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Subfossil faunal and floral remains (Cladocera, *Pediastrum*) in two northern *Lobelia* lakes in Finland

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ABSTRACT

Key-words: *Cladocera,* Pediastrum *remains, NE Finland, paleolimnology, Crustacea, algae*

The analysis of lake sediment cores have been long used as historical integrators of environmental changes. Nutrient poor isoetid lakes remain under studied in the north boreal region. Hence, the bottom sediments of two north boreal *Lobelia* lakes, located in NE Finland were analysed for the presence of Cladocera and *Pediastrum* remains. Sediment cores from the littoral zones were sampled, sectioned every centimetre and aged with ^{210}Pb. The number of taxa of both Cladocera and *Pediastrum* identified in the cores was high, while the number of individuals in each taxon was low. In Lake Kevojärvi, twenty five Cladocera species and eight *Pediastrum* species were found. Along with widely distributed species, typical for north boreal regions, species preferring more temperate environments occurred. In Lake Petäjälampi, the species composition was similar. Twenty one Cladocera species and five *Pediastrum* species occurred there, however with a lower frequency of individuals in each taxon. In both *Lobelia* lakes, analyses of subfossil Cladocera and *Pediastrum* remains, from the sediments deposited within the last 30–40 years indicated a recent increase in trophic status.

RÉSUMÉ

Restes subfossiles faunistiques et floristiques (Cladocères, *Pediastrum*) dans deux *Lobelia* lacs du nord de la Finlande

Mots-clés : *Cladocères,* Pediastrum*, NE Finlande,* paléolimnologie*, crustacés, algues*

L'analyse des carottes de sédiments lacustres a longtemps été utilisée comme intégrateur historique de changements environnementaux. Les lacs à isoètes pauvres en éléments nutritifs demeurent sous-étudiés dans la région boréale nord. Ainsi, les sédiments de deux *Lobelia* lacs au nord boréal, situés dans le nord-est de la Finlande ont été analysés pour la présence de restes de Cladocères et *Pediastrum*. Les carottes de sédiments des zones littorales ont été échantillonnées, sectionnées à chaque centimètre et datées au ^{210}Pb. Le nombre de taxons des Cladocères et *Pediastrum* identifiés dans les noyaux a été élevé, tandis que le nombre d'individus dans chaque taxon a été faible. Dans le lac Kevojärvi, 25 espèces de Cladocères et 8 espèces de *Pediastrum* ont été trouvées. Parmi des espèces largement distribuées, typiques des régions du Nord boréal, des espèces préférant des milieux plus tempérés ont été trouvées. Dans le lac

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Petäjälampi, la composition des espèces a été similaire. Vingt et une espèces de Cladocères et cinq espèces de *Pediastrum* ont été trouvées, toutefois avec une fréquence plus faible d'individus dans chaque taxon. Dans ces deux *Lobelia* lacs, les analyses de subfossiles de Cladocères et *Pediastrum*, à partir des sédiments déposés dans les 30–40 dernières années ont montré une augmentation récente de l'état trophique.

INTRODUCTION

For many years, lake sediments have been used to reconstruct paleoecology and climate changes occurring in the Quaternary, particularly in the Holocene (Birks, 2003). Lakes, as an element of the natural environment, are subject to changes resulting from intrinsic and extrinsic processes. All environmental changes affect biodiversity, and following that, the number of organisms inhabiting the water.

Cladocera (Crustacea) remains, a component of the lake plankton: are preserved as shells in lake sediments. It is possible to identify these subfossils to species, or even sub-species level. Changes occurring through time in the limnic environment and in the vicinity of lakes may be described from these samples (Korhola and Rautio, 2001; Smol *et al.*, 2005). This allows for the reconstruction of not only the development of lakes, but also of changes of regional nature (Sorvari *et al.*, 2000; Kamenick *et al.*, 2007; Sarmaja-Korjonen and Seppä, 2007; Smol and Douglas, 2007; Galbarczyk-Gąsiorowska *et al.*, 2009).

Lakes located in the northern regions, in areas of minimal anthropogenic influence, present a good opportunity to trace natural environmental changes (Anderson *et al.*, 1999; Brodersen and Anderson, 2000; Smol *et al.*, 2005). The biological development of these lakes reflects ecological and climatic changes occurring from the moment of the formation of the lakes until contemporary times (Sarmaja-Korjonen *et al.*, 2006; Szeroczyñska *et al.*, 2007).

Results presented in this paper were obtained during research carried out within the scope of the Project LAPBIAT 2. The main objective of the project was to extend our knowledge of *Lobelia* lakes located in North Europe. *Lobelia* lakes are soft-water lakes, mostly oligotrophic, occurring in the area of the last glaciations. They were named after the plants typical for the clear-water ecosystems – isoetids such as *Lobelia dortmanna*. Several *Lobelia* lakes mostly from Northern and Central European countries have already been studied (Szmeja *et al.*, 1997; Milecka, 2005; Weckström *et al.*, 2010). During the Holocene the trophy of many *Lobelia* lakes changed, the lakes often transformed into meso- or eutrophic lakes (Szmeja, 1994; Milecka, 2005). Particularly in Central Europe, *Lobelia* lakes are often influenced by human activity, which is a threat to their existence. Several *Lobelia* lakes located in North Finland, with sediments comprising a large number of *Isöetes lacustris*, were investigated to provide an insight into the paleoecological changes which affected this type of lakes.

Remains of phytoplankton (*Pediastrum* Meyen, Chlorophyceae) and zooplankton (Cladocera) from the sediment cores of two lakes, located in NE Finland, were analysed, as part of a larger interdisciplinary study on *Lobelia* lakes (LAPBIAT 2).

The objective of the survey was the reconstruction of palaeoecological changes, primarily pre and post 1900 AD, of two *Lobelia* lakes (Kevojärvi and Petäjälampi) based on the subfossils of Cladocera and *Pediastrum*, as well as providing information on the youngest Holocene species composition of the phyto- and zooplankton in north boreal lakes which have been understudied. The influence of the locations of these lakes is discussed, especially in relation to the Arctic Circle on the paleoecological evolution of the lakes.

MATERIAL AND METHODS

> *STUDY SITES*

The research was carried out in lakes situated in the NE Finland (Figure 1). The study included the analysis of sediments from lakes Petäjälampi near Kuusamo, and Kevojärvi in the Kevo

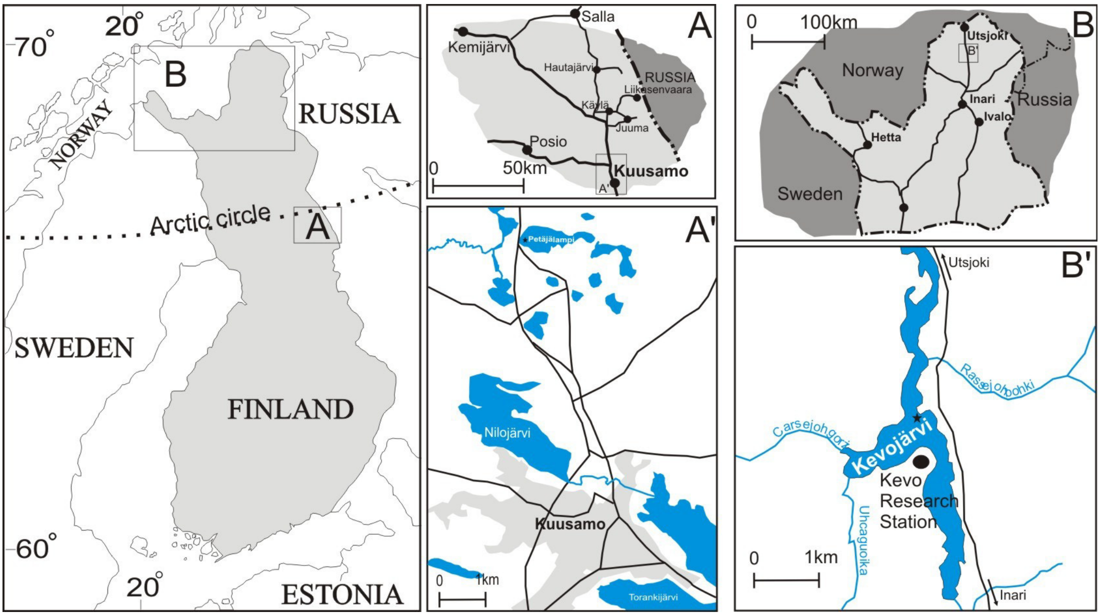

Figure 1
Location of the lakes covered by the study (Lapland, Finland). (A) Map of the Kuusamo region; (A′) Location of Lake Petajälämpi. (B) Map of the Utsjoki region; (B′) Location of Lake Kevojärvi.

Figure 1
Localisation des lacs couverts par l'étude (Laponie, Finlande). (A) Carte de la région de Kuusamo, (A′) localisation du lac Petajälämpi. (B) Carte de la région de Utsjoki, (B′) localisation du lac Kevojärvi.

Strict Nature Reserve. They are classified as oligotrophic-*Lobelia* lakes, inhabited by *Isöetes lacustris* and/or *Lobelia dortmanna* (Hakala *et al.*, 2004; Milecka, 2005).

Lake Kevojärvi is situated in Utsjoki, the northernmost commune of Finish Lapland, *ca*. 75 m above the sea level and *ca*. 350 km north of the Arctic Circle, in the area of the Kevo Strict Nature Reserve (Figures 1B and 1B′). The site belongs to the subarctic or forest-tundra zone, a pine-birch subzone of boreal coniferous forest. The mean annual temperature reported in the meteorological station in Utsjoki is –2 °C. The mean temperature of the warmest month – July – reaches +13 °C. The open-water season in the area of Kevo lasts approximately 5 months; ice-brake usually occurs in early or mid-June, and freezing occurs in October (Kuusisto, 1986; Nevalainen, 2009).

Lake Petäjälampi is located *ca*. 5 km north of Kuusamo, *ca*. 257 m above the sea level and 50 km south of the Arctic Circle, in the province of Oulu (Figures 1A and 1A′). The region represents the northern boreal forest zone habitat. The climate is continental. The mean annual temperature varies between +1 and 0 °C, and the mean temperature of the warmest month – July – reaches up to +15 °C. The annual precipitation is around 600 mm. The open-water season in the area of Kuusamo is approximately 5 months, ice-brake usually occurs in mid- or late May, and freezing occurs in October (Simula and Lahti, 2005; National Board of Survey, 1987).

> *SEDIMENT CORES*

The lakes' sediments were sampled in April and July 2008 and were subject to multidisciplinary paleoecological analyses, *inter alia* subfossil Cladocera and *Pediastrum* algae analysis. Lake sediments were cored from the littoral zones by means of a Livingstone corer in Lake Petäjälampi (in April from ice, at a water depth of 120 cm), and a Kajak gravity corer in Lake Kevojärvi (in July from boat, at a water depth 150 cm). Plastic tubes with a diameter of 6 cm for Livingstone corer and 8 cm for Kajak gravity corer were used. In the laboratory, the tubes with sediments were frozen, subsequently opened and cut into 1 cm slices. The sediments were described in the laboratory. The sampled sediments were mainly composed of organic gyttja and sands (Table I).

> *REMAINS OF CLADOCERA AND PEDIASTRUM*

Samples of 2 cm^3 of fresh sediment for the subfossil Cladocera analysis were prepared according to the standard method proposed by Frey (1986). The sediments were first heated for about 25 min (not using magnetic stirrer) and subsequently, the solution was rinsed and sieved through a 33 μm sieve. All of the cladoceran remains were counted: head shields, shells, postabdomens, postabdominal claws, and ephippia. About 200 cladoceran remains per sample were identified. For concentration calculations the number of specimens was counted, and the percentages are calculated, according to Frey (1986). For each sample, a microscope analysis was performed from four to eight slides, depending on the frequency of cladoceran remains. The identification of species was carried out according to Flössner (1972, 2000), and Szeroczyñska and Sarmaja-Korjonen (2007). The analysis of *Pediastrum* algae was carried out simultaneously with the analysis of subfossil Cladocera. The same preparation method as for extraction of cladoceran remains, was used for extraction of algae. The obtained residuum was sieved using a mesh of 25 μm, which was finer than that used for Cladocera. The identification of *Pediastrum* species was carried out according to Jankovska and Komarek (2000) and Komarek and Jankovska (2001) identifying species to the varieta level.

> *SEDIMENT CORE DATING*

The sediment cores were dated using ^{210}Pb technique in the Quaternary Geochronology Laboratory of the Institute of Geological Sciences, Polish Academy of Sciences in Warsaw. The ^{210}Pb analysis was undertaken for Lake Kevojärvi on 20 samples and for Lake Petäjälampi on 15 samples, at 1 cm intervals. ^{210}Pb activity was measured using alpha spectroscopy and ages were determined using the constant rate of supply (CRS) model (Appleby, 2001) (Figures 2 and 3).

Principal components analysis (PCA) was performed to assess the similarity of the Cladocera communities of the two *Lobelia* lakes. The cladoceran data were presented using CANOCO version 4.5 software (ter Braak and Šmilauer, 2002).

> *RESULTS*

Based on the qualitative and quantitative analysis of subfossil Cladocera, frequency diagrams presenting historical changes occurring in the two lakes were prepared (Figures 5 and 6). In spite of the low frequency of individuals, the number of Cladocera taxa in the sediments was surprisingly high. Generally, in both lakes, twenty eight species belonging to the following six families were found: Bosminidae, Daphniidae, Leptodoridae, Chydoridae, Macrothricidae, and Sididae. Simultaneous analysis of the subfossil *Pediastrum* algae, undertaken on these samples revealed eight *Pediastrum* species in Kevojärvi, and five species in the sediments of Petäjälampi.

Changes in the species composition and frequency of individuals of Cladocera and *Pediastrum* allowed for distinguishing three main development zones for both of the lakes studied. The subdivision of the diagrams was tested by numerical analyses (CONSLINK) Constrained Single link analysis, and (PCA) Principal Component Analysis. CONSLINK well correlated with the finally used local cladoceran assemblages zones (LCAZ) and local *Pediastrum* assemblages zones (LPedAZ). The PCA summarize the distribution of cladoceran taxa across the study lakes (Figures 4a and 4b).

Table I
Lithology, geographical coordinates, water depth, and core length of the lacustrine sediments studied.

Tableau I
Lithologie, coordonnées géographiques, profondeur d'eau, et longueur de la carotte de sédiments lacustres étudiée.

Lake name	Location	Altitude (m asl)	Lake area (ha)	pH	Conductivity	Water depth (sampling site)	Core length	Lithology
Kevojärvi	69° 45.799′ N 27° 00.375′ E	74.7	130.5	7.1	27.5 μS cm	150 cm	29 cm	0–29 cm algal and detritus gyttja
Petäjälampi	66° 00.209′ N 29° 09.202′ E	260	14.6	6.8	2.3 mS m	120 cm	77 cm	0–3 cm algal gyttja 3–15 cm algal gyttja, sands and plant macrofossils of *Isoëtes lacustris* 15–17 cm fine sand with plant macrofossils 17–20 cm detritus gyttja 20–44 cm sand with Fe^{+3} intrusion and plant roots 44–77 cm fine sand

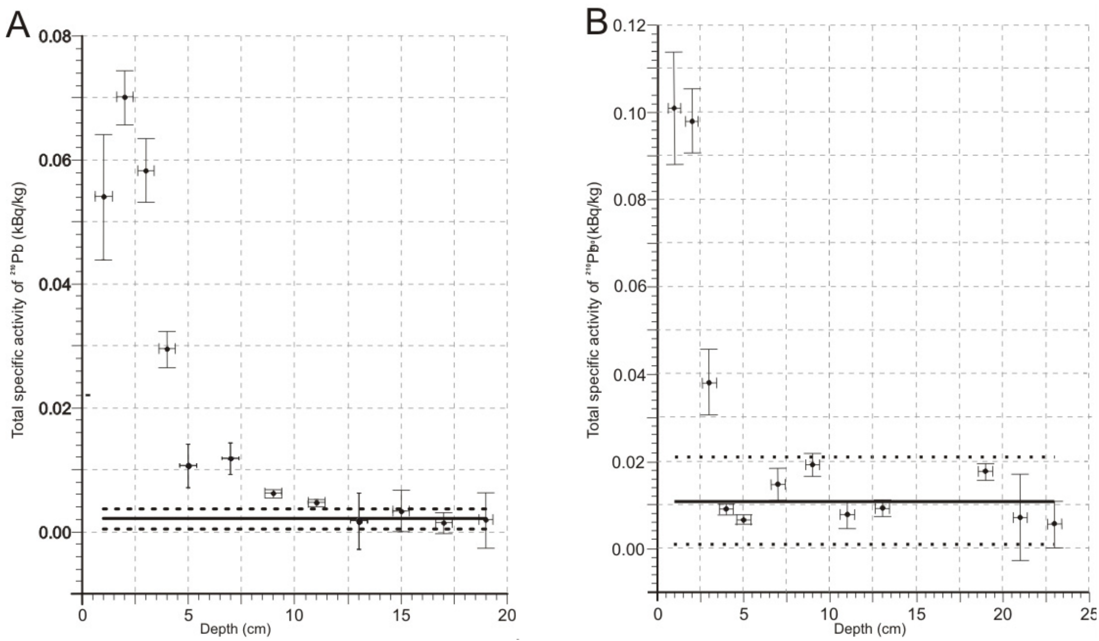

Figure 2
Changes in total ^{210}Pb activity: (A) Lake Kevojärvi, (B) Lake Petäjälampi. Profiles of ^{210}Pb activity versus depth. A solid line is supported ^{210}Pb, and dashed lines are the uncertainty range.

Figure 2
Les changements dans l'activité totale du Pb ^{210} : (A) le lac Kevojärvi, (B) le lac Petäjälampi. Profils d'activité Pb ^{210} en fonction de la profondeur. Ligne continue = Pb et pointillés = plage d'incertitude.

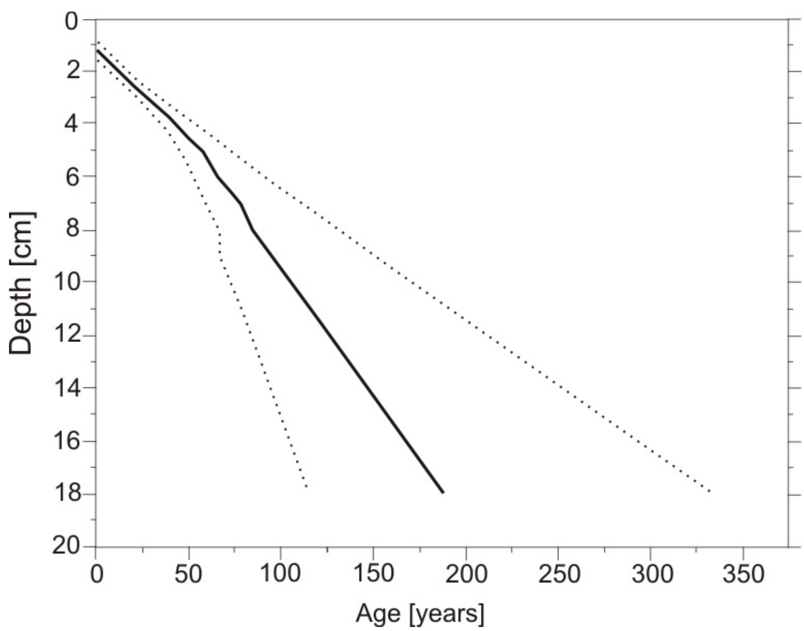

Figure 3
Time-depth model for Lake Kevojärvi. Solid line is the age-depth function and dashed lines are the uncertainty range (±2 standard deviations).

Figure 3
Modèle temps-profondeur pour le lac Kevojärvi. La ligne continue est celle de la fonction âge-profondeur et la ligne pointillée, celle de la plage d'incertitude (±2 écarts-types).

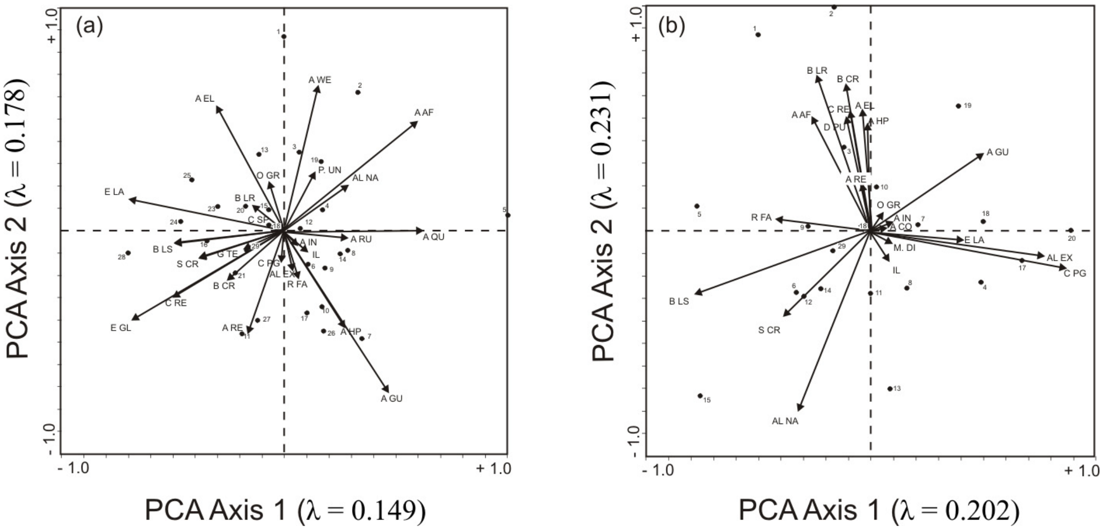

Figure 4
Principal Components Analysis (PCA) biplots for the axes 1 and 2 showing cladoceran species: (a) lake Kevojärvi, (b) lake Petäjälampi. Explanation of species names: A HP Acroperus harpae*; A AF* Alona affinis*; A GU* Alona guttata*; A IN* Alona intermedia*; A RE* Alona rectangula; *A RU* Alona rustica*; A QU* Alona quadrangularis*; A CO* Alona costata*; A WE* Alona werestschagini*; AL EX* Alonella excisa*; AL NA Alonella nana; A EL Alonopsis elongata; B LR Bosmina longirostris; B CR* Bosmina (E.) coregoni*; B LS* Bosmina (E.) longispina*; C RE* Camptocercus rectirostris*; C SP* Chydorus sphaericus*; C PG* Chydorus piger*; D PU* Daphnia pulex-*group; E GL* Eurycercus glacialis*; E LA* Eurycercus lamellatus*; G TE* Graptoleberis testudianaria*; IL* Iliocryptus *sp.; M DI* Monospilus dispar*; O GR* Ophryoxus gracilis*; P UN* Pleuroxus uncinatus*; R FA* Rynhotalona falcata*; S CR* Sida crystallina*; dots with number: sediments depth.*

Figure 4
Graphe des axes 1 et 2 de l'analyse en composantes principales (ACP) des espèces de cladocères : (a) le lac Kevojärvi, (b) le lac Petäjälampi. Explication des noms d'espèces : A HP *Acroperus harpae* ; A AF *Alona affinis* ; A GU *Alona guttata* ; A IN *Alona intermedia* ; A RE *Alona quadrangularis* ; A RU *Alona rustica* ; A QU *Alona quadrangularis* ; A CO *Alona costata* ; A WE *Alona werestschagini* ; AL EX *Alonella excisa* ; AL NA Alonella nana ; A EL Alonopsis elongata ; B LR Bosmina longirostris ; B CR Bosmina (E.) coregoni ; B LS *Bosmina* (E.) *longispina* ; C RE *Camptocercus rectirostris* ; C SP *Chydorus sphaericus* ; C PG *Chydorus piger* ; D PU *Daphnia pulex*-groupe ; E GL *Eurycercus glacialis* ; E LA *Eurycercus lamellatus* ; G TE *Graptoleberis testudianaria* ; IL *Iliocryptus* sp ;. M DI *Monospilus dispar* ; O GR *Ophryoxus gracilis* ; P ONU *Pleuroxus uncinatus* ; R FA *Rynhotalona falcata* ; S CR *Sida crystallina* ; points avec un chiffre = profondeur de sédiments.

> *LAKE KEVOJÄRVI*

Zone I (LCAZ I, LPedAZ I): in this period, littoral Cladocera forms predominated, mainly from the *Eurycercus* genus, including two types, probably of *E. glacialis* (?) and *E. lamellatus*. Among the planktonic forms *Bosmina (E) longispina* prevailed. The sediments of this layer also included numerous remains of *B. longirostris* and hardly any *B. (E) coregoni*. The difference in the frequency of individuals of Chydoridae allowed to distinguish two sub-zones:

sub-zone a – the contribution of Cladocera species living among macrophytes (*Acroperus harpae, Camptocercus rectirostris, Eurycercus* sp.), as well as *P. integrum* and *P. boryanum var. longicorne* among *Pediastrum* increased,

sub-zone b – the contribution of *Alona* species, including small *Alona*, increased to 40%.The Cladocera zooplankton was dominated by *Alonella nana*, and in phytoplankton *Pediastrum boryanum var. boryanum* prevailed.

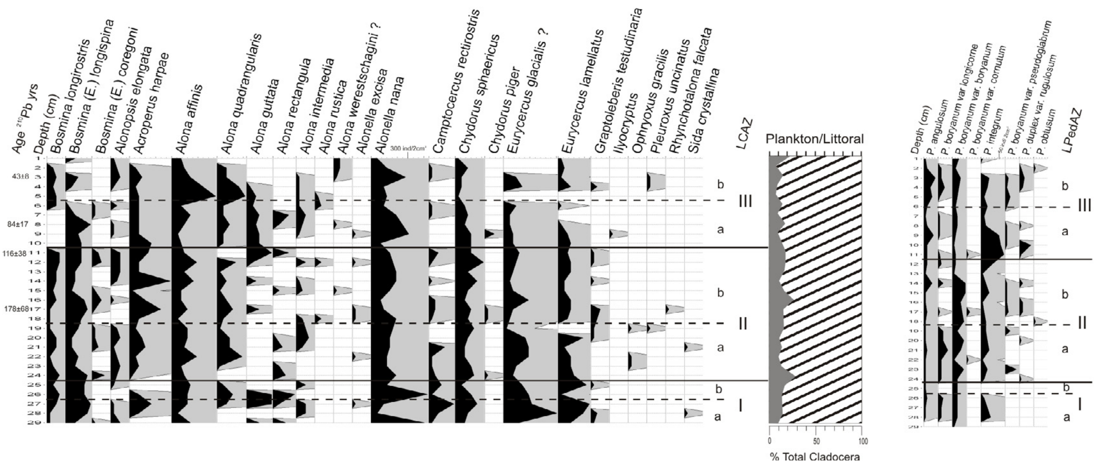

Figure 5

Frequency diagram for Cladocera and Pediastrum specimens in the sediment core from Lake Kevojärvi (2 cm³ of sediment, LCAZ: local Cladocera assemblage zones, LPedAZ: local Pediastrum *assemblage zones).*

Figure 5

Diagramme des fréquences pour les spécimens de cladocères et Pediastrum dans la carotte de sédiments du lac Kevojärvi (2 cm³ de sédiment, LCAZ : zones locales à Cladocères, LPedAZ : zones locales à *Pediastrum*).

Zone II (LCAZ II, LPedAZ II): is characterised by the co-occurrence of three Bosminidae species and an increase in the number of *Pediastrum* species up to eight. The composition of zooplankton included new Cladocera species, which allowed to distinguish two sub-zones:

sub-zone a – the number of species from the *Eurycercus* and *Alona* genus increased. The occurrence of *Ophryoxus gracilis* and *Pleuroxus uncinatus* and, among algae, *Pediastrum duplex var. rugulosum* and *P. boryanum var. pseudoglabrum* was observed for the first time,

sub-zone b – the contribution of *Acroperus harpae* and *Alonella nana* increased. Cladocera species preferring oligotrophic and acidic environment: *Alona rustica*, *Rynchotalona falcata, Alona werestschagini;* and among algae the extremely rare species *Pediastrum obtusum*, appeared.

Zone III (LCAZ III, LPedAZ III): the sediments represents a period which is characterised by a significant variety of Bosminidae species and the predominance of *Alona guttata* (up to 15%) and *Alonella nana* (up to 25%) among the Chydoridae. This allowed to distinguish two sub-zones:

sub-zone a – *Bosmina longirostris* or *Graptoleberis testudinaria* were not present. *Iliocryptus* sp., which had not occurred before, appeared. Among *Pediastrum*, *P. integrum* predominated,

sub-zone b – *Bosmina longirostris* and *Alona* species predominated, particularly those living amongst macrophytes. *Graptoleberis testudinaria* and *Pleuroxus uncinatus* (>2%) species occurred again, although not in large numbers. *Pediastrum* were represented by numerously occurring *P. angulosum* and *P. boryanum var. boryanum.*

The developmental zones distinguished for both Cladocera and *Pediastrum* characterise the status of the lake in the period of deposition of the sediments of the layer analysed. At the time of deposition of the youngest sediments (~30 cm), favourable conditions for the development of zooplankton and phytoplankton occurred in the lake. PCA ordinations (Figure 4a) suggested that there is only weak relationship between cladoceran distributions and the depths (time). At the end of zone Ia, and at the beginning of zone IIIa, the open water zone of the lake was probably more developed. This suggested an increased contribution of the pelagic species *Bosmina (E) longispina* (up to 18%), and *Alonella nana* (>25%), which is a littoral species that also often inhabits the open water zone (Lauridsen *et al.*, 2001; Hessen and Walseng, 2008). At this time, the lake was characterised by a low trophic condition, as indicated by the disappearance or the minimal frequency of *Bosmina longirostris*, and the occurrence of the oligotrophic and acidophilous species *Alona guttata, A. werestschagini*, and *A. rustica* (Krause-Dellin and Steinberg, 1986; Sarmaja-Korjonen and Sinev, 2008), as well as *Pediastrum integrum,* which is a species typical for oligo/dystrophic lakes (Komarek and Jankovska, 2001). The lake's trophic status was somewhat higher during the deposition of sediments at a depth of 3–6 cm. During this time, Cladocera species living among macrophytes (*Alona affinis, A. quadrangularis*) reached their maximum presence (~30%) in the lake. This period also showed an increased contribution of *Pediastrum angulosum* and *P. boryanum var. boryanum*, indicating a slow increase in the trophic condition of the lake and expansion of the vegetation. This enabled the development of macrophytes along with Cladocera species and *Pediastrum*, which is typical of the littoral zone associated with aquatic vegetation. Comparing the species composition from the older (pre- 1900 AD) and younger (post- 1900 AD) sediments, in this lake some differences can be observed (Figure 7). Increased amount of *Alona guttata, Alona intermedia* and *Alona werestschagini* characteristic for lower pH water, occurred in younger sediments.

> *LAKE PETÄJÄLAMPI*

In the 77 cm long sediment core taken from Lake Petäjälampi, remains of Cladocera zooplankton and *Pediastrum* phytoplankton occurred only in the uppermost 20 cm. In sands occurring below 20 cm, a microscope analysis every 2 cm in the 20–40 cm layer, and then every 5 cm in the 40–77 cm layer was carried out. No Cladocera remains were found.

In the sediments deposited in the uppermost layer of the core, three zones were distinguished:

Zone I (LCAZ I, LPedAZ I): in this period, the occurring Cladocera included species associated with both the open water and littoral zones. The sediments from this zone did not include any *Pediastrum* algae. For this zone, a 2 cm layer of sand sediment occurred at 15–17 cm. Sediments located below this layer were dominated by cladoceran remains typical of acidic dystrophic waters, and sediments above this layer include remains typical of lakes with a higher water level. This allowed to distinguish two sub-zones:

sub-zone a – characterised by the co-occurrence of *Bosmina (E.) longispina* and *B.(E.) coregoni.* Among the species of the littoral zone, *Alona guttata, Alonella excisa,* and *Chydorus piger* predominated,

sub-zone b – *Bosmina (E.) coregoni* disappeared completely, and species preferring low pH were scarce. Among the Chydoridae, *Alonella nana* (up to 55%) predominated.

Zone II (LCAZ II, LPedAZ II): *Pediastrum* algae appeared, predominated by *P. boryanum var. longicorne.* Within this zone, a wide variety of Cladocera species occurred, which allowed to distinguish two sub-zones:

sub-zone a – the contribution of *Bosmina (E.) longispina* decreased along with the occurrence of *B.(E.) coregoni*. Littoral species were predominated by *Alonella nana* and *Chydorus piger*,

sub-zone b – *Rynchotalona falcata, Monospilus dispar,* and *Ilyocryptus* sp., *Alona costata and A. intermedia* occurred for the first time. Similarly as in the previous sub-zone, the predominating species were still *Alonella nana*, *Chydorus piger*, and *Alona guttata*. Among the *Pediastrum*, *P. boryanum var. longicorne* occurred along with *P. boryanum var. boryanum.*

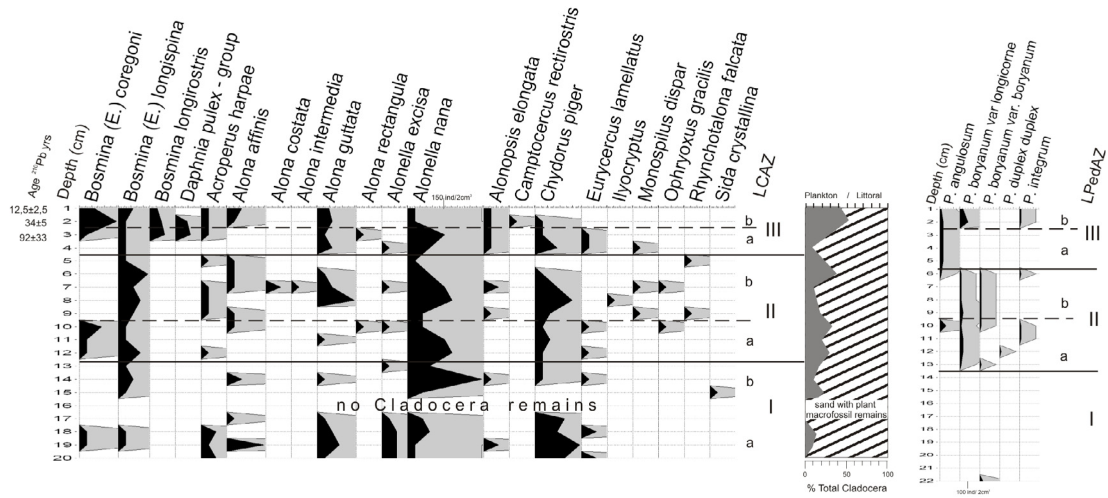

Figure 6
Frequency diagram for Cladocera and Pediastrum specimens in the sediment core from Lake Petäjälampi (2 cm^3 of sediment, LCAZ: local Cladocera assemblage zones, LPedAZ – local Pediastrum *assemblage zones).*

Figure 6
Diagramme des fréquences pour les spécimens de cladocères et Pediastrum dans la carotte de sédiments du lac Petäjälampi (2 cm^3 de sédiment, LCAZ : zones locales à Cladocères, LPedAZ : zones locales à *Pediastrum*).

Zone III (LCAZ III, LPedAZ III): the species composition of the *Pediastrum* changed. Among the Cladocera, *Bosmina longirostris, Daphnia pulex* - group species, and *Camptocercus rectirostris* occurred for the first time. This zone was also divided into two parts:

sub-zone a – *Alonella nana* and *Chydorus piger* predominated. Planktonic species from the *Bosmina* genus and *Daphnia pulex* group occurred. In this period, only one algae species occurred, namely *Pediastrum angulosum*,

sub-zone b – the planktonic species *Bosmina (E.) coregoni* predominated. In the littoral zone, *Camptocercus rectirostris* appeared. Among the *Pediastrum*, *P. integrum*, and *P. boryanum var. longicorne* appeared again.

The zones of the development of the lake, distinguished on the basis of the Cladocera and *Pediastrum* species, characterised the status of the lake in the period of the deposition of the sediments. At that time, the lake had a different status in terms of both the water level and trophy. In the period preceding the deposition of the sand layer, the lake was shallow with low trophic status. *Alona guttata, Alonella excisa*, and *Chydorus piger* occurred, which are species typical of shallow lakes with low pH of the water (Krause-Dellin and Steinberg, 1986). The Cladocera species composition determined in sediments above the sand layer indicated that in the lake the water level was higher. Perhaps the layer of sand was supplied from the slopes of the terrain around the lake or it indicates extremely shallow water in the lake and dry shoreline. During zone II of the development of the Cladocera assemblages, the character of the lake changed. Increased development of zoo- and phytoplankton occurred, particularly in sub-zone IIb, when Cladocera species typical of oligo/mesotrophic lakes occurred for the first time. During the youngest zone, particularly in sub-zone IIIa, the trophy probably increased, which enabled the species in the lake to develop further, both in the open water and littoral zone.

Comparing the species composition and the frequency of individuals from the older (pre-1900 AD) and younger sediments (past 1900 AD), it is apparent that a significantly higher contribution of species preferring waters with low trophic status (*Chydorus piger* and *Alonella*

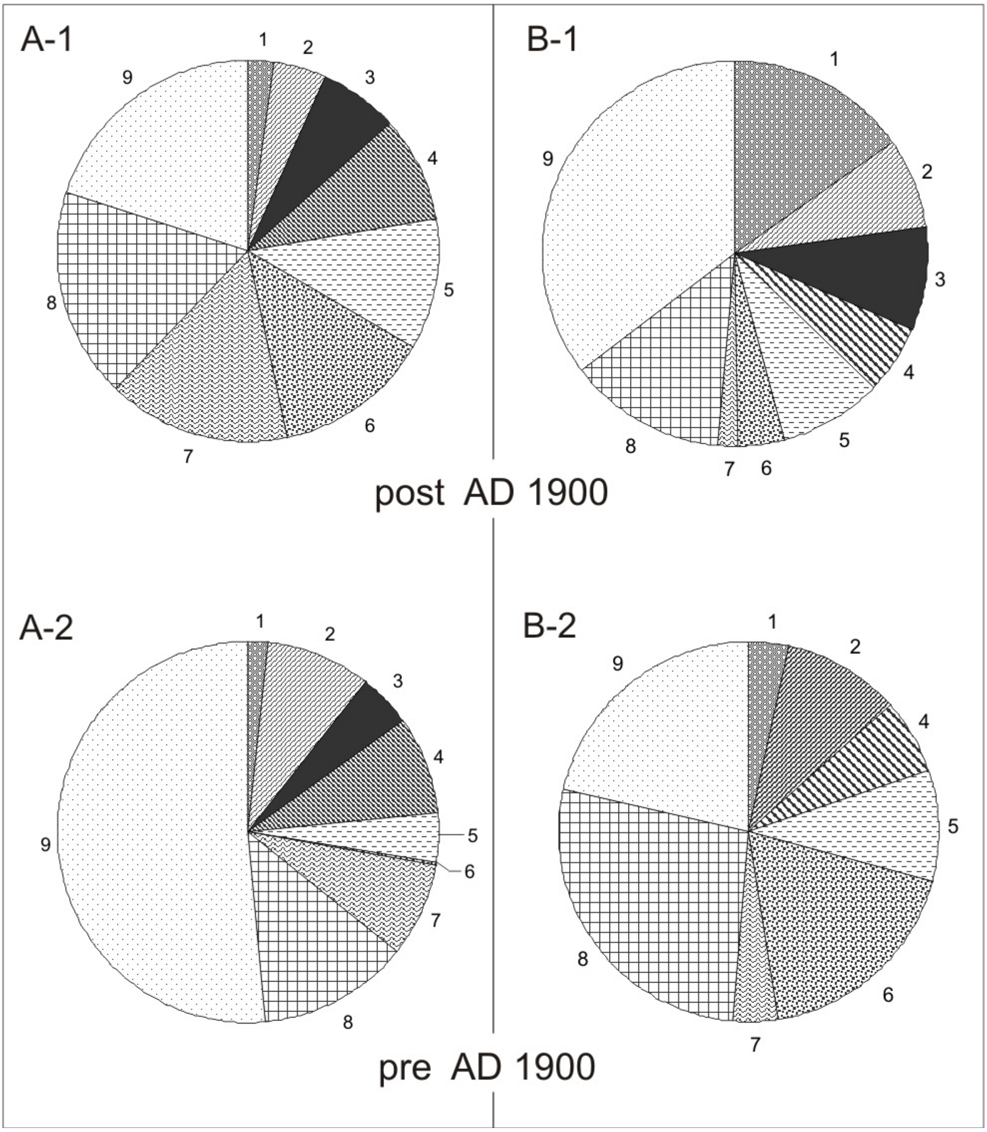

Figure 7
Correlation of percent species composition of subfossil Cladocera in the study of Finnish Lapland lakes. Lake Kevojärvi: A-1 species composition in the sediments from the last ca*. 100 years (layer: 1–9 cm), A-2 species composition in the older sediments – pre- 1900 AD (layer: 10–29 cm). Lake Petäjälampi: B-1 species composition in the sediments from the last 100 years (layer: 1–4 cm), B-2 species composition in the older sediments – pre- 1900 AD (layer: 5–20 cm). Explanation of numbers on the circles for both lakes: 1:* Bosmina (E) coregoni*, 2:* Bosmina (E) longispina*, 3:* Bosmina longirostris*, 4:* Alona affinis*, 5:* Alona guttata*, 6:* Chydorus piger*, 7:* Eurycercus lamellatus*, 8 :* Alonella nana*, 9: others.*

Figure 7
Composition en pourcentages des espèces de subfossiles de Cladocères dans les lacs de Laponie finlandaise étudiés. Lac Kevojärvi : A-1 composition en espèces dans les sédiments des derniers *ca*. 100 ans (la couche : 1–9 cm), A-2 composition en espèces des sédiments plus anciens – avant 1900 AD (couche : 10–29 cm). Lac Petäjälampi : B-1 composition en espèces dans les sédiments à partir des 100 dernières années (couche : 1–4 cm), B-2 composition en espèces dans les sédiments plus anciens – avant 1900 AD (couche : 5–20 cm). Explication des chiffres sur les cercles pour les deux lacs : 1 : *Bosmina (E) coregoni*, 2 : *Bosmina* (E) *longispina*, 3 : *Bosmina longirostris*, 4 : *Alona affinis*, 5 : *Alona guttata*, 6 : *Chydorus piger*, 7 : *Eurycercus lamellatus*, 8 : *Alonella nana*, 9 : autres.

nana) occurred in older sediments than in sediments deposited within the last century (PCA, Figure 4b). The appearance of *Bosmina longirostris* (up to 30%) in the uppermost sediments indicates that the trophic status of the lake increased within the last forty years.

DISCUSSION

Results of the analyses of subfossil Cladocera and *Pediastrum* from the two *Lobelia* lakes located in NE Finland revealed certain similarities despite numerous differences resulting from the lakes' geographical locations and bathymetry. The dates obtained with the application of the Pb-210 method for sediments of both lakes allowed for the correlation of the results of the analysis of Cladocera and *Pediastrum*, particularly for the last century. As demonstrated by the results, in the period of deposition of the sediment layer analysed, the water of Lake Kevojärvi was quite rich in biogenic components and had a rich species composition of both phyto- and zooplankton. Although the lake is situated more to the north, it had a richer Cladocera and *Pediastrum* species composition than Lake Petajälämpi. The Principal Components Analysis, an unconstrained ordination method, summarized the distribution of cladoceran taxa in the studied *Lobelia* lakes. The PCA plot and correlation of percent species composition (Figures 4 and 7) show replacement of species over pre- 1900 AD and post 1900 AD. According to the PCA, the cladoceran communities of Lake Kevojärvi are different from communities of Lake Petajälämpi. Significant differences in the percentages of individual Cladocera species were observed in the sediments mainly for Lake Petäjälampi. In the sediments of this lake, remains of *Bosmina longirostris* and the *Daphnia pulex* -group occurred only in the youngest period. In addition to widely distributed species, *Camptocercus rectrirostris* and *Pleuroxus uncinatus*, species rarely present in cold regions, also occurred. The presence of these species is probably related to the occurrence of the so-called "polar day effect" in lakes located within the Arctic Circle. A similar phenomenon of the occurrence of thermophillic species in tundra regions was described by Jankovska (2007) based on the example of algae from the Polar Urals. They explain it with an intensive warming of lake waters during the short, but intensive arctic summer. In spite of the occurrence of these Cladocera species, the low frequency of all specimens of phyto- and zooplankton and their predominating forms indicate that the waters of the lakes studied were cold and clear, and of oligo or dystrophic type (Zawisza and Szeroczyñska, 2007; Flössner, 1972; Komarek and Jankovska, 2001; Sarmaja-Korjonen and Hyvärinen, 1999).

In sediments deposited within the last century (Zone III), an increase in the number of species and frequency of individuals in both lakes was observed. In the sediments of Lake Petäjälampi, the number of Cladocera species reached 15, including four pelagic species: three Bosminidae species, and one from the *Daphnia pulex* group. In the youngest sediments (the uppermost 5 cm) of Lake Kevojärvi, 15 Cladocera species were identified, including 13 occurring in the littoral and two in the open water zone. A large number of individuals of *Bosmina longirostris*, and *Pediastrum boryanum var. boryanum*, and presence of *Pleuroxus uncinatus*, which are typical of waters with higher trophic status (Hofmann, 1996; Szeroczyñska, 1998, 2002; Komarek and Jankovska, 2001), indicate a contemporary slow increase in the amount of nutrients in the waters of both lakes. The increased development of the Cladocera and *Pediastrum* assemblages within recent decades probably results from an increased supply of nutrients to the lake. The increase in the amount of nutrients in the water could result from the climatic warming causing faster melting of snow and ice, as well as increased transport of nutrients. The open-water season also became longer, along with the activity of the phyto- and zooplankton. Zooplankton occurring in the water of Lake Kevojärvi was also studied by Nevalainen (2009). She described the species composition of Cladocera inhabiting in the littoral zone, observing the occurrence of nine species from the Chydoridae family. Nevalainen, like the authors of the present paper, observed the occurrence of *Pleuroxus uncinatus* and *Alona rectangula*. The occurrence of those species, both in the waters and in sediments of the lakes was surprising, because the species are regarded as typical of lakes with higher trophy, and are very rare in Lapland lakes (Nevalainen, 2009). A similar species composition of subfossil Cladocera (excluding these two species) was also determined by Sarmaja-Korjonen and Sinev (2008) in the surface sediments of four lakes situated in Utsjoki region. A generally similar Cladocera species composition also occurred in the sediments of Lake Somaslampi situated in the west Finnish Lapland (Szeroczyñska *et al.*, 2007). Older sediments of this lake included large numbers of the species, both of the open water zone (4 species) and littoral zone (16 species), but in the surface sediments, only 10 species were found. In the surface sediment of the Lake Saanajärvi, also located in the west Lapland (Rautio *et al.*, 2000), also only 10 species were found. Korhola (1999) in this region, in the surface sediments of 36 small shallow and oligotrophic lakes, identified a total of 29 cladoceran taxa. The number of taxa per lake varied from 4 to 18, with the mean value of 10. In Lake Kevojärvi the rich Cladocera species composition probably results from the influence of warmer air masses approaching from the Barents sea. Also other factors related to the geographic location of both lakes and distance from the arctic circle, such as the elevation above the sea level, vegetation and type of bedrock, can be of great significance. These parameters were illustrated in variable characteristics of both *Lobelia* lakes. If lakes are compared with the ones located more to the south, *e.g.* Poland, Denmark, it is apparent that the taxa suites of all are similar. Common taxa for all of these lakes are *e.g. Rynchotalona falcata, Alonopsis elongata, Daphnia pulex*-group (Milecka and Szeroczyñska, 2005). It can be assumed, however, that the subfossil Cladocera and *Pediastrum* species composition confirmed in NE Finland is typical for *Lobelia* lakes.

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