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# Occurrence and variation in the amount of Characean oospores in Estonian Late-glacial sediments: state of the art and prospectives

## Abstract

The Characeae oospores are frequently found in sediment samples during Quaternary palaecological studies. Counts of oospores of three Estonian Late-glacial (14000 – 11500 calibrated year before present, cal y BP) sediment cores are presented and discussed. The first postglacial findings of Characeae oospores in Estonia date back 13900 cal y BP confirming the early appearance of Characeae in postglacial water bodies. The oospores found in two southern localities belong to *Chara* spp. while only *Nitella* spp oospores are counted in lake situated hundred kilometers in North. In general the number of oospores is low, maximum 50 oospores per 100 cm$^3$ and rises near to the Holocene boundary (11800 cal y BP). The significance and limits of oospore counts for palaeoecological studies are discussed. The studied territory is situated near to the Baltic Sea and has numerous inland lakes offering various possibilities for future applications of Characeae oospore analysis.

**Keywords:** Characeae, Oospores, Estonia, glacial sediments

## 1 Introduction

Characeae, green macroscopic algae, play an important role in recent aquatic ecosystems and were influential parts of past environments as well. It is most probable to find vegetative remains and oospores of Characeae during geological and palaeoecological studies, especially when plant macrofossils are investigated, as the oospores are approximately at the same size than seeds and are preserved in similar conditions as contemporaneous aquatic vascular plants. Seeds, endocarps and other determinable parts of aquatic vascular plants from Europe are well known and studied over a century, while the uncalcified oospores have not got much attention in means of palaeoecology despite their sometimes numerous occurrence in sedimentary archives (e.g. lake sediments). The use of Characeae gyrogonites has already been useful in palaeoecological studies (Soulie-Märsche 1991, Garcia 1994). This paper brings forth the first findings of postglacial Characeae oospores in

Estonia, southeastern sector of last Scandinavian glaciation, discusses the variation in the amount of oospores within cores and presents a few future palaeoecological applications.

## 2 Materials and methods

The sites studied for Quaternary oospores are located in different parts of Estonia, two of them are situated in the southern part of the country and one in the northern coast (Fig. 1). Parallel sediment cores were taken using a 10 cm diameter and 1 m long Russian peat sampler. The cores were described and photographed in the field, wrapped into plastic, transported to the laboratory and stored in a cool room. The cores were subsampled in different ways. In case of Lake Nakri, subsamples were cut in contiguous 2.5-cm intervals from more organic-rich sediments (at time periods between 13000 – 13400 cal y BP and 11200 – 11800 cal y BP, respectively) and 5-cm intervals from inorganic silty/clayey sediments. Cores from Solova Mire and Lake Udriku were subsampled in contiguous 5-cm intervals. Chronology of the sediments was established using AMS radiocarbon dates on terrestrial plant macrofossils. The radiocarbon dates were converted to calibrated age using the OxCal 4.0 program (Bronk Ramsey 2001). All ages mentioned in the text refer to calendar years before present (cal yr BP; 0 = AD 1950).

The sediment sample preparation for palaeobotanical analysis followed conventional procedures (Birks 2001). The sample size varies in different study sites (Nakri: 100 $cm^3$, Solova: 300 $cm^3$, Udriku: mostly 210 $cm^3$). Material retained on sieves was examined using stereo- and light microscopes. Only the Late-glacial part of the sediment cores (formed approximately 14000 – 11800 cal y BP) were analysed for characean oospores.

## 3 Results

The detailed chronology, pollen, plant macrofossil and diatom analyses results of the studied sites are published elsewhere (Amon & Saarse 2010, Amon et al. 2010, Amon et al. in prep.). The oldest so far oospores occur in the southernmost studied locality, Solova, at 13900 cal y BP. In the other two sites, lakes Nakri and Udriku, the occurrence of oospores date back 13500 cal y BP (Fig. 1). None of the samples from any studied core contained calcified oospores. The number of oospores (Fig. 2) in the sites studied display quite a similar pattern starting with only few oospores in the lower part of sediment core and abruptly rising at a certain point, specifically, at 11900 cal y BP in Solova and at 12150 cal y BP in Udriku. In contrast, in Nakri there is no remarkable rise in the amount of oospores in the whole core. The northern locality, Lake Udriku samples contain only *Nitella*-type oospores except one single Chara spp. oospore in the uppermost Holocene sample. The number of oospores in Lake Udriku reaches up to 100 *Nitella* spp. oospores per 210 $cm^3$ during Younger Dryas cold episode. All found oospores in the southern localities (Lake Nakri and Solova Mire) belong to genera *Chara*. In Lake Nakri the overall number of oospores is very low (one to fifteen oospores per sample). In Solova the oospore number itself is larger (the sample size is larger as well) but still insignificant compared with other studies where thousands of oospores are found in one sample

(Birks 2000). The counts of oospores were re-calculated to oospore presentation in 100 $cm^3$ to ease the comparison between reasearch localities (Fig. 2).

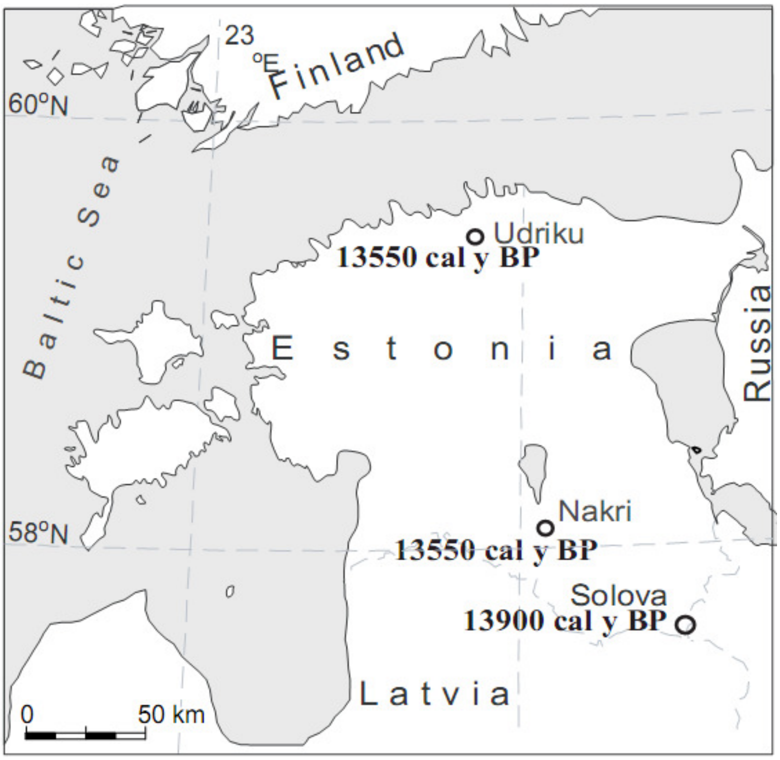


**Fig. 1** The location of the study sites indicating the age of the first postglacial find of Characeae oospore.

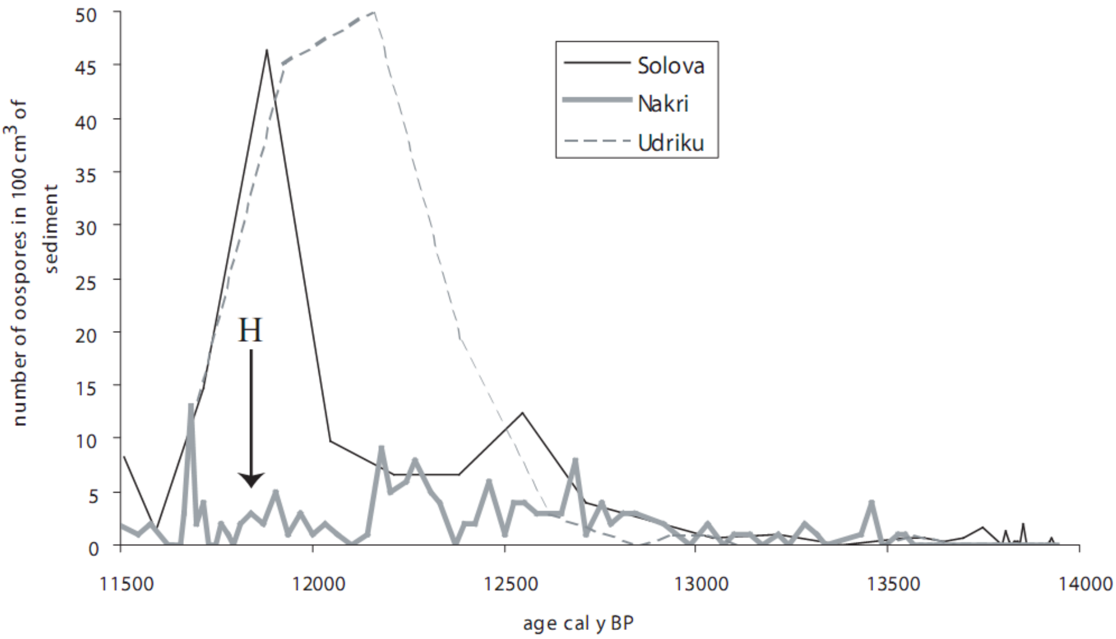


**Fig. 2** Number of characean oospores in three study locations; expressed in 100 cm3, plotted against age (calibrated years). Letter H marks the approximate beginning of Holocene (appr. 11800 cal y BP, Lowe et al. 2008)

# 4 State of the art and prospectives

## 4.1 The first postglacial Characeae oospores in Estonia

The first findings of oospores and therefore the solid proof of establishment of Characeae community after the last glaciation in Estonia date back 13900 cal y BP, in palaeoenvironmental synchronisation scale this date falls to GI-1c warming event (Lowe et al. 2008). This date was acquired from southernmost, Solova locality. The other study site in South Estonia, Lake Nakri is situated only 70 km in Northwest of Solova but the first find of oospores in Nakri is approximately 400 years later. One possible explanation is the size of study location – the sedimentary basin of Solova site is considerably smaller than Lake Nakri and therefore the oospores are more concentrated to the limited area. Another key is probably the sample size that in case of Solova is three times larger than in Nakri. The third study site, Lake Udriku, is situated in North Estonia therefore it was closer to the retreating ice sheet, the deposition of organic material started later and the acquired radiocarbon datings are younger. The ecological conditions were probably in favour of genera *Nitella* as only its oospores have been found.

## 4.2 The number of oospores per sediment sample

In most studies dealing with Quaternary palaeobotanical material, a counting of oospores is performed in the core showing the vertical change of their amount along time (e.g. Väliranta 2006). How interpretable is the amount of oospores found in one sediment sample as well as its vertical change within one sediment core? Characean oospores have been reported to represent pioneer plants (Birks 2000), therefore their presence in Late-glacial sediment is expected. The author of the present study has been counting oospores from the Late-glacial sediments in Estonia, north-eastern Europe (Fig. 2). Could we assume, based on low number of oospores that there were very few Characeae scattered in the lake bottom?

In regards of pollen or plant microfossils there are debates still going on about the relationship between pollen counts and actual landcover (Sugita 2007a, Sugita 2007b). Production, dispersal, settling, sediment reworking, sampling, counting are some research steps that could alter the palaeobotanical outcome and palaeoecological interpretations. In case of Characeae some of these biases are moderated by the fact that most stoneworts grow and will be buried *in situ*. However sampling biases and the representativity of the samples remain significant. In Late-glacial deposits, sediment accumulation rate per year is relatively large and therefore the oospores produced at the same time could be scattered within a significant sediment thickness. The same process could be observed in the case of deposits produced by running water, such as in streams (Soulie-Märsche 1991). Also it must be reminded that usually the core for palaeoecological studies is taken in the central part of the lake depression in order to obtain the most time-representative succession available. However Characeae species prefer very shallow near-shore habitats, which could be underrepresented in such deeper sediments.

Counting results may be even more ambiguous due to Characeae hibernation ecology. Three ways were documented for Charophytes to hibernate: annually by oospores, vegetatively by bulbils and as full-grown plants. The strategies vary from species to species and are dependent mostly on environmental conditions (Martin et al. 2004). Hibernation as full-grown plants will result in oospores, gyrogonites or other resistant parts neither produced nor preserved in the sediment. Several charophyte species are typical pioneer plants, usually highly fertile with high number of oospores per plant. In contrast, other species are restricted to larger, permanent water bodies and are often sterile or represented by only one of the sexes if they are dioecious. Thus the average number of oospores per individual could be very low. Due to these variabilities, it is difficult to conclude on the abundance of charophytes in the vegetation out of the number of oospores found in sediment.

### 4.3 Determination of oospores to the species level

In addition to counting oospores, a promising prospective would be the determination of Characeae species based on oospores found in sediment. Several attempts have been made to gather the information and make usable keys (e.g. Haas 1994, de Winton et al. 2007). Though, the dimension measurements that has been frequently used as key characteristics (Haas 1994, de Winton et al. 2007), they tend to vary and overlap and, what is even more confusing, the specific dimensions differ between authors and in different handbooks (compare Krause 1997 vs. Cirujano et al. 2008).

The development of scanning electron microscopy (SEM) technique as applied to characean oospores, provided a new tool to study and describe the oospore surfaces and wall patterns, which could help in the identification of species. SEM determination has been applied with considerable success to *Nitella* spp oospores (John & Moore 1987), whilst later studies encourage the use of oospore outer wall sculptures also in the determination of *Chara* spp. (Mandal & Ray 2004). Also recent oospore patterns of widely distributed Charophyte species were described in Sweden (Ray et al. 2001) and the Balkan countries (Mandal et al. 2002). Unpublished SEM studies carried out by the author on oospores of several common Characeae species in Estonia (namely *Chara contraria, C. intermedia, C. virgata, C. globularis* and *C. rudis*) indicate that they display considerably different ornamentation patterns. To conclude, it seems to be encouraging evidence that combination of morphological features seen by light microscope (dimension, number of striae etc) coupled with SEM pictures of outer wall ornamentation are useful to determine most Characeae oospores. However, this method needs further testing and to be applied to complete sediment cores in order to distinguish changes in the oospore-reflected community.

### 4.4 Characean oospores as indicators in Quaternary sediments of the eastern Baltic Sea coast (Estonia)

SEM studies are quite expensive and oospore measurements need patience and time. The rationale behind combining them must therefore be well designed. The reason for studying Characeae in detail is to reach a better understanding of past environment and its changes through time. One important guide to palaeoenvironment is recent ecology of Characeae. Key features limiting the occurrence of Characeae are light conditions/water depth, chemical factors (pH, lime/phosphorus content, salinity), temperature, available habitats and substratum (Garcia 1994, Haas 1994).

The early waterbodies forming on Estonian territory after the last glaciation were ice-dammed lakes of glacier meltwater (Rosentau et al. 2009). The water in such waterbodies was fresh but probably turbid and rich of mineral material carried by the glacier. Characeae have been reported as pioneering organisms, however the depth and turbid water of ice-dammed lakes probably inhibited their colonisation.

The largest and most influent waterbody in our region is definitely the Baltic Sea, the largest brackish waterbody in the world. The Charophyte community of the recent Baltic Sea is well known (Torn et al. 2004, Schubert & Blindow 2004) as well as its development after the last glaciation (e.g. Björck 1995, Raukas 1997). The different evolutionary stages described for this sea (Baltic Ice Lake, Yoldia Sea, Ancylus Lake, Litorina Sea and recent Limnea Sea) are classically based on evidence of molluscs and diatom analysis (Raukas 1997) and reflect the shift in water depth and salinity. However these two factors do not change equaly in time or space in different parts of Baltic Sea. The salinity of the different development stages varies between fresh water to 12 permille reaching a maximum at 5000 – 6000 years ago (Westman et al. 1999). The spatial and temporal variability of Baltic Sea coastal palaeoenvironmental conditions is a challenge for studies devoted to characean oospores and the results could be compared and calibrated with diatom data.

Less influent than the Baltic Sea are Estonian inland lakes, which are numerous (over a thousand nowadays). There are no salinity shifts or major fluctuations in acidity in most Estonian lakes during postglacial times but changes in waterbody's trophic level are well recorded in lake sediments. Eutrophication and accompanying reduction in light conditions could be traced using information on characean palaeocommunities from pre-Quaternary periods (Martin-Closas et al. 2006). Also, oospores/gyrogonites have been used to study lake level changes, i.e. paleobathymetry (Soulie-Märsche et al. 2008). It is striking that a morphological feature that challenges the determination of oospores at the species level, i.e. the variability in oospore size and appearance, found to be palaeoecologically useful as it reveals the presence of different aquatic conditions, e.g. lakes vs. ponds (Hutorowitz 2008).

Characeae oospore biocalcification for stable isotope analysis also represents a challenge for future studies (Coletta et al. 2001, Andrews et al. 2004). In Estonia, first attempts have already been carried out on Characeae, though not on oospores / gyrogonites (Kalm & Sohar 2010). The isotope analysis on Characean gyrogonites and encrustations is a method that still needs to solve the ambiguity about what controls the timing of calcification (Andrews et al. 2004). In areas with limestone bedrocks of North Estonia, the results could be hampered by so-called hard water effect.

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