BOREAL ENVIRONMENT RESEARCH 11: 481–492 ISSN 1239-6095
Helsinki 29 November 2006

Benthic communities in relation to environmental factors in small high mountain ponds threatened by air pollutants

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Received 16 Dec. 2005, accepted 23 May 2006 (Editor in charge of this article: Johanna Mattila)

Kownacki, A., Dumnicka, E., Kwandrans, J., Galas, J. & Ollik, M. 2006: Benthic communities in relation to environmental factors in small high mountain ponds threatened by air pollutants. *Boreal Env. Res.* 11: 481–492.

Hydrobiological investigations of ponds situated above the timber line in the Tatra Mountains (Poland) were carried out. These water bodies are fed mainly by rainfall and melting snow. Some of them are temporary while others are permanent and show seasonal variations in chemical properties (e.g. pH 4.6–5.0 to 6.8–7.7). The structure of the algal communities differed in particular ponds, depending on the water pH and its seasonal changes. Moreover, there are differences in the composition of the macro-invertebrate communities between particular ponds, but they were not affected by the water acidification occurring mainly during the snow-melting period. The present investigations show that the impact of acid precipitation on biocenoses living in high mountain water bodies (Tatra Mts) is not clearly evident.

Introduction

Poorly buffered, high altitude lakes are extremely sensitive to anthropogenic impacts (Mosello 1984). Due to their sensitivity they have been used as early warning systems of global changes (Psenner and Schmidt 1992, Psenner 2003). Benthic communities in high altitude regions are especially interesting due to their adaptability in surviving in naturally extreme environmental conditions (e.g. short growing season, limited nutrient availability, low mineral content, low water temperature, exposure to ultraviolet radiation, and the drying and freezing period in shallow sites etc.). In such a hostile environment species live at the extremes and this is why each additional change may result in the disappearance or appearance of some species.

One of the better documented groups of water organisms in regard to acidification is diatoms, used since the work of Hustedt (1938/1939). One of the most commonly known concepts has become the basis for the development of numerical indices and classification systems for water pH estimation using diatoms (e.g. Renberg and Hellberg 1982, Flower 1986, Eloranta 1990, van Dam *et al.* 1994). Hydrobiological investigations of lakes and ponds situated in the Tatra Mountains, began many years ago, but they were usually focused on particular elements of the biocenoses such as zooplankton (Woźniczka 1965, Gliwicz 1967), algae (Marciniak 1982,

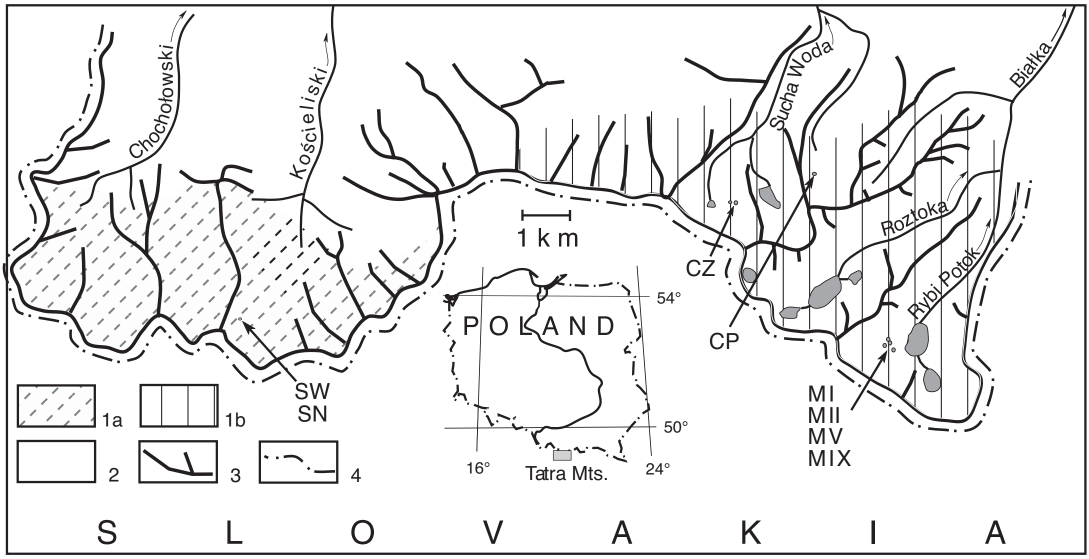

Fig. 1. Area of the Polish Tatra Mountains with the location of the studied ponds. 1a = metamorphic rocks, 1b = granitoids, 2 = limestone, dolomites, sandstones and shales, 3 = mountain ranges, 4 = state border. For pond name abbreviations *see* Table 1.

Lukavsky 1994, Eloranta and Kwandrans 2002), benthic fauna (Kowalewski 1914, Kownacki and Kownacka 1965, Dumnicka and Galas 2002). Hydrochemical studies were also performed in various lakes (Olszewski 1939, Bombówna 1965, Krywult 1990, Wojtan and Galas 1994). Data collection from various lakes over a number of years allow us to follow the possible changes in water chemistry and benthic communities resulting from anthropogenic acidification. The biocenoses of high mountain lakes threatened by the deposition of sulphur and nitrogen compounds from the atmosphere were studied intensively in several EU projects also carried out in the Tatra Mts, where the harmful impact of atmospheric pollution on algae and zooplankton was stated (Fott *et al*. 1994, 1999, Vranovsky *et al*. 1994, Kawecka and Galas 2003). Similar investigations were carried out in lakes situated in other alpine mountain ranges (Manca and Comoli 1999, Tolotti 2001). Studies on the sensitivity of benthic communities to acidification have occasionally been conducted in high mountain lakes (Arzet *et al*. 1986, Krno 1991, Kwandrans 1995, Rieradevall *et al*. 1998, Raddum and Fjellheim 2002). The obtained results concerning benthic fauna are ambiguous. Small water bodies seem to be especially appropriate for such studies since they are sensitive to influences from the surrounding catchment areas (Korhola *et al*. 2002) and atmospheric pollution (Skjelvale and Wright 1998).

Therefore, the aim of the study was to determine the qualitative and quantitative composition of benthic diatoms and macroinvertebrate communities, using data collected from 1998–2000. The relationship between taxa presence versus geochemical parameters and air pollution was analyzed using statistical methods. We made these complex investigations in small high mountain ponds with various characteristics (but natural), situated in the Polish part of the Tatra Mts.

Study area

We carried out the investigations in eight small ponds in the Tatra Mountains National Park, southern Poland (50°–54°N, 16°–24°E) (Fig. 1). The Siwy Wyżni (SW) and Niżni (SN) ponds are situated on crystalline metamorphic rock covered by postglacial sediment and surrounded by alpine meadows and patches of dwarf pine (*Pinus mugo*). The Czerwony Zachodni (CZ), Pańszczycki (CP) and Mnichowy ponds (MI, MII, MV, MIX) lie on the granite bedrock covered by postglacial rock debris. All the studied ponds are surrounded by rocks and alpine meadows. They are small and shallow (Table 1), and fed exclusively by rainfall and melting snow, except for the SW and CP ponds, which are also fed by springs and the Mnichowe ponds which are in turn fed by trickles from peat bogs located above the pond level.

The mean annual precipitation in the Tatra area is 1786 mm per year (The MOLAR Water Chemistry Group 1999). The atmospheric deposition samples were mostly acidic: pH varied from 4.0 to 4.5 and the nitrate concentration is particularly high: 686 mg NO_3 dm^{-3} in spring 1997 (Galas 2002).

Material and methods

A complex hydrobiological study including water chemistry, sediment organic content, benthic diatom and macroinvertebrate communities, was carried out in the selected ponds. We took samples seasonally in the spring, summer, and autumn in the years 1998 (Mnichowy ponds and Siwy ponds), 1999 (CZ) and 2000 (CP).

We collected water samples from the surface layer of the ponds and we analyzed them according to Standard methods (1992). We collected benthic diatom samples from stones by brushing with a toothbrush in a small amount of water in a plastic vial. All samples were collected in small bottles and preserved with 4% formaldehyde. After standard preparation (Kawecka 1980), counting procedures followed the most up-to-date regulations (*see* Kelly *et al.* 1998); we counted at least 250–300 frustules from each sample in randomly chosen microscopic fields using a Nicon E 600 microscope. We calculated the percentage of the taxa in the community and the relative abundances over 5% were designated as abundant. We identified diatoms mainly according to Krammer and Lange-Bertalot (1986–1991), Lange-Bertalot and Metzeltin (1996), and Flower and Jones (1989). Indicator lists mainly based on van Dam *et al.* (1994) were used for pH ecological grouping analyses.

We collected three samples of sediment (only from shore part of ponds) with a 12.56 cm^2 corer, which was driven down to a depth of five cm.

Table 1. Morphometric characteristics of the studied ponds (name abbreviations in parentheses).

	Mnichowy I (MI)	Mnichowy II (MII)	Mnichowy V (MV)	Mnichowy IX (MIX)	Czerwony Zachodni (CZ)	Czerwony Pańszczycki (CP)	Siwy Wyżni (SW)	Siwy Niżni (SN)
Altitude (m)	1833	1865	1869	1869	1694	1654	1718	1716
Area (ha)	0.02	0.05	0.004	0.06	0.27	0.30	0.037	0.046
Max. depth (m)	0.6	0.7	0.3	2.3	1.4	0.9	1.0	1.8
Type of ponds	Temporary	Temporary	Temporary	Permanent	Permanent	Permanent	Permanent	Permanent
Bottom	Stones, sand, mud	Mud	Mud	Boulders, stones, mud	Stones, sandy mud	Stones, patchy mud	Stones, mud	Stones, mud
Shores	Stones, grass	Stones, rock	Stones, peatbog	Stones, rock	Stones, grass	Boulders, stones	Grass	Grass

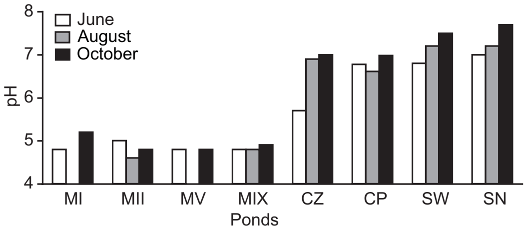

Fig. 2. Seasonal changes of water pH in the investigated ponds (for abbreviations *see* Table 1).

In the laboratory we removed the live benthic invertebrates using a stereoscopic microscope and preserved these specimens in 4% formaldehyde. We dried the remaining material at 105 °C, which was weighed, and ashed at 550 °C for four hours, in order to determine the ash free dry mass (AFDM). The results were expressed as a percentage of the organic matter. The densities of invertebrates were expressed as individuals per square meter. We considered taxa with a percentage value over 10% as dominant.

We identified various groups of macroinvertebrates with different accuracy: Chironomidae, Megaloptera, Oligochaeta and Trichoptera to the species or genus level whilst Nematoda, Ostracoda and Sphaeridae were not identified. We applied the results obtained by Fjellheim and Raddum (1990) in order to determine the acid tolerance of invertebrates. Due to various sampling data in the studied ponds we averaged the results of the chemical analyses and invertebrates densities.

We conducted the Principal Component Analysis (PCA) and then used as a second (environmental) matrix in the CCA analysis of diatoms and bottom fauna distribution, to interpret the major patterns of variation in the chemical and physical data.

Environmental variables (morphometric and hydrochemical) were condensed by factor analysis to three variables. We used new variables as a second (environmental) matrix in CCA analysis of diatoms and bottom fauna distribution. We included the relatively abundant diatom taxa ≥ 1% in the statistical analyses. We clustered variables containing chemical parameters and diatoms data. Grouping was completed by calculating the Euclidean distances and linking them by the Ward method. We used the computer program STATISTICA 5.0 for the CCA analysis and PC ORD 4.20 (McCune and Mefford 1999) for statistical analyses.

Results

Hydrochemistry

Conductivity and the concentration of ions: Ca, Mg as well as SO_4, in the water in all ponds situated on granite bedrock were very low, while in the SW and SN ponds the values of these parameters were higher (Table 2). However, the nutrient concentrations, especially N-NO_3, were relatively high. Regarding pH, three types of ponds could be distinguished: (1) with very low pH (MI, MII, MV, MIX), (2) with neutral pH (SW, SN, CP), and (3) with pH varying significantly during the year from 5.7 in spring to 7.0 in autumn (CZ) (Fig. 2).

Factor analysis allowed us to find two significant factors. The first two factors explained 65.8% of the variance. They comprised parameters connected with pH and nitrogen compounds (Table 3). The third factor was found to be unimportant (it explained 10% of the variance).

Cluster analysis divided the studied ponds into two groups: the first one including four Mnichowy ponds which were separated due to their low water pH, and the second one including the remainder of the studied ponds with higher conductivity and pH (Fig. 3).

Organic matter

The organic matter content in the sediments varied considerably being the lowest in the CZ pond (3%), and the highest in the MV pond (50%) (Fig. 4). In the other ponds this value ranged from 12% to 30%, with the highest values being in the four Mnichowy ponds. We found a higher concentration of organic matter in all the studied ponds in spring.

Benthic diatom communities

Diatom cluster analysis showed two main groups of diatom communities with a subgroup within

Table 2. Chosen hydrochemical characteristics (min–max) of the studied ponds (for abbreviations *see* Table 1).

	MI	MII	MV	MIX	CZ	CP	SW	SN
Year	1998	1998	1998	1998	1999	2000	1998	1998
Oxygen saturation O_2 (%)	78.1–87.4	75.3–82.0	73.3–82.9	78.1–81.6	–	85.8–95.6	81.9–83.3	78.6–108.4
CO_2 (mg dm^{-3})	4.3–5.7	4.6–5.0	4.8–14.0	2.3–5.8	0.8–2.2	1.1–1.2	2.5–3.0	1.1–4.7
Total hardness (°N)	0.12–0.26	0.11–0.26	0.1–0.3	0.13–0.37	0.3–0.8	0.6–0.9	0.6–0.92	0.8–1.01
Carbonate hardness (°N)	0.08–0.14	0.08–0.14	0.08–0.17	0.08–0.17	0.2–0.6	0.45–0.6	0.52–0.72	0.59–0.81
Ca (mg dm^{-3})	0.5–1.5	0.4–1.5	0.4–1.9	0.6–1.9	1.6–3.9	3.6–4.2	2.5–4.1	2.9–3.4
Mg (mg dm^{-3})	0.2	0.1–0.2	0.2	0.1–0.4	0.4–1.0	0.3–0.5	1.1–2.0	1.7–2.1
SO_4 (mg dm^{-3})	1.0–3.7	1.0–3.5	2.0–2.7	1.8–3.5	2.9–4.7	1.1–1.4	2.9–4.1	2.7–7.1
N-NH_4 (mg dm^{-3})	0.263–0.286	0.266–0.344	0.273–0.297	0.172–0.228	0.432–0.544	0.36–0.40	0.226–0.279	0.217–0.373
N-NO_3 (mg dm^{-3})	0.048–0.185	0.028–0.151	0.059–0.205	0.061–0.351	0.224–0.41	0.44–0.49	0.064–0.137	0.04–0.19
PO_4 (mg dm^{-3})	0.03–0.034	0.04–0.055	0.026–0.028	0.036–0.045	0.167–0.339	0.21–0.23	0.019–0.057	0.0048–0.0288
Conductivity (µS cm^{-1})	10.0–10.1	10.3–14.3	13.1–14.2	12.2–19.2	13.7–31	22.7–35.6	27.3–34.5	27.2–44.6

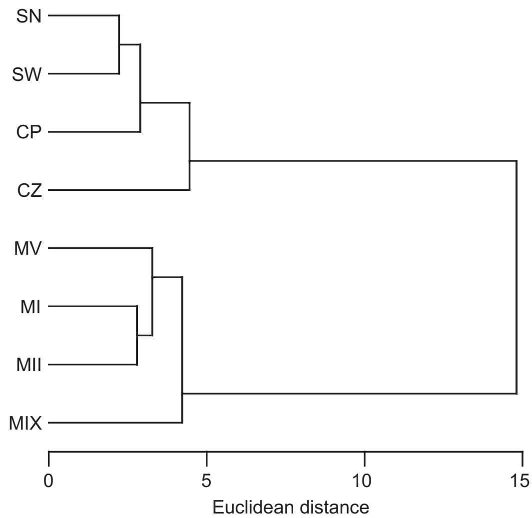

Fig. 3. Results of cluster analysis based on hydrochemical and morphometric parameters. Euclidean distance as a similarity measure and Ward algorithm as a linkage method were used (for abbreviations *see* Table 1).

Table 3. Factor loading of hydrochemical and morphometric parameters in PCA.

	Factor 1	Factor 2	Factor 3
Temperature	–0.23	0.68	0.29
Organic matter	–0.79	–0.03	–0.03
pH	0.95	–0.08	0.09
CO_2	–0.73	–0.15	0.08
Conductivity	0.96	–0.03	0.19
Total hardness	0.49	0.57	–0.37
Carbonate hardness	0.96	–0.07	0.16
Oxidation	–0.57	–0.10	0.65
O_2	0.31	0.00	–0.96
O_2 (%)	0.41	–0.29	–0.52
BOD_5	0.00	–0.63	–0.26
Total residual	0.78	–0.53	0.13
TFRED	0.79	–0.54	0.00
Loss of ignition	0.56	–0.36	0.39
SiO_2	0.62	–0.45	–0.23
Ca	0.95	0.16	0.13
Mg	0.82	–0.47	0.19
Cl	0.51	0.77	–0.20
SO_4	0.62	–0.23	0.42
N-NH_4	0.41	0.79	0.24
N-NO_3	0.48	0.78	0.03
Altitude	–0.93	–0.21	0.05
Surface area	0.59	0.79	0.05
Deepness	0.36	–0.20	0.10
Eingevalue	10.63	5.05	2.54
Explained variance	0.44	0.21	0.11

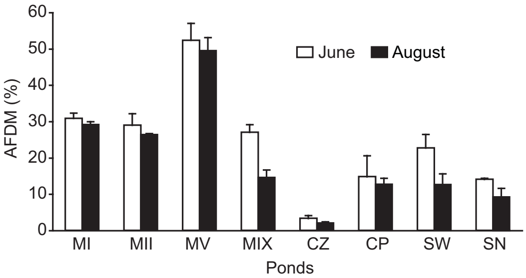

Fig. 4. Organic matter content in sediments (+ S.D.) of the investigated ponds (for abbreviations *see* Table 1).

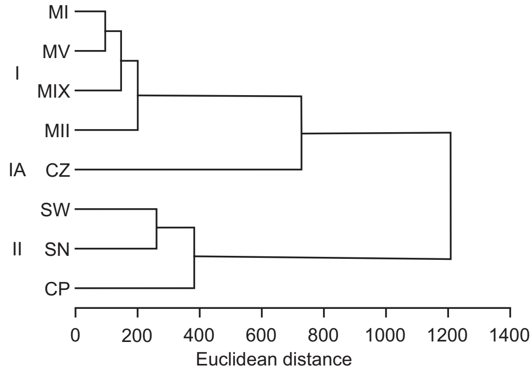

Fig. 5. Results of cluster analysis based on diatom communities. Euclidean distance as a similarity measure and Ward algorithm as a linkage method were used. (For abbreviations *see* Table 1.)

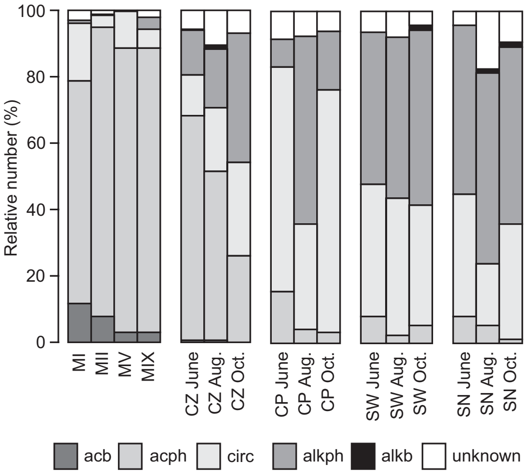

Fig. 6. Relative abundances of diatom pH-groups in the studied ponds; acb = acidobiontic, acph = acidophilous, cir = circumneutral, alkph = alkaliphilous, alkb = alkalibiontic.

cluster I (Fig. 5). We found the most distinct diatom communities in the four Mnichowy ponds (cluster I) with low pH and very low calcium and magnesium content (Table 2). The total number of taxa was low (23–26) and 50% of them were rare (abundance < 1%). We found stable species composition and community structure during all seasons and they were homogenous for each pond among the particular ponds.

The most frequent and abundant species were: *Achnanthes marginulata*, *A. subatomoides*, *Aulacoseira distans*, *Eunotia exigua*, *E. rhomboidea*, *Pinnularia microstauron* and *Tabellaria flocculosa*, (Table 4). The second level of cluster division separated communities within the CZ pond (subgroup IA) where we noted a higher number of taxa (49–57) (Fig. 6). The diatom flora was characterized by the abundant occurrence of *Achnanthes curtissima*, *A. helvetica*, *A. marginulata*, *A. minutissima*, *Cymbella minuta* and *Denticula tenuis*. Cluster II contained the SW, SN and CP ponds, with higher water pH and higher water conductivity. We stated the high number of taxa (53–59) with a distinct dominance of the taxa from the genus *Fragilaria*, which prevailed in diatom communities in the above mentioned ponds throughout the study period. Also common and abundant were *Achnanthes minutissima*, *Cymbella minuta*, *Diatoma hyemalis*, *D. mesodon* (Table 4).

The differences in relative abundance of the indicative groups distinguished with respect to pH preferences (Fig. 6), corresponded very well to the differences between water types of the studied ponds. In the Mnichowy ponds, the acidophilous diatoms were the dominant group, constituting 67%–85% of the total communities. In the CZ pond (pH = 5.8–7.0), we observed a significant seasonal difference in the share of the groups (Fig. 6). During the snow-melting period (June), the acidophilous group prevailed. During autumn, the percentage of the acidophilous forms decreased considerably — neutral and alkaliphilous forms became more abundant. In the SW and SN ponds (pH = 6.8–7.6), alkaliphilous forms dominated during the whole study period with a significant share of the circumneutral group. In the CP pond (water pH oscillating around seven) the share of circumneautral species was the highest during spring and autumn. There was a noticeable increase in the alkaliphilous group in August (Fig. 6).

Table 4. The most abundant taxa (relative abundance > 5%) of diatoms in the studied ponds (for abbreviations *see* Table 1).

MI	MII	MV	MIX	CZ	SW	SN	CP
Achnanthes marginulata	*Eunotia rhomboidea*	*Achnanthes marginulata*	*Aulacoseira distans*	*Achnanthes marginulata*	*Cymbella minuta*	*Fragilaria pinnata*	*Navicula gallica* var. *perusilla*
Pinnularia microstauron	*Achnanthes marginulata*	*Aulacoseira distans*	*Achnanthes marginulata*	*Achnanthes minutissima*	*Fragilaria pinnata*	*Cymbella minuta*	*Cymbella minuta*
Achnanthes subatomoides	*Tabellaria flocculosa*	*Pinnularia microstauron*	*Achnanthes subatomoides*	*Achnanthes curtissima*	*Fragilaria construens* group	*Fragilaria construens* group	*Fragilaria pinnata*
Aulacoseira distans	*Eunotia exigua*	*Eunotia rhomboidea*		*Denticula tenuis*	*Nitzschia perminuta*	*Achnanthes minutissima*	*Achnanthes minutissima*
Eunotia exigua		*Achnanthes subatomoides*		*Cymbella minuta*	*Meridion circulare*	*Meridion circulare*	*Achnanthes petersenii*
				Achnanthes helvetica	*Achnanthes minutissima*	*Achnanthes laevis*	*Diatoma hyemalis/mesodon*
					Achnanthes subatomoides	*Achnanthes subatomoides*	*Eunotia praerupta*
					Diatoma hyemalis/mesodon	*Diatoma hyemalis/mesodon*	
					Fragilaria leptostauron		

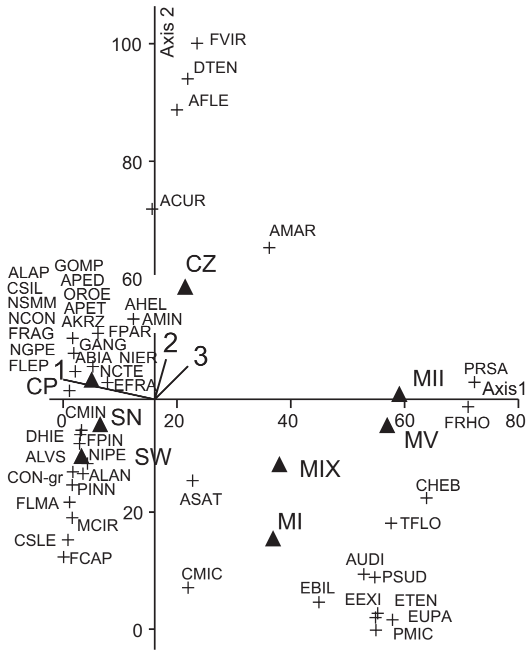

Fig. 7. Canonical correspondence analysis based on diatom taxa with an abundance > 5%. Triangles represent ponds and crosses represent taxa.

The results of CCA indicated a relationship between diatoms and environmental variables (Fig. 7). The first axis explained 47% of the data variability and was positively correlated with pH, and pH-related factors (conductivity, carbonate hardness, Ca and Mg (Table 3)). The second axis was less significant, correlating with the factors linked to the water trophic state, chlorides and surface area. In general, the results of CCA for ponds and for diatoms, clearly separated (similar to the cluster analysis) the group of Mnichowy ponds from the others. The second group was expanded along the second axis with a closer relationship between the two Siwy ponds, CP and the more distant CZ ponds (Fig. 7). The analysis of the taxa gradient (Fig. 7, crosses) dealing with extreme positions along the second axis, confirmed again the relationship with the gradient for water pH.

Macroinvertebrate communities

Chironomidae, Nematoda and Oligochaeta were the dominant groups in benthos of the studied ponds (Fig. 8). We found representatives of the other groups (Sphaeridae, Megaloptera, and Trichoptera) in single specimens or in one pond only (Ostracoda). The density changed from 8700 in CZ to 66 500 ind. m^{-2} in MV. We found a total of 42 invertebrate taxa (of various ranges) in the studied ponds.

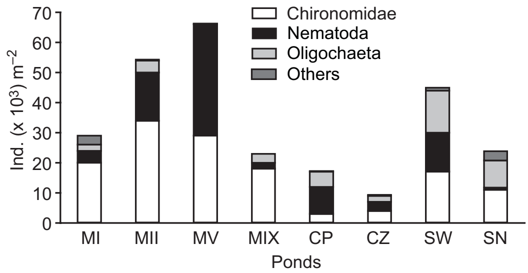

Fig. 8. The densities of different zoobenthos groups in the studied ponds.

We noted the highest species number in the CP pond (21) and in the SW and CZ ponds (17 taxa) while the lowest number of species was noted in the MI, MV and MIX ponds (5–8). Taking into account the species composition of Oligochaeta and Chironomidae, various taxa dominated in the studied ponds (Table 5). We noted the high percentage share of the chironomid *Zalutschia tatrica* in the Mnichowy ponds, while Oligochaeta, represented entirely by *Cernosvitoviella tatrensis*, was found in three of these ponds. The exception was the invertebrate community living in the MIX pond, where *Heterotrissocladius marcidus* was also a very important dominant species (Table 5). In each of the Czerwony ponds, different taxa were more numerous: in the CP pond among the oligochaetes, representatives of the genus *Cognettia* and *Mesenchytraeus armatus* prevailed while Chironomidae were less numerous (no one reached 5% abundance). In the CZ pond Chironomidae were represented mainly by Orthocladiinae (*Heterotrissocladius marcidus*) and Oligochaeta by Tubificidae juv. and *Nais variabilis*. Chironomidae from the tribe Tanytarsini: *Tanytarsus* spp., *Paratanytarsus austriacus*, and Tubificidae: *Tubifex montanus*, *T. tubifex*, *Spirosperma ferox* dominated in both Siwy ponds. Moreover, *Stylodrilus* sp. juv. was numerous in SN. The CCA results indicated two main gradients differentiating the benthos in the studied ponds (Fig. 9), which distinguished separated groups within the

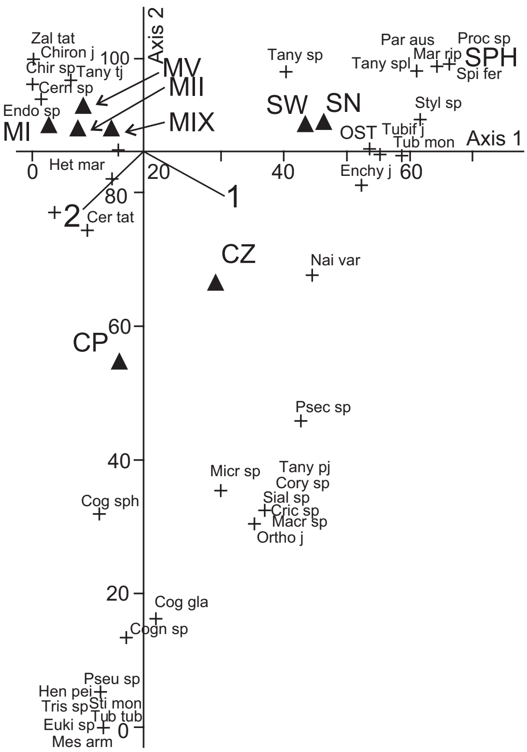

Fig. 9. Canonical correspondence analysis based on benthic fauna. Triangles represent ponds and crosses represent taxa.

Mnichowy and Siwy ponds with the CP and CZ ponds being more dispersed.

Discussion

The studied ponds differed among themselves mainly in the pH and Ca content. The cluster analyses and CCA of the data collected from eight ponds demonstrate the relationships between diatom and invertebrates, including distribution, structure of their communities and environmental variables. As such, they separate the studied high mountain ponds into two groups located along the first axis and their pH reveal the main separating gradient. In many papers (e.g. Fjellheim and Raddum 1990, Planas 1996, Stoermer and Smol 1999), this parameter was highlighted as being a very significant factor regulating the diatom and macroinvertebrate distribution and community structure in streams and lakes.

Table 5. The most abundant taxa (relative abundance > 5%) of macroinvertebrates in the studied ponds (for abbreviations *see* Table 1).

MI	MII	MV	MIX	CZ	SW	SN	CP
Zalutschia tatrica	Nematoda	Nematoda	*Zalutschia tatrica*	Nematoda	Nematoda	*Tanytarsus* sp.	Nematoda
Nematoda	*Zalutschia tatrica*	*Zalutschia tatrica*	*Heterotrissocladius marcidus*	*Orthocladiinae* juv.	*Tanytarsus* sp.	*Spirosperma ferox*	*Cognettia* sp. juv.
Cernosvitoviella tatrensis	*Tanytarsini* juv.		*Cernosvitoviella tatrensis*	*Heterotrissocladius marcidus*	Tubificidae juv.	Ostracoda	*Mesenchytraeus armatus*
	Tanytarsus sp.		Nematoda	Tubificidae juv.	*Paratanytarsus austriacus*	Tubificidae juv.	
	Cernosvitoviella tatrensis			*Nais variabilis*	*Spirosperma ferox*	*Stylodrilus* sp. juv.	
					Enchytraeidae juv.		

The differences in water chemistry between the studied ponds could clearly be explained by differences in local geology and soil cover. The Mnichowy ponds have an especially low pH value due to trickles from the surrounding peat bogs. However, a small increase in the water acidity in the Mnichowe ponds was observed during the last 40 years (Oleksynowa and Komornicki 1961, Kownacka and Kownacki 1965, Krywult 1990, Wojtan and Galas 1994), as a result of the increasing content of nitrates and sulphates in precipitation up to the 1990s (Psenner and Schmidt 1992). However, the decreased pH in the four Mnichowe ponds was not reflected in changes in benthic community composition (Kownacka and Kownacki 1965, Kownacki *et al*. 2000, B. Kawecka pers. com.). In these ponds diatom communities consisted of a small number of species, with the dominance of acidobiontic and acidophilous forms, typical for low buffered, nutrient-poor waters (e.g. Flower 1986, van Dam *et al*. 1994, Kwandrans 1995, Planas 1996). Among benthic fauna *Cognettia* spp. and *Zalutschia tatrica* dominated. The latter species was numerous also in the 1960s (Kownacka and Kownacki 1965). It has been found in oligohumic and polyhumic lakes, ponds, and pools in Swedish Lapland and the Kola Peninsula (Saether 1976) and in the Tatra Mts as a relict of the quaternary glaciations. Genus *Cognettia* is characteristic for acid soil and waterbodies (Healy and Bolger 1984). Therefore, the presence of such a benthic community (with acidobiontic diatoms, *Zalutschia tatrica* and *Cognettia* spp.) can not be seen as an indicator of progressive antrophogenic acidification. The separation of the group of the four Mnichowy ponds based on pH values seems to have a natural character.

In the other investigated ponds the number of species found was distinctly higher and other taxa were the most numerous. Although CP is located on granite bedrock, its water chemistry is more similar to the SW and SN ponds situated on metamorphic rocks. Their waters are characterized by a similar range of conductivity, Ca, and total hardness values as stated earlier (Olszewski 1939, Paschalski 1963), as well as the similarity of their algae and benthic fauna communities. In general, the composition of diatom communities found in the CP, SW and SN ponds, was similar to that of the shore of other lakes in the Tatra Mts (Galas *et al*. 1996, Kawecka and Galas 2003). The invertebrate community (with *Heterotrissocladius marcidus* and *Tubifex* domination) was also typical for most of the Tatra Mts lakes (Hrabě 1942, Kownacki and Kownacka 1965, Galas *et al*. 1996). The lack of representatives of many systematic groups and low species diversity is very often found in high mountain lakes (Rieradevall *et al*. 1998, Stoichev 2004). This could be explained by a whole complex of environmental parameters other than acidification. As stated in our investigations even in the Siwy ponds, where neutral or even alkaline pH was found, there was low diversity of benthic animals.

According to the literature data, the pH value in CP and CZ ponds changed irregularly, but did not decrease significantly since the 1930s (Olszewski 1939, Paschalski 1963, Krywult 1990, Rogala and Kidawa 1994, Wojtan and Galas 1994). In our studies, high fluctuations during the year were recorded (5.7–7.0) in CZ whereas in CP and both Siwy ponds they were smaller. Usually the lowest pH value is found during the snow melting as was found in other Tatra lakes (Rzychoń 1998). Such seasonal changes in pH indicate some anthropogenic effect, mostly connected with atmospheric transportation.

Seasonal changes of pH in the CZ pond were reflected by temporal variations in the structure of the diatom communities where the share of acidophilous diatoms decreased significantly, especially during the autumn when they were replaced by neutral and alkaliphilous ones. In the same pond, the benthic macrofauna composition did not reflect seasonal changes in water pH values. Invertebrate species dominated in the CZ pond (*Heterotrissocladius marcidus*, *Nais variabilis*) and tolerated well changes in environmental conditions. These species live in springs, streams, rivers and stagnant waters (Seather 1975, Dumnicka 2000) and were also stated as being dominant in Tatras lakes of various depth and altitude (Hrabě 1940, Kownacki *et al*. 2000).

Taking into account the interdependence between water parameters, mostly pH, and the studied biocenoses, it may be assumed that algae are a more sensitive indicator of temporal acidification than invertebrates.

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