with a mechanical digger and excavated in 1999 and 2000. The animal bone deposits and stratigraphy were documented by profile drawings and photographs (Figs. 2 and 3). The kettle hole is ~ 100 × 40 m and situated on arable land. The good preservation of the elk is due to their low-lying position below the level of present day drainage.

3.1. Cores and sampling

The cores were collected in 2010 from a position undisturbed by the previous excavation and approximately equidistant...
between deposits 1 and 5 (Fig. 3) (Lat: 55.103, Long: 11.864). A generalised description of the analysed core (180–258 cm below present day surface) can be found in Fig. 4. The shift from gyttja to peat occurs at 164 cm. The distinct 'dark-light-dark-light' gyttja stratigraphy immediately above the grey clay spanned ca. 6 cm at this position. The bone deposits found around the edge of the past lake stratigraphically correlate to the 'light' layer at 253–254 cm. Sub-sampling was undertaken from 180 through to 258 cm at 1 cm intervals for the estimation of organic and calcium carbonate content by loss-on-ignition (LOI) and pollen analysis.

3.2. Loss-on-ignition

Known weights of samples at 1 cm intervals between 180 and 258 cm were placed in crucibles and oven dried at 105 °C overnight. The remaining material was then fired at 550 °C for 4 h and at 1000 °C for 2 h (Boyle, 2001). The weight loss was calculated as a percentage of dry weight (Fig. 4).

3.3. Pollen analysis

A total of 44 samples were analysed from between 182 and 258 cm mostly at 1 cm analysis intervals in the lower section of the core (in stratigraphic association with the bone deposits) and at 2–3 cm intervals in the upper section. The samples were mounted in silicone oil after preparation following standard procedures (Fægri and Iversen, 1989) and each sample was spiked with one Lycopodium tablet for the estimation of pollen influx (Stockmarr, 1971). Percentage calculations are based on the total terrestrial pollen sum. At least 500 terrestrial pollen grains were counted in most of the samples but a few levels were counted to +350 grains and one level to only 278 grains due to low pollen numbers. Influx was calculated using the modelled sedimentation rate per year (grains/cm²/y). No weighting for variable pollen production by individual taxa has been applied.
4. Dating

4.1. Sediment chronology

The age model is based on 7 AMS radiocarbon ages of terrestrial macrofossils extracted from 1 cm sediment samples and includes a replicate sample from the lowest level in the Holocene sediments (254–255 cm) (Table 1 and Fig. 5). The replicate sample was submitted due to the outlier at 248–249 cm and confirms the age of the earliest lake sediment deposition. Dated samples were positioned at lithological boundaries. The radiocarbon ages were calibrated using OxCal 4.2 and IntCal09 and the age—depth model was produced with OxCal 4.1.7 (Bronk Ramsey, 2008; Bronk Ramsey, 2009; Reimer et al., 2009). Ages are reported as cal BP where BP denotes 1950 AD or as before 2000 AD (b2k). The replicated cali-

...tation is modelled to between 10,554 and 10,296 cal BP. The uppermost position, dated to date the shift to the Boreal period (Corylus >5%), is modelled to between 10,554 and 10,296 cal BP.

Based on this model, sedimentation rates show a decreasing trend between the onset of lake sedimentation at 11,310 cal BP (254 cm) and 10,740 cal BP followed by a period of high sedimentation rates (0.095 cm/y) until 10,450 cal BP. The shift to the Boreal biozone is modelled to 10,440 cal BP. The model omits the outlier at 248 cm as other data indicates a possible disturbance relating to lake levels (see 6.1). The stratigraphic position of the elk bone and antler deposits LM1–3 (249–254 cm) are modelled to between 11,310 and 11,250 cal BP. Analysis of samples for microtephra gave inconclusive results (Bramham-Law, pers. comm.).

4.2. Bones and antler

Nine bone samples and one antler sample were submitted for AMS radiocarbon dating and calibrated using OxCal 4.2 and IntCal09 (Fig. 6 and Table 2) (Bronk Ramsey et al., 2012; Reimer et al., 2009). During the excavation all the elk deposits were recorded as belonging to the same early Preboreal sediments but the resultant 14C ages range from 10,127 to 8877 14C BP indicate that they probably represent multiple events. Using the deviation, in terms of the standard deviation from combined weighted mean of all samples, the samples produced four separate groups (Table 3) suggesting four separate events. To further clarify, a Bayesian phase

<table>
<thead>
<tr>
<th>Table 1</th>
<th>AMS radiocarbon dates for Lundby Mose sediment core calibrated using OxCal v4.1.7 with IntCal09 (Reimer et al., 2009; Bronk Ramsey, 2009).</th>
</tr>
</thead>
<tbody>
<tr>
<td>Core depth (cm)</td>
<td>Lab no.</td>
</tr>
<tr>
<td>189–190</td>
<td>AAR14656</td>
</tr>
<tr>
<td>216–217</td>
<td>AAR14657</td>
</tr>
<tr>
<td>229–230</td>
<td>AAR14658</td>
</tr>
<tr>
<td>241–242</td>
<td>AAR14659</td>
</tr>
<tr>
<td>248–249</td>
<td>AAR14660</td>
</tr>
<tr>
<td>254–255</td>
<td>AAR14661</td>
</tr>
<tr>
<td>254–255</td>
<td>AAR16264</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 2</th>
<th>AMS radiocarbon dates for Lundby Mose bone calibrated using OxCal v4.2 with IntCal09 and Bayesian phase analysis (Reimer et al., 2009; Bronk Ramsey et al., 2012). The elk antler adze (AAR15630) is omitted from the model.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lab no.</td>
<td>Bone deposit</td>
</tr>
<tr>
<td>AAR15630</td>
<td>1</td>
</tr>
<tr>
<td>AAR15632</td>
<td>6</td>
</tr>
<tr>
<td>AAR5470</td>
<td>2</td>
</tr>
<tr>
<td>AAR5471</td>
<td>3</td>
</tr>
<tr>
<td>AAR15635</td>
<td>5</td>
</tr>
<tr>
<td>AAR15631</td>
<td>15</td>
</tr>
<tr>
<td>AAR15636</td>
<td>5</td>
</tr>
<tr>
<td>AAR15633</td>
<td>4</td>
</tr>
<tr>
<td>AAR15637</td>
<td>29</td>
</tr>
<tr>
<td>AAR15639</td>
<td>30</td>
</tr>
</tbody>
</table>

Analysis was performed using OxCal 4.2 with IntCal09. The resulting model has an agreement index of 117% and the plotted boundaries between the different groups also show four, clearly separate, phases (Fig. 6 and Table 2).
Phase 1 is based on 1 date, a shoulder blade (scapula) from LM6 (AAR-15632) and modelled to 11,960–11,610 cal BP (95.4%). Phase 2 is based on 3 dates of left mandibles from deposits LM1 (AAR-5470), LM2 (AAR-5469) and LM3 (AAR-5471). Phase 2 is modelled to 11,610–11,180 cal BP (95.4%). Phase 3 is based elk bones from LM4 (AAR-15633), elk and red deer (Cervus elaphus) from LM5 (AAR-15635, AAR-15636) and an aurochs bone (AAR-15631). This phase is modelled to 11,120–10,740 cal BP (95.4%). The last phase, Phase 4, is a small deposit of bones from a wild boar (Sus scrofa) (C229) and modelled to 10,170–9,910 cal BP (95.4%) (Fig. 6).

### Table 3
Lundby Mose bone deposits.

<table>
<thead>
<tr>
<th>Deposit Type</th>
<th>No. of individuals (elk)</th>
<th>Species</th>
<th>Sex and age</th>
<th>Age</th>
<th>No. of bones</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Offering</td>
<td>1</td>
<td>Elk</td>
<td>94.5–8.5 yrs</td>
<td>Early PBO</td>
<td>97</td>
</tr>
<tr>
<td>2 Offering</td>
<td>2</td>
<td>Elk</td>
<td>7–3 yrs</td>
<td>Early PBO</td>
<td>729</td>
</tr>
<tr>
<td>3 Offering</td>
<td>3</td>
<td>Elk</td>
<td>7–8 yrs</td>
<td>Early PBO</td>
<td>515</td>
</tr>
<tr>
<td>4 Offering</td>
<td>1</td>
<td>Elk</td>
<td>3 yr</td>
<td>Early PBO</td>
<td>127</td>
</tr>
<tr>
<td>5 Settlement waste</td>
<td>3</td>
<td>Elk, perch, pike</td>
<td>1–1.5 yrs</td>
<td>PBO</td>
<td>256 (Elk)</td>
</tr>
<tr>
<td>6 Diffuse concentration</td>
<td>17</td>
<td>Elk</td>
<td></td>
<td>Early PBO</td>
<td>13</td>
</tr>
</tbody>
</table>

5. Results

5.1. Archaeology and osteoarchaeology

The first three elk deposits (LM1, LM2 and LM3) (Fig. 3) were excavated in 1999 following the initial discovery (Hansen, 2003; Hansen et al., 2004; Hansen and Brinch Petersen, 2006) and were embedded in a layer of light coloured gyttja. The deposits were located in the south western part of the kettle hole and each covered a total area of approximately 1 m² (Figs. 3 and 7). These very tight clusters of bones indicate that they were thrown or put into the lake bound in some sort of wrapping, probably elk hide.

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**Fig. 6.** Calibrated bone dates, phases and boundaries. The elk antler adze is omitted from the model.
The northern part of the kettle hole was excavated in 2000 and another small elk deposit (LM4) was found along with the much larger deposit LM5 (Fig. 3).

The zoological analysis of the bones from Lundby Mose has shown that every elk carcass was incomplete (Leduc, 2010, 2012a). The missing parts form large skeletal portions such as heads, complete limbs, half parts of the axial skeleton and half ribcages. The good condition for organic preservations allows us to interpret these absences not as a product of differential preservation but as a result of human choices in terms of carcass treatment and selective transport or disposal (Leduc, 2012b, 2014). Many of the elk bones have numerous cutmarks. In LM1, 60.6% of the number of identifiable specimens (NISP) and 72.7% of the minimum number of elements (MNE) show cutmarks. Fewer cutmarks were seen in the other deposits but they are still noteworthy: LM3 (46% of NISP and 53.4% of MNE), LM4 (36.2% of the NISP and 53.4% of the MNE) and LM5 (27.7% of the NISP and 36.7% of the MNE). Cutmark location and arrangement highlights several phases of the carcass treatment, hide and sinew removal, disarticulation at all levels of the skeleton and meat removal on all bulky parts (Leduc, 2012a). Almost all bones containing marrow have been characteristically marrow split except from those of LM6. In spite of intensive refitting analyses of the marrow split bones, it was not been possible to connect the individual deposits and this suggests that the deposits represent multiple events (Leduc, 2012a, 2012b, 2014).

Single bones and small collections of bones from other animals, e.g. aurochs (Bos primigenius) (×15) and wild boar (×15) (Fig. 3) were additionally found. These both displayed a distinctly different character to the elk deposits and the wild boar deposit is dated significantly later (Table 2, Phase 4).

5.1.1. LM1

LM1 consists of 97 elk bone fragments and all except 3 bones probably belong to the same individual with a skull morphology suggesting a female. An age of between 4.5 and 8.5 years has been estimated based on teeth wear pattern (Leduc, 2012a). Many of the bones from the individual in LM1 are missing including a portion of the thoracic vertebra and ribs, the upper part of the right forelimb, the entire back of the animal, the carpals, tarsals and the lower parts of the leg and the right metatarsal. All skeletal remains containing marrow were marrow split and cutmarks suggest that slaughtering took place on site (Leduc, 2012a). An elk antler adze and two first incisors from an older individual were also included in the deposit (Fig. 8a).

5.1.2. LM2

LM2 was positioned 8 m south of LM1 and thus closer to the ancient lake shore (Fig. 3). The bones were less well preserved and more fragmented than those of LM1 and this is reflected in the analysis. LM2 consisted of two individuals with age estimates of 3–4 years and 8 years. Gender determination was not possible due to the poor preservation. Only 77 skeletal parts could be identified from within the 729 bone fragments found in LM2.

5.1.3. LM3

LM3 yielded 514 bones from 3 individuals and positioned approximately 15 m east of LM1 and LM2 (Fig. 3). Three male individuals aged 3, 4 and 6 years were identified. A sternum pierced by a flint point was also found in this deposit (Fig. 8b).

5.1.4. LM4

LM4 was found in the northern part of the lake basin, approximately 40 m north of the three first deposits. This
depots contained 127 elk bones from a single individual. It has an estimated age of 1–1.5 years but sex could not be determined.

5.1.5. LM5

LM5 was found in the northern part of the basin and is significantly different from the other deposits (Figs. 2, 3 and 9, Table 3). Firstly, it extends over an area substantially larger than deposits LM1–4 and secondly because it included a number of bones of species other than elk. These included red deer, wild boar, aurochs, roe deer (Capreolus capreolus), wild horse (Equus ferus), and hedgehog (Erinaceus europaeus) along with bones from freshwater fish and waterfowl. In all, 256 bones from at least three elk were found in LM5 but neither age nor sex could be determined. A group of 3 elk metapodials were interpreted as a hoard of raw material intended for bone tool manufacture. Additionally 12 flint artefacts, mostly simple blades, were found.

5.1.6. LM6

LM6 is situated east of deposits 4 and 5 (Fig. 3) and significantly different to the other bone deposits. It consists of 13 bones spread over an area of 20 square meters and therefore not a distinct concentration as per deposits LM1–4. According to the excavators, the bones in this deposit were found at lower stratigraphic levels than LM5 but unfortunately the stratigraphic context of the finds was destroyed when the profile collapsed due to a sudden flooding of the excavated area. None of the bones from LM6 were marrow split.

5.1.7. Other deposits

To the east of LM1–3 were found bones from aurochs (×15) and wild boar (×29) (Fig. 3). A radiocarbon age of the aurochs bone gave a date contemporaneous with LM5 (Table 2). The wild boar bones (×29) were dated considerably younger than the elk deposits and of Boreal age (Table 2).

5.2. Pollen analysis and LOI

The sequence has been grouped into zones based on combined visible changes in sediments, LOI, pollen percentages and pollen influx for the purposes of this description (Figs. 4, 10 and 11).

5.2.1. Zone a) c. 11,380–11,325 cal BP (259–255 cm)

The LOI profile from these clay rich sediments indicates low values of both organic and calcium carbonate content and thus indicates a high proportion of clastic material. Two pollen samples are available giving ~60% woodland taxa and 20–25% grasses and terrestrial herbs (based on total terrestrial pollen sum). Furthermore, high percentages of Cyperaceae (sedges) are recorded (max. ~80%), decreasing between the two samples, and indicate the presence of wetlands. High percentage values of the alga Pediastrum are also seen. Total pollen concentration values are low, averaging ~86,000 grains/cm². The age model is not considered sufficiently reliable to calculate total influx for this zone.

5.2.2. Zone b) c. 11,325–11,250 cal BP (255–249 cm)

Sedimentation in the basin switches from clays to gyttja at c. 11,325 cal BP. As can be seen in Fig. 4, an alternating sequence characterised by variable organic input continues until c. 11,250 cal BP. The elk bone deposits were excavated from this distinctive sediment stratigraphy and this is clearly identified in the core. At this core position these alternating layers are of similar thicknesses, but the available profile sketches and excavation photographs show that the lighter, more calcareous layers dominate closer to the edges of the lake. Relatively high percentage pioneer type woodland pollen taxa (~80%) mainly birch and pine are recorded. Within the terrestrial herbs are also recorded, albeit at very low percentages, Plantago major (greater plantain) and Rumex acetosella (sheep’s sorrel). All taxa contribute to the low total pollen influx values (~7000 grains/cm²/y). Wetland taxa percentages are much lower than in the previous zone (a) at ~30–40%. The sequence shows peaks in Filipendula (meadowsweet), Equisetum (horsetail) and Salix (willow) concentrated in this zone and decreasing percentages of Empetrum nigrum (crowberry).

5.2.3. Zone c) c. 11,250–11,160 cal BP (249–242 cm)

At c. 11,250 cal BP (249 cm), a rapid and brief increase is seen in organic and CaCO₃ contents and in pollen influx. This is also the position of the outlier in the radiocarbon dates and a marked decrease in Pediastrum percentages. Subsequent to this peak, organic content values remain higher than previously (~25%), whereas CaCO₃ content shows only a minimal increase. Percentages of woodland taxa show an increasing trend with a corresponding decrease in grasses and terrestrial herbs. A slight halt in increasing trend of woodland taxa and a resurgence of Poaceae (grasses) is evident at c. 11,200 cal BP. Salix, Filipendula, and Equisetum all show declining percentage trends through the time period of this zone and Betula (birch) shows a strong increase from ~40% to over 60% by 11,160 cal BP. No significant hiatus at c. 11,250 cal BP is indicated by the pollen percentages which continue to demonstrate an undisturbed classical immigration sequence of thermophilous trees and shrubs during the Holocene (Iversen, 1960). Within this group, E. nigrum disappears and Equisetum and Filipendula decline as would be expected from the classical...
Fig. 10. Lundby Mose percentage pollen diagram on age (cal BP) scale calculated on total terrestrial pollen. Also showing depth scale, lithology, LOI data, pollen zones and position of the associated bone deposits.
sequence and this is seen in both percentage and influx. Total terrestrial influx values increase to ~21,200 grains/cm²/y in this zone.

5.2.4. Zone d) c. 11,160–10,980 cal BP (242–230 cm)

Betula dominates pollen percentages during this period. Poaceae percentages remain fairly stable (~20%) but within the longer term decreasing trend and with a general decrease in the contribution from other terrestrial herbs. Wetland taxa are below ~10% and remain so throughout the remainder of the analysed portion of the core. Total pollen influx average ~18,700 grains/cm²/y. This zone shows an increase in CaCO₃ content to ~30% relative to organic content of ~20% (Figs. 4 and 10).

5.2.5. Zone e) c. 10,980–10,740 cal BP (230–217 cm)

Percentage organic content recovers during this period to between ~40 and 50%. The woodland taxa are still dominated by Betula but Pinus (pine) increases its relative contribution for a c. 100 year period that centres at c. 10,850 cal BP. A little later at c. 10,800 cal BP, and for a shorter time period, influx values of especially Betula but also Pinus are decreased to levels resembling those prior to c. 11,250 cal BP. However prior to c. 10,740 cal BP, the influx values, which are mainly controlled by the Betula influx, fluctuate between c. 5000 and 20,000 grains/cm²/y so this decrease is not especially marked. Grass percentage values remain between 9 and 20% of total terrestrial pollen. Total pollen influx values continue to increase and are now ~18,500 grains/cm²/y. The presence, although at very low percentages, of P. major, Plantago lanceolata, Rumex acetosa and the return of Artemisia sp. is also seen in this zone.

5.2.6. Zone f) c. 10,740–10,450 cal BP (217–190 cm)

Vegetational composition is now dominated by woodland taxa (>90%) and strongly dominated by Betula and Pinus. Terrestrial herbs, mainly Poaceae, now decrease to minimal values as does the contribution of wetland taxa. Organic content decreases and CaCO₃ increases slightly relative to Zone e). Pediastrum increases slightly compared to the previous three zones (c, d and e). Total pollen influx values average ~27,500 grains/cm²/y.

5.2.7. Zone g) c. 10,450–10,350 cal BP (190–182 cm)

This zone shows a sharp increase in Corylus (hazel) increasing from around 5%–37% within c. 100 years. Betula shows a corresponding decrease in dominance corresponding to the rise in Corylus. Woodland taxa continue to dominate and total influx values reach maximum at an average of ~34,600 grains/cm²/y. Organic content remains relatively high, fluctuating around 30%.

6. Discussion

6.1. Dating and core chronology

All age calibrations from the early Preboreal give large ranges with overlapping probability distributions due to the major plateau in the IntCal09 calibration curve (Mellars, 1990; Cziesla and Pettitt, 2003; Reimer et al., 2009). According to the Greenland Ice core chronology (GICC05) the rapid warming marking the shift from the Younger Dryas cold period to the Holocene occurs within just a few years at 11,703 b2k (11,653 cal BP) (Rasmussen et al., 2006; Blockley et al., 2012). The shift from the grey, clay-rich Younger Dryas gyttja to Holocene gyttja in the Lundby Mose sediment core (Zones a/b) is modelled to between 11,348 and 11,276 cal BP (Fig. 5) (unmodelled ages of earliest Holocene gyttja are 11,602–11,246/11,595–11,243 cal BP (Table 1)). This suggests a significant time difference (~300 years) between the Greenland Younger Dryas–Holocene shift as defined in the ice cores (Rasmussen et al., 2006) and the sedimentary and biostratigraphic shift seen in the Lundby Mose sediments. A hiatus could exist between the Younger Dryas and Holocene sediments if lake levels were either so low that sedimentation ceased or if the lake dried out and eroded the topmost
deposits. This is not however, suggested by our data as no erosive boundary is evident and the two pollen levels counted from the clay rich sediments already show high percentages of woodland taxa (>60%) (Fig. 10). It is more likely that the earliest Holocene pollen is found within the top few centimetres of the ‘Younger Dryas type’ sediments together with significantly increased values of Cyperaceae, which is typical for Younger Dryas sediments in Denmark.

Higher up in the sequence, the date outlier at 248 cm along with the sediment changes and pollen influx peak could also suggest a possible hiatus at this depth. However it is evident that no significant hiatus is indicated by the pollen sequence and the age—depth model does not indicate that any significant length of time is missing from the sequence. Although it is recognised that this could be misleading as the model assumes continuous sedimentation. For the purposes of this paper therefore, and in the absence of further evidence, we propose that no significant hiatus exists and that the anomalous data represents redeposited older sediments which may relate to lake level changes associated with melting dead ice.

The terrestrial macrofossil dates from the distinctive Preboreal gyttja in the sediment core models to an age between c. 11,325 and 11,250 cal BP (Fig. 5, Table 1). The bone deposits are associated with these sediments. The two oldest bone and antler ages are from deposits LM1 and LM6 and date to between c. 11,980 and 11,610 cal BP (Fig. 6, Table 2). This mismatch would suggest that either the sediments are giving ages too young or that the bone and antler are giving ages which are too old. Two points can be made here with reference to these radiocarbon ages. Firstly, the antler adze dates a few centuries older than the other bone dated from the same deposit (LM1) and secondly, the age of the bone from LM6 was excavated from an uncertain stratigraphic context due to the collapse of the profile and therefore it is possible that it was deposited in the Younger Dryas. This is however, considered unlikely as although there is evidence of elk in Scania at this time (Magnell et al., 1999), none of the other many elk bones found in Denmark have as yet been dated to the Younger Dryas period (Aaris-Sørensen, 2009). Thus the scapula from LM6 probably represents the earliest deposit in Lundby Mose but of Holocene date. One explanation for why the antler adze is older than the other dated bone of LM1 may be that it was already an old adze when it was deposited. The adze is broken at the base so this could be a plausible explanation. It is also possible that the difference in age between the elk bones (LM1 and LM6) and the antler adze (LM1) and the earliest Holocene sediments may relate to a hitherto undocumented reservoir effect. Not only were the early Holocene soils unstable and calcareous in this region at the time, it is known that elk can consume a large proportion of their diet from aquatic plants, especially in certain seasons (Belovsky and Jordan, 1981; Fraser et al., 1984). Although the 14C values of these bones are similar to the later dated bones and are within the terrestrial range, it still may be possible that the freshwater reservoir effect may be biasing the results in this case and producing ages which are too old (Fischer et al., 2007; Olsen et al., 2010). A sample from the LM6 elk bone is presently being analysed by compound specific radiocarbon dating to further assess this.

6.2. The Preboreal environment

The pollen diagrams illustrate the classic immigration sequence of thermophilous trees and shrubs of the early Holocene and the formation of the Preboreal forest after the end of the Younger Dryas seen in previous pollen work (Iversen, 1973). The distinct peaks of E. nigrum followed by Filipendula and Equisetum in the early Preboreal are seen together with those of Populus and Juniperus. These two latter taxa show peaks somewhat smoother than those often seen in other diagrams but this may be due to the high resolution provided by the Lundby Mose sediments (Zones a and b; Figs. 10 and 11).

At first sight, the pollen percentage assemblage would indicate a fairly established forest both prior to and continuing into the earliest gyttja sediments with Betula and Pinus dominating for the whole of the Preboreal time period (Fig. 10). It is important to note however, that influx values are extremely low prior to c. 11,250 cal BP (Zones a and b). Pollen percentages describe the relative composition of the pollen taxa illustrating their changing dominance/weakness in comparison to each other in the total spectra. Pollen influx describes the actual number of pollen deposited in the sediments per year and indicates the pooled production of pollen by the vegetation. Each can be affected by other variables, for example the taxa in percentage diagrams are interdependent and only describe their relative composition. On the other hand, pollen influx values can be distorted by variable sedimentation changes and cannot be applied where the chronology, and therefore the sedimentation rate, is inadequate. Woodland pioneer type taxa percentages are already high in the early Preboreal which would indicate the presence of forest (Zones a and b) but this contrasts with the distinctly low influx values and the presence of open ground type taxa which together would indicate a more open landscape. Total influx values are strongly correlated to Betula but all influx values are low regardless of whether the taxa are wetland herbs, terrestrial herbs or woodland taxa. Thus the pollen percentages and influx values could suggest that forest taxa were present in the environment but with low pollen production. This effect would be amplified by any long distance transport of forest pollen which would produce a more significant proportion of the total due to limited local input. A more open landscape at this time is supported by the correlation of pollen influx values with those of organic content as open landscapes generally input less organic material into a lake than forested landscapes (Bennike et al., 2004).

The Lundby Mose data presented here show that although the proportions of the different taxa are as seen in previous percentage studies, the influx data suggests that a ‘Preboreal forest’ in the classical sense is delayed at least until c. 11,250 cal BP, and possibly even longer. This is at least 400 years after the shift to the Holocene as per the ice cores. The accepted picture of the early Holocene vegetation in southern Scandinavia is based upon the many pollen and macrofossil studies (Nathorst, 1871; Hartz and Milthers, 1901; Jessen, 1920) produced by pioneers in the field. In the following years research questions were mainly aimed towards understanding the immigration of different plant taxa during the Holocene and the development of forest (e.g. Iversen, 1942, 1960; Berglund et al., 1994). Most of these were based upon pollen percentage data. The absence of concentration or influx data (or plant macrofossil data) in these pollen diagrams may have given a distorted picture of the landscape development. Recent research into Allerød landscapes using both pollen and plant macrofossil data have shown a significant delay (c. 200 years) between the appearance of trees in the pollen diagram and their actual presence in the landscape (Mortensen et al., 2011, 2014a, submitted for publication). A late Glacial pollen and macrofossil analysis from Hassela, 40 km south of Lundby Mose, stretches only a short time into the Holocene but no macrofossils of tree birch are found while pollen percentages would otherwise indicate the presence of forest (Mortensen et al., submitted for publication). Similarly at Slotseng, southern Jutland, the first c. 200 years of the Holocene had very low pollen influx and no macrofossils of tree birch (Mortensen et al., 2011). In the Slotseng study, Betula pollen was separated on the basis of size, into tree birch and dwarf birch (Betula nana) and shows that in the first c. 200 years, dwarf birch continues a decreasing trend begun at
the end of the Younger Dryas but also that tree birch was minimal. Most Danish Holocene pollen analyses do not separate between tree and dwarf birch but those available indicate a longer than expected delay between the beginning of the Holocene and the classical early Holocene forest landscapes (Kolstrup, 1982; Kolstrup and Buchhardt, 1982).

How far the forest had developed is an important question relative to human settlement. The pollen data from Lundby Mose suggests that the bones from LM1–4 (Phases 1 and 2) and those from LMS (Phase 3) were deposited in different types of landscapes. The tight bundles of elk bones (LM1–4) are associated with an environment where soils are unstable and the pioneer forest is limited with patchy areas of more open grasslands (Zone b, c. 11,325–11250 cal BP). The settlement waste deposit with multiple species (Table 3) is associated with an environment where the Preboreal forest is more established but where some grassland still persists (Zones d/e, c. 11,160–10,740 cal BP) and therefore an environment well suited to the variety of fauna found in this deposit. These grasslands do not disappear until after c. 10,740 cal BP. It is also interesting to note here that a number of terrestrial herbs which can be associated with humans or animals disturbing the ground and trampling are especially present in pollen Zones b and e. i.e. the zones associated with the bone deposits. Climate reconstructions and orbital forcing show that temperatures would have been suitable for the establishment of an extensive Preboreal forest (Coope and Lemdahl, 1995; Lowe et al., 1995). It is clear that the taxa were present in the region, but it is not clear how quickly they thrived or how quickly forests were formed with their associated stabilization of the soils. The discrepancy seen in these few available datasets between pollen percentages and those of plant macrofossils and pollen influx during the Preboreal thus raises the question of whether this could also apply to other Preboreal sites in Denmark. If this is the case, our interpretation of the pollen percentage diagrams previously published, and upon which many of our perceptions of the Preboreal landscape are based, should be adjusted. The correct reconstruction of the actual, local vegetation and the presence/absence of forest are vital to our interpretation of archaeological material and to the understanding of early Mesolithic subsistence and culture.

The break of c. 50–100 years (Zone c) in the increasing percentage trend of Betula and the decreasing trend of Poaeeae is of a similar pattern to that seen in the pollen data analysed from a core collected from Belling Lake in 1939 (Iversen, 1942, 1967; de Klerk, 2004). Although it is not possible to date this early work, a rapid climatic cooling in the early Preboreal has since been identified in many other climatic proxies and known as the Preboreal Oscillation (PBO) and is associated with a major freshwater input into the North Atlantic (Fairbanks, 1989; Bard et al., 1996; Björck et al., 1997; van der Plicht et al., 2004; Rasmussen et al., 2006; Bos et al., 2007; Blockley et al., 2012). The PBO is dated to 11,450–11,350 in the Greenland ice core chronology GICC05 (Rasmussen et al., 2007), but it is difficult to correlate this event with terrestrial sediment proxies due to both radiocarbon plateau and proxy responses. The PBO is clearly registered in the ice cores c. 300 years after the onset of the Holocene and lasts around 100 years, but its response in terrestrial ecosystems (often based on summer proxies only) appears to be delayed and may not begin until towards the end of the ice core responses (Björck et al., 1997; Bos et al., 2007). In the Lundby Mose data the changes are seen centred at c. 11,230 cal BP and are within the wiggle-matched dates of the PBO (Rammelbeek Phase) of The Netherlands (Bos et al., 2007). The PBO occurs within a time period when climate is dynamic and unstable, and when the vegetation is developing and responding to many changes in addition to those of regional climate. As with all proxy reconstructions from this time period it is difficult to disentangle these different responses and be certain whether they are in association with the PBO as identified in the ice cores.

The biostratigraphic end of the Preboreal period is positioned at the point when Corylus avellana t. pollen rises above c. 5% of total terrestrial pollen. This sharp rise is modelled to c. 10,450 cal BP (10,509–10,387 cal BP) in the Lundby Mose sediments and one of the older dates of this event in Denmark which can vary by up to 800 years (Iversen, 1967; Fritzbøger and Odgaard, 2010).

6.3. The archaeological material

6.3.1. Cultural affiliation

Early Mesolithic culture is primarily defined through its lithic artefacts (Brinch Petersen, 1966; Sørensen, 2006). Only uncharacteristic specimens were found at Lundby Mose and it is difficult to definitively link the deposits to a cultural affiliation. A few artefacts were found which can aid the association of the Lundby Mose material with their archaeological context. Lithic analysis of the few flint blades and flakes found in LMS has shown that they may belong to the early Mesolithic Maglemose phase 0 (Sørensen, 2006), although the number of artefacts is insufficient for quantitative analysis. A settlement site, Lundby IV, lies close to the kettle hole and is also typologically dated to the earliest part of the early Mesolithic Maglemose culture (Johannson, 1990). The earliest sites in southern Scandinavia, belonging to Maglemose phase 0, are defined by both microlithic typology (Brinch Petersen, 1966) and lithic technology (Sørensen, 2006) are Barmosen 1 (Johannson, 1990) Draved 611 & 604 south (Sobotta, 1991) and Klosterlund (Tauber, 1971). Outside of southern Scandinavia Preboreal Mesolithic sites known from northern Germany are Duvensee (Bokelmann et al., 1983), Bedburg-Könighoven (Street, 1991), Friesack 4 & 27 (Gamsch, 1991, 2000; Görßdorff and Gramsch, 2004) and Haverbeck (Tolkildorf et al., 2009). Two other sites close to Lundby Mose; Favrbo (2 elk) and Skottemarke (6 elk) have been dated to approximately the same period as Lundby Mose Phase 3 (Sørensen, 1978; Fischer, 1996). The artefacts found at Skottemarke (large flake axes, a broken microlith and fine notched bone points) (Fischer, 1996) suggest that the elk were deposited very close to a settlement site.

Two other artefacts are of much more importance when considering the typological dating of the elk deposits. Firstly a sternum pierced by a flint point was found in the deposit containing 3 elkls (LM3) (Fig. 8b). The base of the point was broken off leaving only the tip deeply embedded in the bone. This cannot be extracted without either breaking the bone or the point and it is not possible to determine the flint type from a visual analysis of the exposed part. The tip may have lateral retouch on one side but this is not diagnostic as this feature can be found on flint points from both the late Palaeolithic and the early Mesolithic. The second artefact is the worn elk antler adze found in LM1 (Fig. 8a). Elk antler adzes are so far only known from Preboreal, early Mesolithic contexts in southern Scandinavia and sites in adjacent areas such as Friesack IV in Germany (Pratsch, 2011) and Star Carr in Yorkshire, England (Clark, 1954; Mellars and Dark, 1998). On the Scandinavian Peninsula elk antler adzes are also found in later contexts (Mikkelsen and Høeg, 1977) and on the upper Volga, they are dated to both the Preboreal and the early Boreal periods (Hartz et al., 2010). It is significant for the interpretation of the Lundby Mose site that no elk antler adzes have been found in a late Palaeolithic context and that the pollen analysis shows that the adze is associated with the Preboreal.

So far the best key to understanding how humans responded to the Holocene climatic changes seems to be via the Epiahrensburgian and the ‘long blade’ industry (Goh, 1991; Johannson and Stapert, 1999; Terberger et al., 2009). This lithic industry has
been dated to the end of Younger Dryas/beginning of the Preboreal in the United Kingdom and France (Barton and Roberts, 2004). In southern Scandinavia the Long Blade Industry has been identified at the site Norrégård IV in Jutland (Sørensen and Sternke, 2004) and at Årup in Scania. At Årup one lithic concentration has been categorised as Ahrensburgian (Karsten and Nilsson, 2006), but as it is based on lithic technology and a single radiocarbon date, it is more likely that it belongs to the Epi-Ahrensburgian/Long Blade industry sphere (Sørensen, 2007; Brinch Petersen, 2009).

6.3.2. The bone deposits

Lundby Mose is by far the largest Preboreal elk deposit site known and it is evident that the deposits LM1–4 do not represent a random disposal of bones. The bones in these deposits have been carefully selected and not mixed with other species and are interpreted as ritual deposits (Hansen et al., 2004; Pedersen, submitted for publication). The many cutmarks show the importance of separating the bones from the meat and hide although the many marrow split bones show that some parts of the elk were cooked and eaten close to the kettle hole. It is significant that not all of the bones from the elk skeletons were deposited in the kettle hole. Missing parts include the metapodials, (where the best meat could be found) and the skulls. The missing parts were possibly transported to, as yet unknown, settlement sites in the vicinity.

LM5 is evidently dissimilar to the other deposits (Table 2, Fig. 9) and has multiple species represented. The composition of bones is similar to those found at the Boreal sites in Kong-Svärdborg bog (Aaris-Sørensen, 1976) and supports the interpretation of LM5 as a refuse layer rather than as a ritual offering as per LM1–4. No Mesolithic settlement sites have, as yet, been directly dated to the early Preboreal in southern Scandinavia and LM5 most likely represents waste from the site Lundby IV which lies ~100 m NW of the deposit. Lundby IV can be compared to the site Barmose I, which is typologically dated to the earliest part of the Maglemose culture, phase 0 (Sørensen, 2006), and radiocarbon dated to the later part of the Preboreal (Johansson, 1990; Fischer, 1996). This agrees with the radiocarbon ages from this study. The Lundby IV site was identified only through surface finds and has never been excavated. No settlement features were found on the shores of the kettle hole during the excavation of Lundby Mose, although field walking did produce early Mesolithic to late Neolithic flint artefacts in the vicinity of the Preboreal lake.

The four different phases at Lundby Mose are dated to c. 11,500 cal BP, c. 11,200 cal BP, c. 10,800 cal BP and c. 10,300 cal BP (Fig. 6). Of these only the 3rd and 4th phases correspond with known, dated, early Mesolithic settlements (Brinch Petersen, 2009). The first and second phases are considerably older than the previous known oldest Mesolithic settlement sites from the area. Only Stellmoor (Fischer and Tauber, 1986) and the dated Long Blade Industry sites from northern France and the United Kingdom (Wymer et al., 1975; Lewis, 1991; Fagnart, 1997) are as old as the earliest Lundby Mose phases.

It is relevant to ask whether the oldest deposits are the remnants of the last Palaeolithic hunters or the first of the Mesolithic (Hansen and Brinch Petersen, 2006). Apart from the elk antler adze there are other features from the Lundby Mose deposits that link this site to the early Mesolithic rather than the late Palaeolithic. Based on the analysis of the bones from Lundby Mose it can be concluded that the characteristic breakage of the mandible is part of a characteristic Maglemose bone breakage pattern, which has also been identified in the other early Mesolithic sites at Favro, Skottemarke, Mullerup and others (Leduc, 2012b). Additionally, all the preserved shoulder blades from Lundby Mose show that the spine was removed. This distinctive feature was also identified at the Mesolithic sites Skottemarke and Favro and was probably part of a post-kill ritual (Mahl, 1978). Thus, the absence of adzes in the late Palaeolithic, the characteristic bone breakage and the association with the Preboreal pollen assemblage argues in favour of an early Mesolithic Maglemose context for the first two phases at Lundby Mose. These early phases are associated with an environment with limited and/or patchy forests. The later phases in Lundby Mose are associated with the further development of forest, more variable faunal remains and known settlement sites in the region. Since these observations are specific to this region, it seems reasonable to suggest that the shift from late Palaeolithic to Mesolithic cultures was part of the human response to the environmental changes that took place at the beginning of the Preboreal and seen mainly in southern Scandinavia.

7. Conclusions

The Lundby Mose data and the integration of research disciplines have aided our understanding of how humans responded to the major environmental changes affecting northern Europe during the shift to the Holocene. The archaeological and the palaeoenvironmental data show different human practices associated with different landscapes. These are separated by only a few hundred years and show a change from the sporadic ritual use of the site in an underdeveloped forest to a semi-permanent settlement in a more developed forest supporting a greater variety food sources. This site represents some of the earliest Mesolithic traces from the region and reveals an ability to rapidly adapt to major environmental changes with their associated changes in food and material resources.

The main conclusions can be summarized thus:

- Lundby Mose is the largest known site of elk deposits dating to the early Mesolithic/early Preboreal in the northern European plain and is the earliest Holocene evidence for the presence of humans in southern Scandinavia.
- The deposits illustrate two different site types: bundled elk bones indicating a temporary cultural act and settlement waste associated with a semi-permanent settlement.
- The bundled elk bones were deposited in an environment where forest was not yet fully developed. The bones show numerous cutmarks and were marrow-split before selected skeletal parts were bundled together and placed or thrown into the shallow lake.
- The settlement waste dates to c. 100–200 years later than the bundled bone deposits. This deposit is associated with a more developed Preboreal forest landscape and a much wider range of fauna. This phase may be associated with a known settlement site located close to the ancient lake.
- No occupation sites have been found from the early Preboreal/early Mesolithic during the time period when this data suggests limited forest cover.
- This work along with other recent studies raises questions as to how well pollen percentage diagrams alone describe the actual landscape during climatic transitions. The comparison of pollen percentage and influx data suggests that the establishment of forest in Denmark occurred several hundred years later than that suggested by the classic picture produced by past pollen percentage studies.

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