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COMPARISON OF SUBFOSSIL DIATOMS (BACILLARIOPHYTA) FROM TWO OLIGOTROPHIC LAKES: MAŁY STAW (KARKONOSZE MTS., POLAND) AND SOMASLAMPI (LAPLAND, FINLAND)

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Abstract. Holocene diatoms were studied from sediments cores retrieved from Mały Staw Lake in Karkonosze Mts. in Poland and from Somaslampi Lake in Finnish Lapland. In the core from Mały Staw Lake (882 cm long) 184 taxa representing 30 genera were identified. With respect to ecological preferences indifferent forms were the most abundant. The core was divided into six diatom assemblage zones (DAZ: DMS-1–DMS-6) based on CONSLINK cluster analysis. The core from Somaslampi Lake was 249 cm long. The number of taxa identified was significantly higher (250 taxa belonging to 40 genera). In the latter core four diatom assemblage zones (DAZ: DS-1–DS-4) were recognized. Alkaliphilous and indifferent taxa predominated in Somaslampi Lake. Despite the differences in climatic conditions, natural habitats and bedrock, numerous diatom species occur in both lakes; however, they differed in abundance. Generally, the most abundant taxa with respect to biogeography represent forms of the so-called nordic-alpine provenance, typical for oligotrophic lakes.

Keywords: diatoms, oligotrophic lakes, Karkonosze Mts., Lapland, Finland.

Abstrakt. Analizę diatomologiczną wykonano dla próbek osadów holoceńskich z Małego Stawu w Karkonoszach (Polska) i z jeziora Somaslampi w Laponii (Finlandia). Z rdzenia osadów Małego Stawu o miąższości 882 cm oznaczono 184 taksony należące do 30 rodzajów. Do gatunków dominujących należą okrzemki obojętne względem pH. W diagramie okrzemkowym wydzielono 6 poziomów okrzemkowych (diatom assemblage zones - DAZ: DMS-1 - DMS-6) w oparciu o wyniki analizy klastralnej. W profilu osadów jeziora Somaslampi o miąższości 249 cm zidentyfikowano 250 taksonów należących do 40 rodzajów. W diagramie wyróżniono 4 poziomy okrzemkowe (DAZ: DS-1 - DS.-4). W jeziorze Somaslampi dominują formy alkalifilne i obojętne. Pomimo różnic wynikających z odmiennych warunków klimatycznych, środowiska naturalnego i podłoża, zaobserwowano występowanie tych samych gatunków okrzemek w obydwu jeziorach, ale w różnych zawartościach procentowych. Większość taksonów okrzemek występujących w badanych profilach określanych jest jako formy północno-alpejskie, typowe dla jezior oligotroficznych.

Słowa kluczowe: okrzemki, jeziora oligotroficzne, Karkonosze, Laponia, Finlandia.

INTRODUCTION

Mały Staw (Karkonosze Massif, Sudety Mountains) and Somaslampi (Finnish Lapland) are lakes representing two fairly different environmental settings. Karkonosze Mountains belong to the so-called "Black Triangle" situated across the border between Poland, Germany and the Czech Republic. The "Black Triangle" is one of the most heavily polluted regions in Europe. Mały Staw is an oligotrophic lake with acidic water due to natural conditions as well as to documented anthropogenic pollution (Abraham *et al.*, 2001). Massive pollution from nearby brown coal power plants caused "acid rain" and consequently resulted in increased water and soil acidification. On the contrary, Finnish Lapland is one of the least polluted regions in Europe, although it receives some atmospheric acidic precipitation from southern Scandinavia and Central Europe (Rühling, 1992). Diatoms studied originated from cores spanning entire Holocene record of studied lakes. The sediments of Mały Staw Lake and

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Somaslampi Lake have previously been the subject of multi-disciplinary studies. They described, e.g., sedimentology of Mały Staw Lake (Piasecki, 1958; Wicik, 1984, 1986) and *Cladocera* remains (Szeroczyńska, 1993). Preliminary results of the multi-proxy analysis of Somaslampi Lake sediments were published by Gąsiorowski *et al.* (2003).

STUDY SITES

Mały Staw is a mountain lake, located in a post-glacial cirque in the northeastern part of Karkonosze Mts. (Fig. 1) at 1183 m a.s.l. This is the most famous lake in Karkonosze Mts. accessible for tourists within the area of the Karkonosze National Park. Its origin is related to the last glaciations. The Karkonosze are composed of Variscan granites of various types and Proterozoic metamorphic rocks in minor part of massif (Kryza *et al.*, 1997). The bedrock is poorly buffered. Thus, the amount of alkali mobilized in the surface zone during chemical weathering is too low to neutralize natural and anthropogenic acidity. Consequently, pH of precipitation varies between 2.75 to 3.70 (Migała *et al.*, 1993). The lake lies in a mountain climate zone characterized by cold, short summers (mean July temperature is + 15°C) and long winters (mean January temperature is –5°C). The snow-cover period varies between 70 to 180 days during a year.

Fig. 1. Location of Mały Staw Lake

The Somaslampi Lake is located in the northwestern part of Finnish Lapland, in the Kilpisjärvi region at 760 m a.s.l. (Fig. 2). The lake is situated *c.* 450 km north of the Arctic Circle and *c.* 50 km from the Arctic Ocean. Most of lake basins in Fennoscandia region are of glacial origin (Korhola, Weckström, 2004). The lake is covered by ice for most of the year and isolated from the human impact. The catchment consists of Palaeozoic Caledonian nappe (*c.* 400 Ma), composed of sandstones, conglomerates, and dolomitic limestones with small amounts of alkaline mafic plutonic rocks. In general, the bedrock is alkaline and characterized by high buffering capacity, witch increases the pH of the lakes' water (Weckström, 2001). This region remains under the impact of the North Atlantic oceanic climate and the Eurasian continental climate with mean annual temperature amounting to –2.6°C (Sorvari, 2001). The snow-cover period varies from 180 to 220 days during a year.

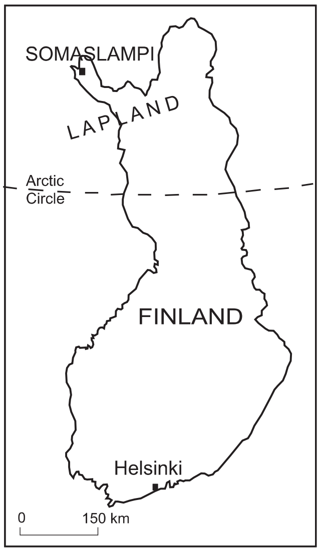

Fig. 2. Location of Somaslampi Lake

Physical and selected chemical parameters of Mały Staw Lake and Somaslampi Lake are given in Table 1.

Table 1

Location and selected environmental parameters of Mały Staw Lake and Somaslapi Lake

Parameter	Mały Staw Lake	Somaslampi Lake
Altitude [m a.s.l.]	1183	760
Area [ha]	2.88	16.20
Depth [m]	7.3	10.0
Secchi [m]	< 7	5.2
pH*	6.20	7.3–7.6
Conductivity [µS/cm]*	13.0	32.2
Temperature [°C]*	14.4	
Dissolved oxygen [mg/dm^3]*	8.28	

* chemical variables measured in July 2002

MATERIAL AND METHODS

Samples for diatom analysis were prepared according to Battarbee (1986) method. Sediment samples from Mały Staw Lake were collected at 20 cm intervals, while from Somaslampi Lake at 10 cm intervals. Samples of 1 cm^3 in volume were treated with 10% HCl to dissolve carbonates, washed several times with distilled water and boiled in 30% H_2O_2 until all organic material was oxidized. Then the samples were washed several times with distilled water. Permanent preparations were mounted with Naphrax® (R.I = 1.75). In each sample more than 300 valves were counted using an Olympus

BX 40 light microscope with x100 oil immersion objective. Scanning electron microscope analysis was performed with JEOL JSM-840 A. Diatom identification was based on Krammer and Lange-Bertalot (1986, 1988, 1991a, b), HÍkansson (1990), Lange-Bertalot and Metzeltin (1996). Diatom preferences with respect to water pH were based on Hustedt (1937–1939), Meriläinen (1967) and van Dam *et al.* (1994). Diatom species diversity was calculated using the Shannon-Weaver Diversity Index (H') and Evenness Index (J'). Diversity indices were used to examine the general trends in diatom distribution and estimate diversity between diatom assemblages in studied areas. Evenness (J') is a measure of the similarity of different species. The Shannon-Weaver Diversity Index and Evenness Index (Shannon, Weaver, 1949) were calculated with the program MVSP (Multivariate Statistical Package) version 3. Changes in diatom species composition were divided into diatom assemblage zones (DAZ) based on CONSLINK cluster analysis (Birks, 1986).

DESCRIPTION OF THE CORES STUDIED

Core of Mały Staw Lake
(water depth 730 cm; lithology after Wicik, 1984)

Depth [cm]:	Lithology:
10.0–857.0	clay-detritus gyttja with interbedding at the depth:
745.0–747.5	light-grey clay;
747.5–751.0	dark-grey organic-mineral matter;
751.0–751.2	fine-grained sand;
751.2–752.0	dark-grey organic-mineral matter;
752.0–757.5	fine-grained sand with organic detritus;
857.0–882.0	clay, sand, dust.

Core of Somaslampi Lake
(water depth 1000 cm; previously unpublished data):

Depth [cm]:	Lithology:
5.0–61.0	dark brown, hydrated, ferruginous sandy silt, more diatomaceous in lower part; sharp base formed by light-grey clayey silt;
61.0–156.0	brown, massive, diatomaceous and saprolitic ooze rich in sandy silt, more ferruginous in its lower part, with dispersed moss detritus; sharp base boundary formed by black silty clay horizon;
156.0–183.0	grey, semi-loose, silt, well sorted, containing organic detritus of terrestrial origin (birch leaves, fine wood fragments, mosses);
183.0–205.0	brownish black, massive, poorly laminated (light grey laminae against dark background) diatomaceous ooze, rich in ferruginous (iron sulphides) saprolitic clay;
205.0–230.0	thin to very thin intercalations form indistinct contact between both units;
230.0–249.0	grey, semi-loose, poorly sorted silty sand with moss detritus; hard rock occurred at the base

RESULTS

DIATOM STRATIGRAPHY

Mały Staw Lake

The core length of Mały Staw Lake was 882 cm. Altogether 184 diatom taxa representing 30 genera were identified in the sediment studied. The most abundant taxa include *Aulacoseira lirata* (Ehr.) Ross (40%), *A. italica* (Ehr.) Simonsen (35%), *A. alpigena* (Grun.) Krammer (34%), *Achnanthes minutissima* Kützing (31%), *Naviculadicta schmassmannii* (Husted) (23%), *Tabellaria flocculosa* (Roth) Kützing (15%), *Navicula seminulum* Grunow (14%). Changes in the diatom species composition allowed to discern six diatom assemblage zones (DAZ: DMS-1–DMS-6). The relative abundance of the dominant diatom taxa is shown in Figure 3.

DMS-1. The lowermost part of the core included in the DMS-1 zone encompassed the sediment interval of 882–860 cm. This zone is characterized by occurrence of few diatom taxa. The most abundant species included *Achnanthes minutissima* Kützing (30% at 882 cm), *Navicula digitulus* Hustedt, and *Naviculadicta schmassmanii*.

DMS-2. The DMS-2 encompassing the sediment interval of 740–860 cm is dominated by tychoplanktonic *Aulacoseira italica* (> 30% at 830 cm), benthic *Navicula seminulum* Grunow and *Achnanthes curtissima* Carter. Small *Fragilaria* species (e.g. *F. brevistriata* Grunow, *F. pinnata* Ehrenberg) reach their maximum abundance. A small number of diatom species, which prefer meso-eutrophic to eutrophic water, such as *Asterionella formosa* Hass. and *Achnanthes laceolata* (Bréb.) Grunow, *Aulacoseira granulata* (Ehr.) Simonsen, are also found.

DMS-3. Tychoplanktonic *Aulacoseira alpigena* and *A. italica* dominate in the DMS-3 zone (420–740 cm). The top of the DMS-3 is marked by a drastic decrease of *A. italica* corresponding with considerable increase of *A. alpigena* (up to 30% at 470 cm). Decrease of some benthic species e.g. *Fragilaria* sp. sp., *Navicula* sp. sp. is observed. A few meso-eutrophic and eutrophic taxa are still present and an increase of *Aulacoseira granulata* is observed.

DMS-4. The following zone, DMS-4 (240–420 cm) is dominated by *Aulacoseira lirata*. On the other hand, *A. alpigena* and *A. italica* show a decrease in this sediment interval. In addition, abundance peaks of acidophilous taxa, e.g. *Eunotia incisa* Gregory, *Tabellaria flocculosa* (Roth) Kützing,

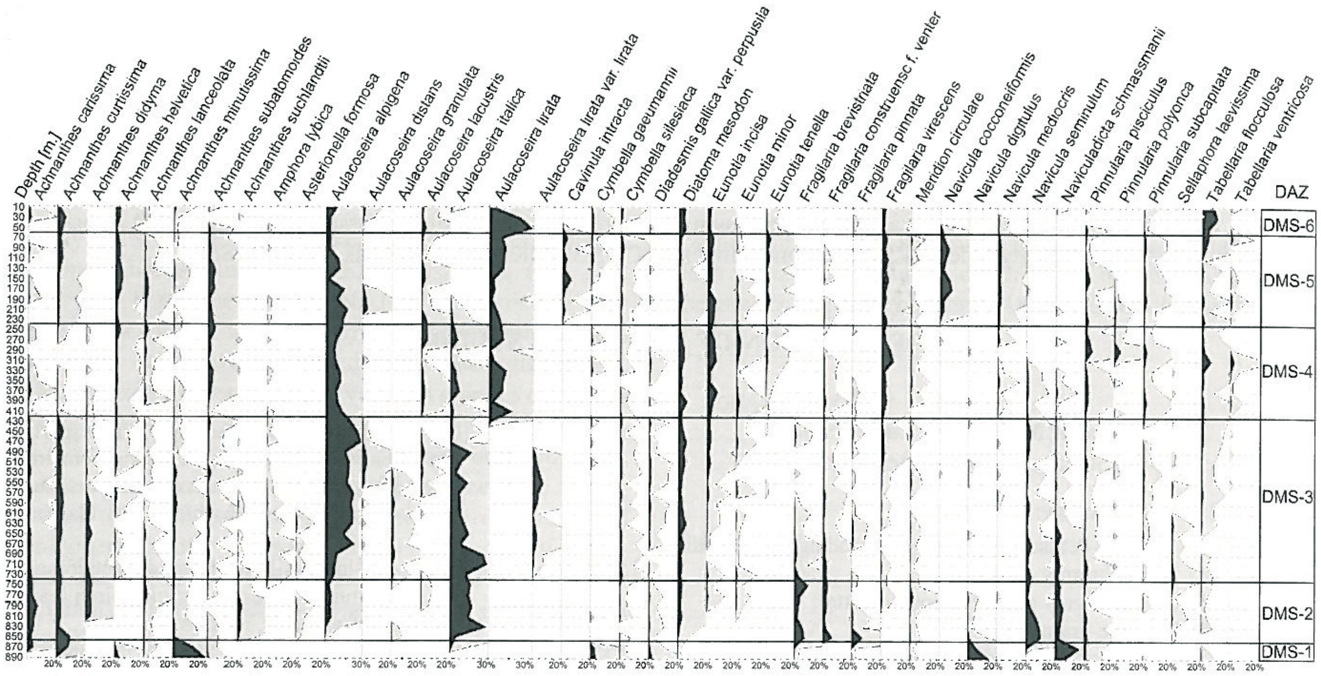

Fig. 3. Most abundant diatom species found in the sediments of Mały Staw Lake

Pinnularia polyonca (Bréb.) W. Smith and acidobiontic *Tabellaria ventricosa* Kützing are observed.

DMS-5. The DMS-5 encompassing sediment interval of 60–240 cm is characterized by predominance of *Aulacoseir*a sp. sp. An increase of indifferent *Cavinula cocconeiformis* (Greg.) Mann & Stickle and *C. intractata* (Hust.) Lange-Bertalot is observed. Small increase of benthic *Achnanthes* sp. sp., such as *A. helvetica, A. subatomoides, A. lanceolata* is noticeable.

DMS-6. The next zone, DMS-6 (10–60 cm) is characterized by maximum abundance of *Aulacoseira lirata* (up to 40% at 50 cm) and an increase in *Tabellaria flocculosa* frequency. Decrease of *Eunotia* sp. sp. and *Aulacoseira lirata* in the top of core is noted.

Regarding ecological preferences, indifferent taxa are the dominant group in the sediments of Mały Staw Lake, comprising 24 to 78% of all diatoms. Amongst the predominant species there occurred: *Aulacoseira italica, Navicula seminulum, Achnanthes minutissima, A. curtissima*. Acidophilous species also are very abundant and their content varied between 0.5 and 70%. The most common taxa are: *Aulacoseira alpigena, A. lirata, Tabellaria flocculosa, Eunotia incisa*. Alkaliphilous diatom include *Fragilaria brevistriata, F. construens* f. *venter, F. pinnata, Aulacoseria granulata* varied between 3 and 50%, whereas acidobiontic taxa (e.g. *Tabellaria ventricosa, Eunotia exigua, Navicula subtilissima*) comprised to up 6.5% in the core.

Somaslampi Lake

The distribution of the diatom flora in core from Somaslampi Lake is illustrated in Figure 4. The core length studied was 249 cm. A total of 250 diatom taxa belonging to 40 genera were identified in the core. The most abundant species included *Navicula seminulum* Grunow (36%), *Fragilaria pinnata* Ehrenberg (31%), *Cyclotella rossii* Hĺkansson (25%), *Fragilaria pseudoconstruens* Marciniak (22%), *Achnanthes pusilla* (Grun.) De Toni (22%), *Cyclotella bodanica* Grunow (21%). The diatom stratigraphy was divided into four diatom assemblage zones (DAZ: DS-1–DS-4).

DS-1. The DS-1, encompassing sediment interval of 230–249 cm, is characterized by low species diversity. The lowermost part of the core is dominated by the benthic, eutrophic *Navicula seminulum* Grunow, *Achnanthes pusilla* (Grun.) De Toni and *A. nodosa* Cleve. The tychoplanktonic *Tabellaria flocculosa* was also recorded.

DS-2. The deposition of DS-2 (190–230 cm) coincided with a drastic increase in abundance of *Stauroneis neohyalina* Lange-Bertalot. A nordic-alpine *Achnanthes laterostrata* Hustedt is also abundant. Benthic forms i.e. *Navicula concentrica* Carter and *Navicula costulata* Grunow, inhabiting water of increased conductivity to slightly saline water (Krammer, Lange-Bertalot, 1986) are observed. The upper part of the DS-2 is dominated by *Fragilaria pseudoconstruens*. Eutrophic *Stephanodiscus minutulus* (Kütz.) Cleve & Möller and *Cocconeis placentula* var. *lineata* (Ehr.) Van Heurck are noted.

DS-3. The DS-3 encompassing sediment interval of 100–190 cm is dominated by small *Fragilaria* species, i.e. *F. pinnata* (up to 30%), *F. brevistriata* Grunow and *F. oldenburgioides* Lange-Bertalot. The moss epiphyte *Pinnularia balfouriana* Grunow ex Cleve reaches its maximum abundance in this part of core. The upper part of the DS-3 is characterized by predominance of C*yclotella bodanica* and decrease of *Fragilaria* species.

DS-4. The following DS-4 zone (5–100 cm) is characterized by dominance of planktonic species *Cyclotella rossii* and *Fragilaria pinnata*, whereas *Cyclotella bodanica* gradually re-

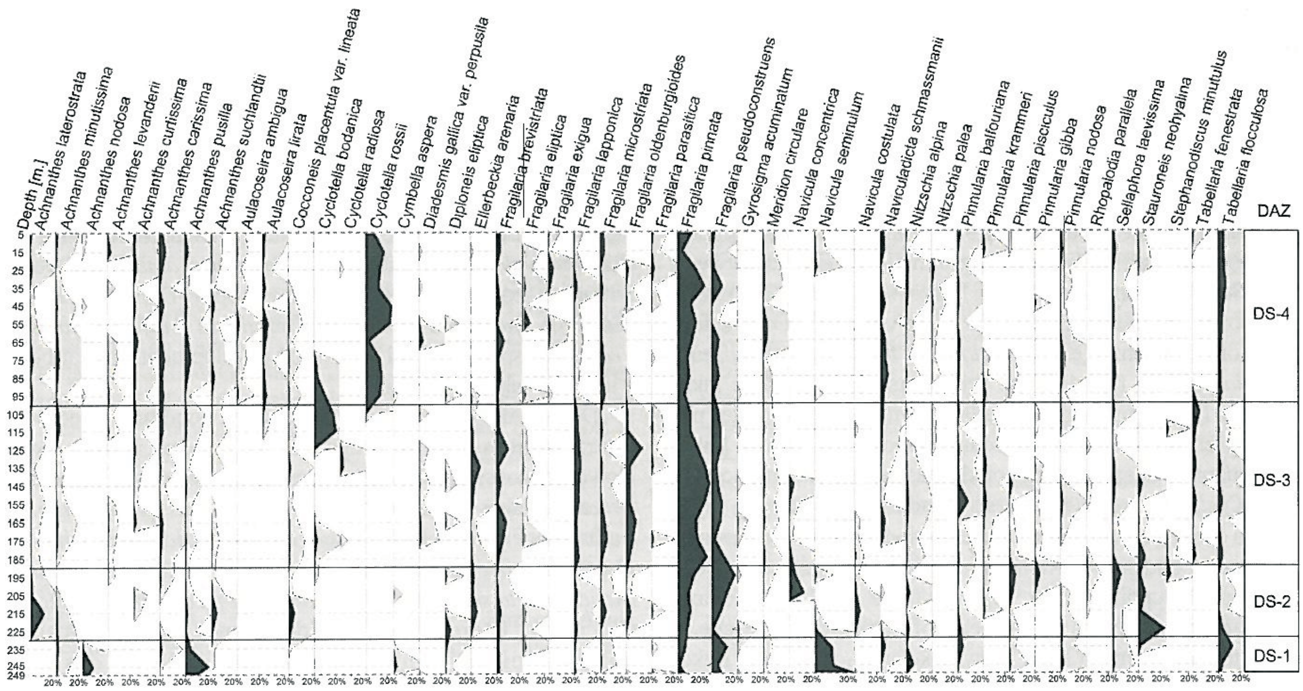

Fig. 4. Most abundant diatom species found in the sediments of Somaslampi Lake

treated. In the topmost part of the core, acidophilous forms (e.g. *Pinnularia nodosa* (Ehr.) W. Smith, *Eunotia glacialis* Meister, *Tabellaria flocculosa*) are noted.

Regarding ecological preferences, alkaliphilous forms are the dominant group, comprising 26 to 73% of all taxa, whereas indifferent taxa vary between 11 and 64%. Amongst the dominant alkaliphilous and indifferent species are: *Fragilaria pinnata, F. pseudoconstruens, Cyclotella rossii,* and *Navicula seminulum*. Acidophilous diatoms, including *Pinnularia subcapitata, P. nodosa, Tabellaria flocculosa, Aulacoseira lirata* varied between 0.5 and 9%, whereas alklibiontic taxa (e.g. *Gyrosigma acuminatum* (Kütz.) Rabenhorst, *Rhapalodia paralella* (Grun.) O. Müller) constituted up to 2.5% of diatoms in the core.

DIATOM SPECIES RICHNESS AND DIVERSITY

The changes of the diatom richness and diversity in the cores from Mały Staw Lake and Somaslampi Lake are illustrated in Figure 5. The Shannon-Weaver Diversity Index (H') in the sediments of Mały Staw Lake varied between 2.40 (at 882 cm) and 3.52 (at 290 cm), with average value of 3.14, while Evenness Index (J') varied between 0.72 (at 882 cm) and 0.88 (at 190 cm), with average value of 0.80. In the sediments of Somaslampi Lake the lowest species diversity (H' = 2.70) is noted at 249 cm and the highest species diversity (H' = 3.65) is observed at 5 cm. The average value of H' equals 3.20. The Evenness Index varied from 0.67 to 0.85 at 249 cm and 65 cm, respectively. The average value of J' equals 0.79 in Somaslampi Lake.

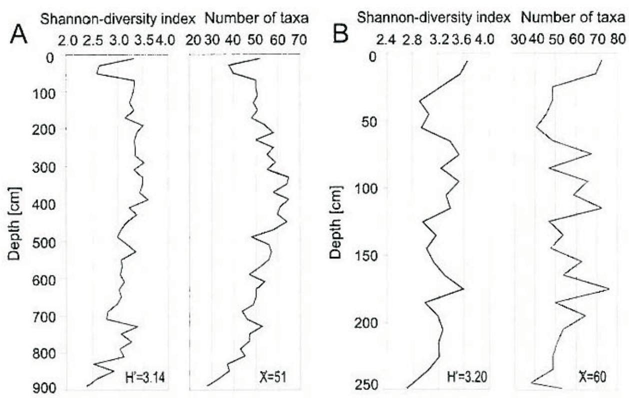

Fig. 5. Summary diagrams of diatom diversity and species richness in the sediments of Mały Staw Lake (A) and Somaslampi Lake (B)

DISCUSSION AND CONCLUSION

Mały Staw Lake and Somaslampi Lake are located in different geographical zones with different environmental conditions. Both studied lakes are oligotrophic, clear-water lakes with low conductivity. Diverse bedrocks result in different buffering capacity. Consequently, crystalline bedrock of Mały Staw Lake caused long-term acidification and the present lake-water pH equals 6.2. The catchment area of Somaslampi Lake consists of alkaline-rich rocks and is well buffered, causing that the lake-water pH is 7.3. In addition, Somaslampi Lake is isolated from human impact, contrary to Mały Staw Lake, suggesting its higher stability in pH development. In both lakes, the number of species is very high and the average diatom species number is 51 in the sediments of Mały Staw Lake and 60 in the sediments of Somaslampi Lake. Comparison of the Shannon-Weaver Index (Fig. 5) shows insignificant changes in the H' indices between Mały Staw Lake and Somaslampi Lake. However, differences in planktonic to benthic diatoms ratio are observed. Only a few planktonic diatoms (e.g. *Asterionella formosa, Aulacoseira granulata*) were found in the sediments of the Sudetic lake, which is typical for high alpine lakes with acid lake-water pH (Koinig *et al.*, 1998). In the sediments of Somaslampi Lake, more planktonic species are noted. Presence of planktonic taxa (e.g. *Cyclotella rossii*) suggests conditions promoting algal growth connected with long ice-free period, i.e. warmer seasonal temperature and nutrient-rich surface water (Catalan *et al.*, 2002; Grönlund, Kauppila, 2002). Higher number of planktonic taxa could also be connected with increase of water level in the lake.

In the sediments of Mały Staw Lake and Somaslampi Lake, the majority of diatom species is typical for clear, oligotrophic, acid lakes in alpine and arctic regions (e.g. Lange-Bertalot, Metzeltin, 1996; Seppä, Weckström, 1999; Tolotti, 2001; Laing *et al.*, 2002; Marchetto *et al.*, 2004) accompanied by, for example, *Aulacoseira alpigena, A. distans, Achnanthes didyma, Fragilaria pinnata,* and *F. pseudoconstruens*. In the sediments of Mały Staw Lake, the diatom-based trophic classification (van Dam *et al.*, 1994) suggests increased trophic status in the bottom part of the DMS-2. Occurrence of eutraphentic *Navicula seminulum* and *Fragilaria construens* f. *venter* points to a minor increase in trophy. In the DMS-3, *Aulacoseira granulata*, usually common in eutrophic lakes, is present. It suggests insignificant changes in trophic conditions. In the sediments of Somaslampi Lake, an increse in trophy is also observed. The presence of eutraphientic taxa, such as *Navicula seminulum, Stephanodiscus minululus* and *Cocconeis placentula* var. *lineata* in lower part of the core suggests changes in the trophic status. In the upper parts of the core, development of planktonic forms, including *Cyclotella* species and *Aulacoseira ambigua* (Grun.) Simonsen, points out to an increase of trophy. During the DS-3, peaks of the moss epiphyte *Pinnularia balfouriana* and *Fragilaria* species could reflect the development of peat bogs within the lake catchment.

Despite the dissimilarities in climatic conditions, bedrock, natural habitats, numerous diatom species occur in both lakes. However, considerable differences in species composition between the lakes are observed. Included in this group are, e.g.: *Achnanthes curtissima, A. carissima, Aulacoseira lirata, Fragilaria brevistriata, F. pinnata, Navicula seminulum, Naviculadicta schmassmanii, Pinnularia pisciculus, Tabellaria flocculosa*. Interesting is the occurrence of the so-called nordic-alpine forms, such as *Achnanthes didyma, A. laterostrata, A. pusilla*, *Cymbella gaeumannii, Naviculadicta schmassmannii, Pinnularia balfouriana*. Some of them have been also noted in the Polish Tatra Mountains (Marciniak, 1982; Marciniak, Cieśla, 1983; Kawecka, Galas, 2003).

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