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SEXUAL REPRODUCTION OF CHYDORIDS (ANOMOPODA, CHYDORIDAE) AS INDICATOR OF CLIMATE IN RECENT SEDIMENTS OF LAKE AITAJÄRVI, NORTHERN FINNISH LAPLAND

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Abstract

The present work is a part of the development of a method which uses the relative proportions of asexually and sexually reproducing chydorid females to reconstruct the length of the open-water season. Surface sediments (5 cm) of Lake Aitajärvi, northern Finnish Lapland, were examined for modern and recent proportions of chydorid cladoceran ephippia in subarctic climate near the pine limit. The total chydorid ephippium proportions (TCE) were steadily 9.5–9.7% in the Aitajärvi sediment but declined to 8.4% in the uppermost sample. The result was compared with the surface sediment TCE from four lakes in southern Finland where it varied between 3–6%. It was also compared with the TCE from two lakes in northernmost Finnish Lapland above the treeline in very severe climate, where it was 26–30%. These very high values suggest that there might be a threshold in climate conditions between Aitajärvi and the two northernmost lakes that alters the reproduction of chydorids towards an even more important role of sexual reproduction.

Key words: chydorid ephippia, subfossil Cladocera, climate, length of open-water season, Finnish Lapland

INTRODUCTION

Past climate change has been one of the main topics of research lately and several methods to reconstruct past climate have been developed, many of them based on subfossil remains of organisms preserved in lake sediments. For example, climate reconstructions based on pollen, diatoms and chironomids have been presented for Fennoscandia (*e.g.* Bjune *et al.* 2004, Korhola *et al.* 2000, Seppä *et al.* 2002, Seppä & Birks 2001, Velle *et al.* 2005). These reconstructions have estimated the Holocene mean annual or mean July temperatures.

However, it has been difficult to estimate the length of winter or summer. If oceanic climate type prevailed in the past, winters could have been mild and summers rather cool. If a mean July temperature reconstruction was produced, it may give a picture of a rather cold period, even though the actual open-water season was long. Sarmaja-Korjonen (2003, 2004) suggested that the relative proportions of asexually and sexually reproducing chydorid females could indicate the length of the open-water season (ephippium analysis).

Chydorid cladocerans (water-flees of family Chydoridae) use two strategies of reproduction, asexual and sexual. In a northern climate during most of the open-water season only asexually reproducing females are found. Environmental stress, such as the oncoming winter triggers sexual reproduction, decreasing temperature and light being the main stimuli (Frey 1982). Males and sexually reproducing females appear in early autumn and resting eggs are produced then. The resting eggs of this family are protected by a special modified shell, ephippium. Ephippia preserve well in lake sediments, as well as other chitinous exoskeletal remains of the family, including the shells of asexual females, and can be identified to species level.

If the open-water season is long the period of asexual reproduction is long before the sexual reproduction starts, which results in a high proportion of shells of asexual females in sediments. *Vice versa*, if the open-water season is short, the period of asexual reproduction is relatively shorter and results in a lower proportion of asexual shells and also a higher proportion of ephippia in sediments. It is necessary to calculate percentage abundances because population sizes vary between lakes, resulting in different concentrations of subfossil remains. Therefore, the total sum of chydorid shells and ephippia, although it contains also shells of males and possible barren instars, may be regarded to represent the entire open-water season, including periods of both reproducing strategies.

Sarmaja-Korjonen (2003, 2004) and Nevalainen (2004) found that the proportions of total chydorid ephippia varied during the Holocene in lake sediments from southern Finland. The proportions were highest in the early Holocene after the retreat of the Scandinavian Ice Sheet and declined when climate became warmer. The results from sediment cores, however, represent past climate which can only be reconstructed indirectly. Therefore, it is important to know modern/recent proportions of chydorid ephpippia in order to be able to estimate past conditions.

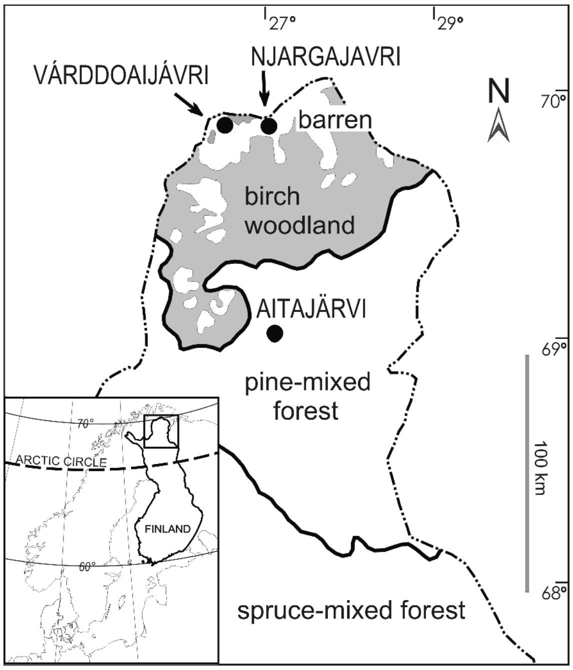

Fig. 1. Location of Lake Aitajärvi in northern Finnish Lapland, near the northern limit of pine. The forest zones are simplified. Lakes Njargajavri and Várddoaijávri are located on barren ground above the present treeline. Area of birch woodland is indicated with grey color and barren ground inside the birch woodland area with white.

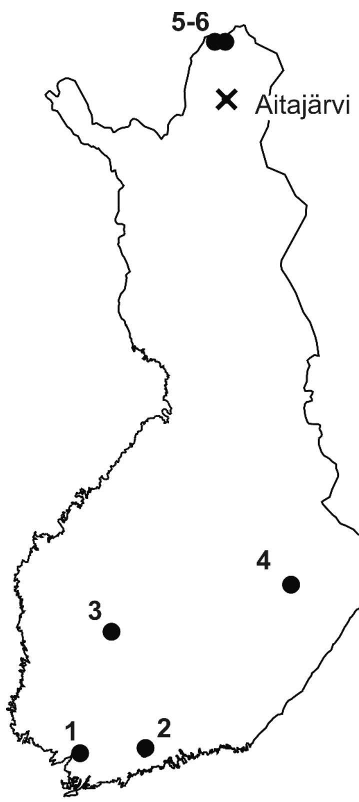

Fig. 2. Location of the 6 lakes whose surface samples were analysed for chydorid ephippia. The lakes are 1. Ylisjärvi, 2. Rusutjärvi, 3. Haukkajärvi, 4 Särkijärvi, 5. Njargajavri, 6. Várddoaijávri. Further information about the lakes and the results is presented in Tab 1.

The aim of the present study was to study chydorid ephippium proportions from surface sediments of a lake (Aitajärvi) in northern Finnish Lapland, near the northern limit of pine forests. Finland, being a long country, extends from hemiboreal forest in the southwestern corner to subarctic tundra-like heath in the north (between 60° and 70° N). Therefore, surface sediments from 6 other lakes in different parts of the country, with clear differences in climate, were also examined and compared with the results from Lake Aitajärvi.

SITE DESCRIPTION AND LABORATORY METHODS

Aitajärvi (69°08' N, 27°14' E, 250 m a.s.l.) is a small lake (ca 6.4 ha), the easternmost one of twin lakes called by the collective name Aitajärvet, situated in northern Finnish Lapland (Fig. 1). The lake was formed when the Scandinavian Ice Sheet retreated from the area between 10000 and 9500 ^{14}C yr BP (ca. 11500–11000 cal. BP) towards the SW (Hyvärinen 1973). It is shallow throughout (max. 2 m), with water depth of 115 cm at the coring site. Aitajärvi lies near the northern limit of pine forests (Fig. 1), and the vegetation around the lake is relatively open pine forest on sandy esker soil.

The mean annual temperature is –1.3°C, the mean summer temperature 11.2°C and the growing season *ca*. 125 days long in the Aitajärvi region (1961–1990 average, Finnish Meteorological Institute). The ice-free season lasts from the beginning of June until the end of October and the surface water temperatures are highest in July and August, about 14–15°C (Atlas of Finland 1986, 1987).

Sarmaja-Korjonen (1999) studied a long sediment core from Lake Aitajärvi for Cladocera, counting subsamples at 10 cm intervals and enumerating all cladoceran remains. In the present study the uppermost 5 cm of the core was analysed. Samples of 1 cm^3 (fine detritus gyttja) were prepared by heating and stirring in 10% KOH for 20 min and washed through a 44 µm mesh. The samples were mounted in glycerine jelly stained with safranine on a hot-plate. Only chydorid shells and ephippia were counted. The sum of shells and ephippia enumerated varied between 293 and 400. The basic sum for percentage abundances of ephippia was the sum of chydorid shells + chydorid ephippia. Nomenclature is according to Røen (1995). *Chydorus sphaericus* is considered as *C. sphaericus sensu lato* (s.l.) (*e.g*. Frey 1986).

Surface sediments (gyttja) from 6 other lakes (Tab 1, Fig. 2) were collected with a Russian corer or a Limnos sampler. The samples were treated with similar laboratory methods as those from Lake Aitajärvi and more than 200 chydorid shells + ephippia were counted from each sample.

RESULTS AND DISCUSSION

In the uppermost sediments of Lake Aitajärvi (0–5 cm) (Fig. 3) *Alonella nana* (Baird) was clearly the dominant (*ca*. 50%), together with *Alona affinis* (Leydig), *Alonella excisa* (Fischer), *Rhynchotalona falcata* (Sars), *Chydorus sphaericus* s.l., *Alona rustica* Scott and *Acroperus harpae* (Baird) which occurred in lower percentage abundances. Ephippia of

Table 1

Location, mean temperatures and TCE (total chydorid ephippia) percentage of six lakes which were studied for comparison with the Lake Aitajärvi results

Lake no. in Fig. 2	Lake	Latitude N	Longitude E	Mean summer temperature °C	Mean annual temperature °C	TCE %
1	Ylisjärvi	60°22'	23°17'	15.6	+5.1	4.1
2	Rusutjärvi	60°26'	24°59'	15.7	+4.7	2.7
3	Haukkajärvi	62°2'	23°48'	14.3	+3.2	6.0
4	Sarkijärvi	62°39'	29°18'	15.4	+3.0	3.1
5	Njargajavri	69°52'	27°11'	9.6	-2.3	30.0
6	Várddoaijávri	69°53'	26°32'	9.3	-2.6	26.2

all species were found. The proportion of chydorid ephippia (total chydorid ephippia, TCE) remained constant (9.5–9.7%) at 5–2 cm and decreased to 8.4% at 0 cm.

The uppermost conventional radiocarbon date (1390 ± 100 BP, Hel-3969) from Lake Aitajärvi was determined from the depth 27–38 cm (Sarmaja-Korjonen 1999). When calibrated with CalPal Online program (http://www.calpal.de), it resulted in *ca*. 1300 cal. BP. Although the date gives only a rough estimate of the age of the upper core, it suggests that the sedimentation rate might be of the order of *ca*. 0.25 mm yr^{-1} and the age for the 5 cm horizon of *ca*. 200 years. However, since gyttja in uppermost sediment cores is usually quite loose, the 5 cm section most probably represents a considerably shorter period of time.

The TCE results from Lake Aitajärvi can be compared with the TCE of surface sediment samples from 6 lakes (Tab 1, Fig. 2). In lakes Ylisjärvi, Rusutjärvi and Särkijärvi the TCE varies between 2.7 and 4.1% and in Haukkajärvi it is rather high, 6.0%. The mean annual temperature at these lakes ranges between 5.1 and 3.0 °C, whereas it is – 1.3° C in the Aitajärvi area. Growing season in southern Finland is *ca*. 175–170 days long, 50 days longer than in the Aitajärvi region and open-water season two months longer. Therefore, the result of *ca*. 9% in Aitajärvi and mostly *ca*. 3–4% in southern Finland is well in accordance with the difference in climate.

TCE of *ca*. 30.0% was found in the surface sediment of Lake Njargajavri which is located in the Utsjoki region, *ca*. 100 km north of Aitajärvi. It lies on an elevated area (355 m a.s.l.) in a very severe climate above the present treeline (Sarmaja-Korjonen *et al.* 2006, Väliranta *et al.* 2005). TCE was 26.2% in Lake Várddoaijávri (404 m a.s.l.) which is located in the same area in similar climate conditions. The mean annual temperature is *ca*. –2.3° C at Njargajavri and –2.6° C at Várddoaijávri and the length of thermal growing season is less than *ca*. 100 days. Thus, the TCE is more than twofold in these lakes compared to Lake Aitajärvi.

Despite the difference in climate conditions between Lake Aitajärvi (pine forest) and lakes Njargajavri and Lake Várddoaijávri (barren, elevated), it appears that possibly the difference in climate is not the only explaining factor for the difference. It is possible that there is some threshold between

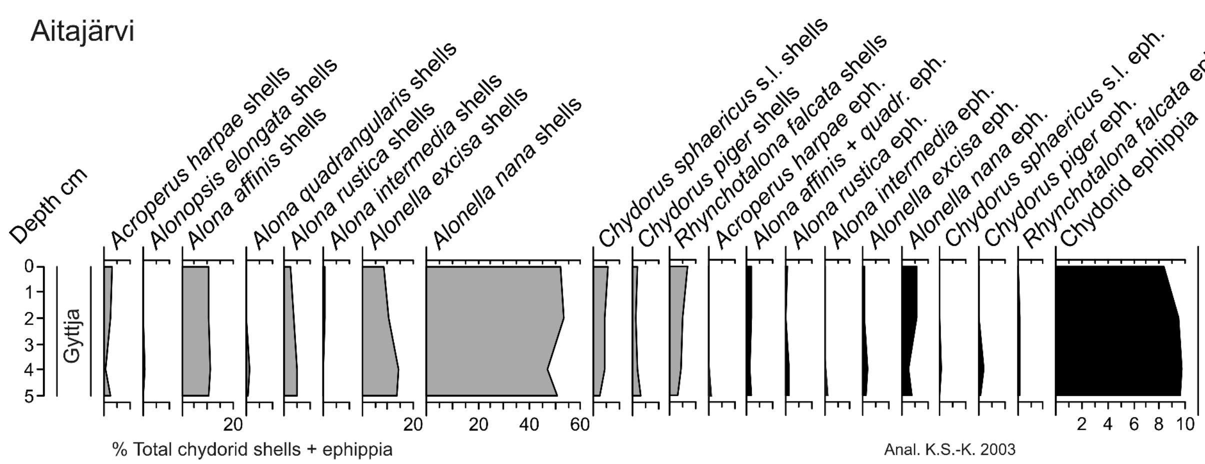

Fig. 3. Proportions of shells of chydorid Cladocera in the uppermost sediments of Lake Aitajärvi in northern Finnish Lapland. The grey curves show the proportions of shells of asexually reproducing chydorid females (also including shells of males and barren instars). The curves in black show the proportions of shells of sexually reproducing chydorid females, i.e. the ephippia, which are special modified shells protecting resting eggs. The proportions were counted from the basic sum of total chydorid shells + ephippia. The last curve (horizontally enlarged) on the right shows the proportion of total chydorid ephippia (TCE).

the lakes above which the role of sexual reproduction changes. In very severe conditions sexual reproduction may become even more important for the survival of species and energy is not wasted in asexual reproduction at the same extent. Sexual reproduction may begin as early in the open-water season as possible (Frey 1982, Sarmaja-Korjonen 1999), resulting in high proportions of ephippia in sediments.

High TCE values were also found in the late-glacial sediments of Lake Bølling Sø in Denmark (Bennike *et al.* 2004). During the early Younger Dryas they were *ca*. 25–30%, comparable to those in lakes Njargajavri and Lake Várddoaijávri presently, and *ca*. 10% during the late Younger Dryas, comparable to the recent/modern values in Lake Aitajärvi. In Lake Bølling Sø the proportions abruptly lowered to *ca*. 0–1.2% at the onset of the Holocene (Bennike *et al.* 2004.), which suggests that the open-water season was longer in Denmark at the beginning of the Holocene than it is presently in southern Finland. The trend of such low proportions was interrupted twice when the proportions rose to *ca*. 5 and 10%, possibly reflecting the short, early Holocene cold events (Johnsen *et al.* 2001).

To conclude, the present results from 7 lakes in Finland suggest that the TCE is clearly higher in the northern parts of the country and apparently reflects the length of the open-water season. The very high TCE in lakes above the treeline in very severe climate conditions also suggests that there might be a threshold in the conditions that alters the reproduction strategy of chydorids towards an even more important role of sexual reproduction. However, more data on TCE across the country are needed before more conclusions can be drawn and the results can be used in reconstructions of past climate.

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