The Arresø area

Arresø (Fig. 1) is the largest lake in Denmark, with an area of 3987 ha. The lake is shallow with a mean water depth of 3.1 m and the greatest depth is 5.6 m (Fig. 1B). The eutrophic lake is exposed to wind, and during stormy weather surface currents up to 30–50 cm/sec can be created. Deep areas are confined to narrow troughs that are probably kept free of sediments due to bottom currents. The lake level is 4.0 m above present sea level (Høy 1996; Fronval et al. 2012). The tidal range in the region is about 10 cm at spring tide (Leppäranta & Myrberg 2009).

In the Middle Holocene the Arresø area was a marine bay or fjord called Arrefjord by Rørdam (1892). Figure 2 shows the palaeogeography of Arrefjord according to Andersen & Houmark-Nielsen (2014). Two older palaeogeographical maps were published by Rørdam (1892) and Milthers (1922). Rørdam showed a larger extent of Arrefjord than later reconstructions, including a strait from Arrefjord to Roskilde Fjord to the south. Coring is needed to show if such a strait existed. Several small shallow inlets were situated along the shores of Arrefjord (Fig. 2). The fjord was connected to the Kattegat sea to the north-west via
from Arresø to Kattegat was at first located north-west of the lake, but this outlet was later closed and then changed southward to Roskilde Fjord. The new outlet was eventually also closed due to sand drift, and farms and fields along the shores of Arresø were occasionally flooded during the spring. In 1717 to 1719, a canal was dug between the lake and Roskilde Fjord (Fig. 1B); this canal still exists.

Raised marine deposits and fossil coastal cliffs are found along the shores of Arresø (Rørdam 1892; Milthers 1922). Rørdam (1892) noted that the marine shells found along the shores of Arresø are small and thin, indicating brackish-water conditions. However, at Vejlebro at the southern end of Arresø (Fig. 1), the shells are unusually large and thick, indicating higher salinities, which could be due to strong currents at this locality.

Milthers (1922) provided lists of marine molluscs from five localities with raised fjord deposits around Arresø. The lists comprise the following mollusc species: *Mytilus edulis* (blue mussel), *Cerastoderma edule* (cockle), *Macoma balthica* (baltic tellin), *Scrobicularia plana* (peppery furrow shell), *Tritia reticulata* (netted dogwhelk), *Littorina littorea* (edible periwinkle) and *Lacuna vincta* (banded chink shell). The low species diversity and the species assemblages indicate brackish-water conditions.

Archaeological sites around Arrefjord

Several archaeological sites around the present lake have been excavated. It was imperative to establish
when the Arresø shifted from being a salt-water fjord to a fresh-water lake in our effort to understand the sites which date from the early Mesolithic until the Bronze Age (Fig. 3). This was one of the main reasons for the collaboration between the Geological Survey of Denmark and Greenland and Museum Nordsjælland.

At Vejlebro south of Arresse (Fig. 1), a Mesolithic settlement with shells of *Cerastoderma edule*, *Mytilus edulis*, *Littorina littorea* and rare *Ostrea edulis* (oyster) was investigated by Malmros (1975). Radiocarbon dating gave ages between c. 7600 and 6000 years BP. At Vejlebro there is also an offer well with animal bones and pieces of wood from the Bronze Age. Prehistoric wells from the region are often placed in wetland areas and cannot be seen as reliable indicators of settlements and lake levels in the Bronze Age.

At another Mesolithic site, Kassemose, which is located north-west of the present day Arresø (Fig. 1), excavations revealed a Mesolithic shell midden, roughly from the same time period as the settlement at Vejlebro. The Kassemose settlement is situated on high ground like that at Vejlebro. Shells of the molluscs *Ostrea edulis*, *Cerastoderma edule*, *Mytilus edulis*, *Littorina littorea* and *Tritia reticulata* were reported. This site also contains a rich assemblage of bird and mammal bones which were identified by Herluf Winge in 1908 (unpublished data in the archives of Museum Nordsjælland).

A third site that provides indications of the salinity in prehistoric time is a Bronze Age grave at Junghøj on the southern shore of Arresø (Fig. 3). The grave is covered by stems and leaves of *Zostera* (Appel & Pantmann 2013) which shows that Arresø was a salt-water fjord in the time period around 3200–3000 years BP. After the end of the Bronze Age (about 2500 years BP) there are no clear archaeological records that can provide information about the development of the Arresø area.

**Methods**

Coring was carried out from a floating platform with a Russian peat corer (Jowsey 1966). The chamber was 1 m long and had a diameter of 7.5 cm. The corer was hammered down into the sediment. We cored first at 55°59.255′N, 12°06.797′E where the water depth is 2.2 m (site A in Fig. 1) and then at 55°59.480′N, 12°06.797′E where the water depth is 4.4 m (site B). We also cored closer to the shore, but found only sandy sediments that were not suitable for palaeoecological studies.

Whole cores were cleaned and subsampled in the laboratory. Contiguous 4 cm thick samples were taken for macrofossil analyses. Sediment samples were wet sieved on 0.4, 0.2 and 0.1 mm sieves, and the residue left on the sieves was transferred to a petri dish. Macroscopic remains of plants and animals were identified and counted using a dissecting microscope. The numbers in the macrofossil diagrams refer to the number of shells per sample; however, many of the shells represent small juvenile specimens. Many of the shells, especially of *Mytilus edulis*, were fragmented – in this case, hinge fragments were counted. In general, preservation was good to excellent, but at some levels carbonate shells were somewhat dissolved. This means that thin-shelled organisms may be under-represented at these levels. A total of 320 samples were analysed for macrofossils.

The mollusc nomenclature in this paper follows the World Register of Marine Species (2017), where synonyms are also listed. We have referred shells of the bivalve *Cerastoderma to Cerastoderma* spp. Most of the shells we found belonged to *Cerastoderma glaucum* (= *Cerastoderma lamarcki*), but *Cerastoderma edule* was also present, as well as numerous transitional forms between them. Rasmussen (1973) showed that all transitional forms between the two species currently live in Isefjorden close to Arresø. Specimens of *Hydrobia*...
spp. (spire shell) cannot be reliably identified to species from shell morphology alone, but it seems that the three species reported from Danish waters by Muus (1967) are represented in the material from Arresø.

Selected remains were dried and submitted for radiocarbon dating using accelerator mass spectrometry. Dating was carried out at the Aarhus AMS Centre, Aarhus University. Radiocarbon ages were calibrated to calendar years before present (BP) and we discuss only the calibrated ages in the text and in Table 1.

For marine samples, we used a reservoir age of 400 years. In the calibration program, this corresponds to a ΔR value of 0. However, the local reservoir age may have varied in the past (Olsen et al. 2009), and ages of marine shells are therefore somewhat uncertain.

Results

Sediments

Simplified sedimentological core logs are shown in Fig. 4. The sediments at core site A consisted, from the bottom upwards, of (1) 16 cm poorly sorted sand and fine gravel with angular granules and pebbles and wood fragments, found at c. 8 m below the lake bottom, (2) 269 cm dark grey homogeneous clay and silt with marine shells, sandy at the top, (3) 8 cm laminated clay and silt without marine shells, (4) 279 cm brown homogeneous gyttja with marine shells, and (5) 232 cm light greenish homogeneous loose detritus gyttja.

At core site B, the sediments consisted, from the bottom upwards, of (1) 7 cm grey hard and firm diamicton with root and wood fragments found at c. 6 m below the lake bottom, (2) 7 cm brown gyttja with abundant Ruppia fruits, (3) 312 cm dark grey very fine-grained sand, silt and clay with marine shells and some granules and small pebbles at the base, (4) 116 cm brown homogeneous gyttja with marine shells, and (5) 130 cm light greenish homogeneous loose detritus gyttja with an erosive lower boundary.

Macrofossils

Core site A. The macrofossil diagram from core site A was divided into seven assemblage zones (A1–A7; Fig. 5).

Zone A1 represents the sediments found below the marine sediments. In addition to wood fragments, one nutlet of Betula sect. Albae (tree birch), one sclerotium of the fungus Cenococcum geophilum and one seed of Phragmites australis (common reed) were found.

Zone A2 is rich in tests of foraminifers (dominated by Ammonia beccarii and Elphidium sp.) and shells and shell fragments of Mytilus edulis. The gastropods Rissoa membranacea, Rissoa lilacina and Littorina littorea and the bivalve Scrobicularia plana are also fairly common, whereas Macoma balthica is rare. Hydrobia spp., Cerastoderma spp. and Ostrea edulis occur in the lower part of this zone, whereas the bivalve Corbula gibba, the sea urchin Echinocardium cordatum and the ostracod Cyprideis torosa are found in the upper part of the zone. Rare species in this zone include the hydroid Dynamena pumila, the polychaete worms Nereis sp. and Pectinaria sp., the gastropods Tritia reticulata, Bittium reticulatum,
Zone A5 is rich in shells of *Mytilus edulis* and *Littorina littorea*. In the upper part of the zone, Cerastoderma spp., *Hydrobia* spp. and the submerged macroalga *Zannichellia palustris* are present in high and increasing concentrations. A shell of *Arctica islandica*, a shell of *Velutina plicatilis* and a jaw of *Nereis* sp. were also noted. An endocarp of the pondweed *Potamogeton pectinatus* was found in the uppermost sample. The total number of mollusc taxa in this zone is seven.

Zone A6 is characterised by abundant valves of *Cyprideis torosa*; another ostracod genus, *Candona*, is common.

Zone A7 is dominated by cladocerans and chironomids. In the lower part, the charophyte *Chara* sp., the ostracods *Darwinula stevensoni*, *Limnocythere* spp., *Candona* spp. and the cladoceran *Leydigia* sp. are common, and the ostracod *Ilyocypris* sp. and the gastropod *Bithynia tentaculata* also occur. Statoblasts of the bryozoan *Cristatella mucedo* are rare in the lower
part of the zone, shows a peak and then disappears. The Cristatella mucedo peak coincides with rare occurrences of Potamogeton spp., Zannichellia palustris and the caddis fly Orthotrichia sp. Daphnia cf. pulex shows a marked peak in the upper part of the zone. Zone A7 also includes rare finds of other invertebrates such as the leaches Piscicola geometra and Erpobdella sp. and the fly Sialis sp., as well as vascular plants such as Myriophyllum sp., Potamogeton obtusifolius, Potamogeton natans, Typha sp., Juncus sp. and Hydrocotyle vulgaris.

Core site B. The macrofossil diagram from core site B was divided into five assemblage zones (B1–B5; Fig. 6).

Zone B1 (diamicton) contains roots of woody plants. Zone B2 is dominated by fruits of Ruppia sp. and also contains rare shells of Hydrobia sp.

Zone B3 is rich in tests of foraminifers and shells of Hydrobia spp. Rissoa spp. (Rissoa membranecea and R. albella), Cerastoderma spp. and Corbula gibba are fairly common throughout the zone, and Echinocardium cordatum is common in the lower and middle part of the zone. Ostrea edulis, Littorina littorea, Scrobicularia plana and Mytilus edulis show a marked peak in the lower part of the zone and occur sparingly in the rest of the zone. Rare species in this zone include the polychaete worms Nereis sp., Spirorbis sp. and Pectinaria sp., the gastropods Euspira nitida, Tritia reticulata, Bittium reticulatum, Turritella communis, Aclis ascaris, Marshallora adversa, Lacuna vincta, Retusa truncatula, Retusa obtusa, the bivalves Musculus discors, Pecten s.l. sp., Kurtiella bidentata, Arctica islandica, Spisula subtruncata, Phaxas pellucidus, Abra alba, Thracia phaseolina, Mya truncata and Barnea candida, marine ostracods, marine bryozoans and the vascular plant Zannichellia palustris. A total of 28 taxa of molluscs are recorded in this zone.

Zone B4 is dominated by foraminifers and shows peaks of first Mytilus edulis and Cerastoderma spp., then Macoma balthica, then Corbula gibba and finally Scrobicularia plana. Rare species in this zone include the polychaete worm Nereis sp., the gastropods Lititorina littorea, Rissoa membranecea, Rissoa lilacina, Tritia reticulata, Bittium reticulatum, Aclis sp., Retusa truncatula, the bivalves Musculus sp., Kurtiella bidentata, Spisula sp. and Abra alba. A total of 17 species of molluscs are recorded in this zone.

Zone B5 is dominated by Cladocera, Chironomidae, Characeae, Cyprideis torosa and Mytilus edulis. Only the lower part of the lake sediments at core site B was analysed.

Radiocarbon ages and sedimentation rates

A total of six samples were dated (Table 1; Figs 3, 7). One sample of a wood fragment provides an age of the terrestrial vegetation that covered the area before
it was inundated by the sea; this sample gave a mean probability age of 8822 years BP. The oldest dated shell yielded an age of c. 8399 years BP. A shell of Ostrea edulis from core site A was dated to c. 7983 years BP; another Ostrea edulis shell was dated by Fronval & Jensen (1992) to 7739 years BP (Table 1). Two shell samples that bracket the thin layer of laminated sediment found in the core from site A gave ages of 6691 and 6170 years BP. Finally, the youngest dated shell gave an age of 2561 years BP, which provides an age for the youngest marine phase in the Arresø area. This is identical to the youngest age of a marine shell reported by Fronval & Jensen (1992): 2561 years BP (Table 1).

Ages versus depth are plotted in Fig. 7 and a tentative age-depth curve is suggested. There are too few ages to draw a conclusive age-depth curve, but it is clear that the sedimentation rate was higher in the lower part of the succession than in the upper part. In the lower part, it is about 1.5 mm/year and in the upper part about 0.8 mm/year. The ages also show that there is a small hiatus between the non-marine sediments at the bottom of the succession and the marine sediments above.

Discussion

The sand at core site A is interpreted as a glaciofluvial deposit and the diamicton at core site B as a till. The sand and the diamicton are both found at 10.1–10.2 m below lake level, and we suggest that the Holocene sediments are underlain by till and sandur plains at about the same level. During the early Holocene, the area that is now covered by lake Arresø was probably above sea level. Wood fragments and root fragments found in the sand and diamicton come from the final stage of this time period, according to the radiocarbon dated sample. Cenococcum geophilum is a fungus that lives in soil (Jensen 1975). We see no indication of an early Holocene lake phase prior to the marine transgression of the area. This indicates that there was no threshold between the Arresø area and the sea in the early Holocene, and we suggest that the Arresø area was forested during the early Holocene (Fig. 3).

First Holocene marine phase

During the early Holocene, the relative sea level rose rapidly in the region (e.g. Christensen et al. 1997; Bennike et al. 2012), and when the sea began to inundate the Arresø area, Ruppia sp. and Hydrobia sp. were amongst the first to immigrate. Both are extremely common in shallow-water coastal areas with brackish water and soft bottom in present-day Denmark (Muus 1967). Deposits from this short-lived phase are only

![Fig. 7. Ages plotted versus depth for core site A. The dashed line shows a tentative age-depth model.](image)

Table 1. AMS radiocarbon ages from Arresø

| Laboratory number | Material      | Depth bct (cm) | Age (¹⁴C years BP) | Calibrated age (years BP) | Calibrated age (years BP) |
|-------------------|---------------|----------------|-------------------|--------------------------|--------------------------|
| AAR-24986         | Cerastoderma sp. shell | 236            | 2802 ± 27         | 2435–2681                | 2561                     |
| AAR-24987         | Cerastoderma sp. shell | 496            | 5742 ± 30         | 6058–6261                | 6170                     |
| AAR-24988         | Hydrobia sp. shells | 518            | 6242 ± 37         | 6586–6794                | 6691                     |
| AAR-24989         | Ostrea edulis shell | 728            | 7530 ± 30         | 7918–8077                | 7983                     |
| AAR-24990         | Cerastoderma sp. shell | 783            | 7943 ± 34         | 8331–8493                | 8399                     |
| AAR-24991         | Twig          | 789            | 7950 ± 40         | 8647–8982                | 8822                     |
| AAR-771⁵          | Cerastoderma sp. shell | 2820 ± 80     | 2349–2730         | 2561                     |
| AAR-775⁵          | Ostrea edulis shell | 7270 ± 120    | 7516–7960         | 7739                     |

1 bct: below core top. 2 Radiocarbon ages reported in conventional radiocarbon years BP (before present = 1950; Stuiver & Polach (1977)). The ¹⁴C ages have been corrected for isotopic fractionation by normalizing to a δ¹³C value of –25 ‰. 3 Calibration to calendar years BP is according to INTCAL13 and MARINE13 data (Reimer et al. 2013). For marine samples we used a reservoir age of 400 years. 4 Mean probability ages. 5 From Fronval & Jensen (1992).
preserved at core site B, where fine-grained gyttja is found (Fig. 6, zone B2).

During the time period from c. 8400 to c. 6700 years BP, fine-grained sand, silt and clay with little organic matter was deposited (Fig. 4). The relative sea level was still rising fairly rapidly during this period, although at a decreasing rate (Bennike et al. 2012). The high mineral content of the sediment and the high sedimentation rate of 1.5 mm/year may reflect that the sea eroded the glacial deposits of the area, forming coastal cliffs at exposed sites. Also at this time, the accommodation space was large and allowed sediments with rich marine faunas (Figs 5, 6; zone A2 and zone B3) to accumulate in the Arrefjord area.

Rich marine faunas are also indicated by a species-rich assemblage of bird bones from the Mesolithic site Kassemose (H. Winge, unpublished data 1908). The bird fauna comprises Gavia stellata (red-throated diver), Gavia arctica (black-throated diver), Morus basanius (northern gannet), Bucephala clangula (common goldeneye), Melanitta fusca (velvet scoter), Mergus merganser (goosander), Cygnus cygnus (whooper swan), Cygnus columbianus (Bewick’s swan) and Alca impennis (great auk). At present, several of these species breed north of Denmark and are only present in Danish waters during the winter. Some of them, notably Gavia stellata, Gavia arctica, Morus basanius and Melanitta fusca are usually confined to open waters.

The most species-rich marine faunas found during the current study come from core site B (zone B3), where there may have been a strait with fairly strong bottom currents (Fig. 2). At core site A, the species diversity was somewhat lower (zone A2), reflecting that this core site was located in a bay. The marine faunas indicate fairly high salinities, probably about 25 ‰ at its peak (see below) which is dated to c. 8000 years BP.

The oldest marine shell that was dated gave an age of 8399 years BP which provides a minimum age for the first marine flooding of the area. The sample comes from a depth of 6 m below present sea level. The age is in good agreement with the dating of the oldest marine shell from Sejerø Bugt that gave an age of 8513 years BP (sample Poz-8822; 8060 ± 50 14C years BP; 21.0 m below present sea level; Bennike & Jensen unpublished data). It also agrees with radiocarbon age determinations of marine shells from Aarhus Bugt where the oldest dated sample gave an age of 8338 years BP (sample Poz-7844; Jensen & Bennike 2009).

Lake or brackish-water phase

At core site A, a thin layer with laminated sediments is found above the mineral-rich marine sediment (Fig. 5, zone A3). This layer contains no marine fossils but an abundance of shells and head shields of Alona cf. rectangular, which is a planktonic cladoceran. The lack of remains of benthic animals and the preservation of lamination indicate poor living conditions for benthic animals, perhaps due to low oxygen levels at the bottom. The abundance of Alona remains shows that the surface waters were fresh, and it is possible that there was a strong halocline that prevented mixing of waters. Laminated sediments are commonly found at the transition from marine to lacustrine sediments in lakes that have been isolated from the sea (e.g. Bennike et al. 2002). The laminated unit is dated to 6700–6200 years BP. The layer may have accumulated when the connection to the sea was closed by sediments or during a period with low relative sea level, or a combination of these two possibilities. A low-stand at about 6500 years BP has been suggested for Denmark by Christensen & Nielsen (2008), but this low-stand was followed by several low-stands of similar magnitude.

Second Holocene marine phase

After the short-lived lake or brackish-water phase registered at core site A, a distinct change in sediment properties is seen at both core site A and B, from mineral-rich sediments to organic-rich sediments (Fig. 4). Marine gyttja was deposited until the fjord turned into a lake. The shift in sediment type indicates a shift to a more low-energy regime. There is also a marked decrease in the diversity of marine species. At core site A the number of mollusc taxa decreases from 20 in zone A2 to 11 in zone A4, and at site B from 28 in zone B3 to 17 in zone B4. This decrease in species numbers indicates a lowered salinity, which probably reflects that the connection to Kattegat had become more restricted. Another possible cause of the change in sediment and fauna could be that the older part was influenced by fairly large tidal amplitudes, whereas these were smaller during deposition of the upper part. The possibility that the tidal amplitude was larger in the early Holocene than at present is debated (e.g. Nielsen 1938; Troels-Smith 1995; Christensen 1995; Petersen 2004). The reason for the lowered sedimentation rate to 0.8 mm/year could be that the accommodation space decreased as the fjord gradually filled with sediment. The upper part of the marine gyttja (assemblage zone A5) is characterised by common fruits of Zannichellia palustris and rare fruits of Potamogeton pectinatus. Both plants are submerged macrophytes that are typical of shallow-water, low-salinity areas with soft bottom. Their presence at site A indicates a change in the environment which could be lowered salinity, decreasing water depth, or a combination. The marine limit is at 4–5 m above present sea level, and the sediments are found at about 2 m above sea level. They accumulated during a period of relative...
sea level fall and were deposited in shallow water with decreasing water depth. The high concentration of marine shells also points to shallow waters where increasing energy levels removed fine-grained matter from the core site, leaving the shells behind.

Isolation of lake Arresø
At core site A the period with *Zannichellia palustris* is followed by a short period dominated by the ostracod *Cyprideis torosa* (Fig. 5, assemblage zone 6). *Cyprideis torosa* can tolerate a wide range of salinities but is adapted to brackish-water environments with fluctuating salinities (Pint et al. 2012), and the sediments accumulated during the transition from fjord to lake. *C. torosa* is often present in abundance at the transition from lake sediments to marine sediments that accumulated during the Early Holocene transgression of the Danish straits. Only two samples, corresponding to 7 cm of sediment, show very high concentrations of *C. torosa*, but the species continues to be present in the next samples before it disappears. Nevertheless, the transition from fjord to lake must have occurred over a short time interval.

At site B there is also a marked peak of *Cyprideis torosa*, but at that site *C. torosa* occurs together with fresh-water animals. The lower lake sediments also contain frequent remains of *Mytilus edulis* which were reworked from the marine sediments. The difference between site A and B reflects that site B is more exposed to westerly winds than site A.

Lake sediments
The early lake sediments are characterised by *Chara* sp., fresh-water ostracods and rare fresh-water gastropods, as seen in the lower part of assemblage A7 and in assemblage B5 (Figs 5, 6). Taken together, these taxa indicate alkaline waters. The common presence of the submerged macrophyte *Chara* sp. indicates that the lake was shallow. When the lake became isolated from the sea, the lake level must have been the same as the sea level, but as the relative sea level fell the lake level increased relatively. During the 1800s, the lake level increased further because the outlet to the sea was closed by aeolian sand (Rørdam 1893). Sand erosion in the region increased during the Late Holocene because of deforestation and intense grazing by livestock, and perhaps also as a consequence of decreasing temperatures during the Little Ice Age. Increasing threshold elevation probably started in the 1500s (Høy 1996) or even earlier and was the reason for the inundation of the Vejlebro area south of Arresø. Increasing water depth could be the reason for the following disappearance of submerged macrolimno-phytes. At about 80 cm sediment depth, submerged macrolimnophytes reappear at core site A (not shown in Fig. 5) together with *Cristatella mucedo* that is typical of macrolimnophyte-rich lakes. This may reflect that the lake became shallower due to ongoing sedimentation. At the top of the succession, macrolimnophytes again disappear; this may be due to recent anthropogenic eutrophication of the lake (Høy 1996).

Holocene occurrence of *Ostrea edulis* in Denmark
At present, *Ostrea edulis* is absent from the inner Danish waters. During the Stone Age (Fig. 3), it was much more common, and its Holocene occurrence in Danish waters has been much discussed (e.g. Nordmann 1903, 1906; Spärck 1942). To thrive, the oyster needs salinities above 25‰, nutrient-rich warm waters, preferably strong bottom currents, and a firm substrate. The species was widespread in Denmark during the Stone Age, with particularly rich occurrences in Limfjorden and in eastern Jylland. The former common occurrence of *Ostrea edulis* indicates higher salinities and warmer waters than at present. Higher temperatures in Denmark during the Stone Age than today is also indicated by remains of other plants and animals such as *Najas minor* (brittle naiad), *Enmys orbicularis* (European pond turtle), *Pelecanus crispus* (Dalmatian pelican) and several species of marine fishes that require high temperatures to thrive (Degerbol & Krog 1951; Hatting 1963; Bennike et al. 2001; Enghoff et al. 2007). Pollen based studies indicate that the July mean temperature during the Holocene thermal maximum from 8000 to 6000 years BP was about 1.5°C higher than during the pre-industrial period in north-western Europe (Seppä et al. 2009).

During the Stone Age, *Ostrea edulis* was also common in Roskilde Fjord and Isefjorden, whereas it did not thrive in Øresund where there are only scattered fossil occurrences, with the southernmost fossil sites on Sjælland north of Copenhagen at 55°46’N (Westerby 1927) and in the Copenhagen harbour (Andersen 1985). Its rare occurrence in Øresund is probably due to outflowing low-saline and cold water from the Baltic Sea. Its peak occurrence in Arrefjord is dated to the early part of the Holocene thermal maximum, at 8000–7700 years BP. *Ostrea edulis* was heavily exploited during the late Mesolithic and early Neolithic, which resulted in the accumulation of numerous shell middens along the coasts in Denmark. Several hundred radiocarbon age determinations of *Ostrea edulis* shells from Danish shell middens show a maximum of ages at about 6000 years BP (Andersen 2007), around 2000 years after the peak occurrence in Arrefjord. This could indicate that the peak occurrence in Arrefjord is a local phenomenon.
Conclusions

This macrofossil study of the palaeo-environmental history of Arresø shows that the area has a complex Holocene history. The area was transgressed by the sea at about 8500 years BP and the oldest dated shell gave an age of 8400 years BP. From 8400 to 6700 years BP, the Arresø area housed a species-rich marine fauna with the high-temperature and high-salinity requiring Ostrea edulis. At about 6500 years BP there was a short-lived lacustrine or brackish-water phase, but marine conditions were soon re-established and lasted until c. 2500 years BP. During the second marine phase, the salinity had decreased, probably because the connection to the sea became more and more restricted and shallow. The marine fjord was isolated from the sea in a rapid process shortly after 2500 years BP. The lake stage began with a shallow lake with alkaline waters, which was followed by a deeper lake with more acidic waters and finally by eutrophic waters.

The fact that Arresø was a fjord until 2500 years BP is important from an archaeological point of view. Several archaeological sites now have to be analysed in the light of having been in direct contact with the sea. For example, the life expectancy of people was significantly shorter than today. In the future, these new results must be taken into account in interpretations of the relationship between people and landscape in the area around the present-day Arresø.

Acknowledgements

We thank the Danish Nature Agency (Naturstyrelsen) for permission to collect sediment cores from Arresø. The study was supported by Geocenter Denmark. Comments by Stuart Watt, the editors Michael Houmark-Nielsen and Lotte Melchior Larsen as well as an anonymous referee helped to improve the manuscript.

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