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Rare and vulnerable species in the mollusc communities in the mining subsidence reservoirs of an industrial area (The Katowicka Upland, Upper Silesia, Southern Poland)

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Abstract

Pollution of the water environment by mining waters is a problem not only in Poland, but worldwide. This study investigated the mollusc communities in seven mining subsidence reservoirs affected by coal mine output (the Katowicka Upland, Upper Silesia, Southern Poland). The objective of the survey was to determine the relationship between the molluscs and their environments and to evaluate the ecological-conservation value of freshwater habitats which support rare and vulnerable molluscs. From 1993 to 2005, 23 mollusc species were recorded. Our result confirmed an invasion by *Potamopyrgus antipodarum* (Gray, 1843), whose density varied from 2 to 2422 individuals/m^2 in the waters of the Katowicka Upland. A few rare and vulnerable species were found, e.g. *Acroloxus lacustris* (Linnaeus, 1758), *Hippeutis complanatus* (Linnaeus, 1758), *Ferrissia wautieri* (Mirolli, 1960), *Anodonta anatina* (Linnaeus, 1758), *Musculium lacustre* (O.F. Müller, 1774) or *Pisidium casertanum* (Poli, 1791). Principal component analysis showed a positive correlation between mollusc density and pH, the concentration of chlorides, the total hardness, alkalinity and total dissolved solids, and a negative correlation between the number of species and phosphates. Because of the distinctive environmental features of the mining subsidence reservoirs in Czułów, the research area has provided a refuge for wildlife.

Keywords: Mining subsidence reservoirs; *Ferrissia wautieri*; *Potamopyrgus antipodarum*; Rare species; Mollusc communities; Upper Silesia

Introduction

Coal mining influences the vertical movement of the geological beds above the working area. The character and strength of this movement depends on the thickness of the coal strata, the depth of its dipping and on hydrology. This results in the ground sinking above the coal mine depletion. After a certain period of time, subsidence hollows fill with surface and ground water (Rzętała 1998). In this way, mining subsidence reservoirs are created and eventually colonized by macrophytes, invertebrates, amphibians and waterfowl. The mining and metallurgical industries of the Katowicka Upland (Upper Silesia, Southern Poland) have led to changes in water circulation and have caused a water shortage. The

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majority of watercourses of the Katowicka Upland have a high level of chlorides, sulphates, phosphates, nitrates, heavy metals and radioactive matter (Jankowski & Rzętała 2000; Lebecka 1993; Michalik-Kucharz, Strzelec, & Serafiński 2000; Rybicka Helios 1996). These water conditions are reflected in high values of conductivity, total dissolved solids and BOD_5 (Jankowski & Rzętała 2000; Michalik-Kucharz et al. 2000). Mining waters, which carry about 6500 t Cl^- and 0.5 t SO_4^-/day, discharge into rivers, mainly the Wisła River and the Odra River (Czaja 1999; Ericsson & Hallmans 1994). An example of this type of watercourse is the Mleczna River, which carries municipal, industrial and mining waters from the "Murcki" coal mine in Czułów, near Katowice (Czaja 1999). The waste rock deposited on mine dumps constitutes an additional source of chlorides, sulphates and heavy metals. Pollution of the water environment by mining waters is a Polish, European and worldwide problem (Jarvis & Younger 2000).

The objectives of the present survey were to carry out a zoocenological study of the mollusc communities in Polish mining subsidence reservoirs, as well as to attempt to elucidate the relationships between the molluscs and their environments, and to evaluate the ecological-conservation value of freshwater habitats which support rare and vulnerable molluscs.

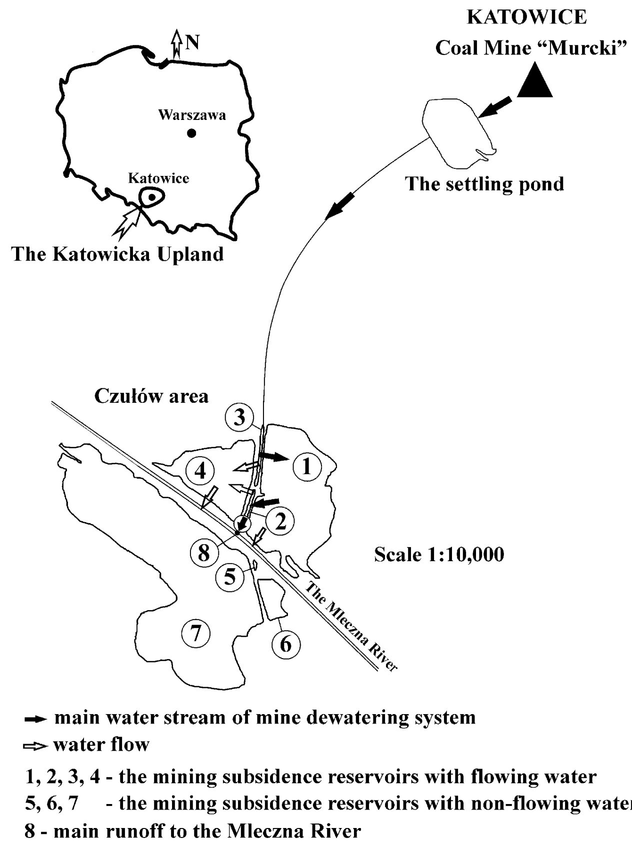

Fig. 1. Location of the study area.

Materials and methods

Study area

The study area is a part of the Katowicka Upland, whose basement complex consists of carboniferous rocks. Dolomites and limestones of Trias lie above the carboniferous rock (Kondracki 2002). The study was carried out in the years 1993–2005 in Czułów, near Katowice. Seven mining subsidence reservoirs, which have different water sources, were investigated; a part of the Mleczna River, was investigated as well. The reservoirs originated from the effects of the "Murcki" coal mine in the 1970s. Mining subsidence reservoirs 1, 2, 3, 4 (Fig. 1) are reservoirs with flowing water, supplied by both surface and deep waters. Mining water flows into reservoir 3 and then through reservoirs 1, 2, 4 and on into the Mleczna River. Mining subsidence reservoirs 5, 6, 7 are reservoirs with non-flowing water. The surface area of the reservoirs amounts: 100 (No. 5), 150 (No. 2), 240 (No. 3), 2,400 (No. 6) 3,200 (No. 4), 5,000 (No. 1) and 25,000 (No. 7) m^2, respectively. The average depth of the reservoirs ranges from 0.5 to 2.0 m. The reservoirs have now been reclaimed, and the waterbanks are partially concrete-lined and stabilized with waste rock and slag. The reservoirs are used by anglers and hunters. They are stocked with fish: *Tinca tinca* (L.), *Carassius auratus gibelio* (Bloch), *Carassius auratus* (L.), *Anguilla anguilla* (L.), *Cyprinus carpio* (L.), *Esox lucius* (L.), *Perca fluviatilis* (L.), *Rutilus rutilus* (L.) and *Scardinus erytrophthalmus* (L.). The macrophytes have been partially removed and the reservoirs' output has been regulated as part of the reservoir management process.

Methods

The samples of molluscs were taken by means of quantitative methods by placing a quadrat frame (25 × 25 cm) randomly on the ground. The frame was placed 16 times at each of the sampling sites, which constituted one sample. One sample which consisted of 16 quadrat frames, included bottom sediments up to 5 cm, macrophytes and water surfaces. Only living specimens of molluscs were collected. The bottom sediments were taken by means of a core-type sampler. The collected material was brought back to the laboratory in plastic bags. The samples were then filtered using a 0.5-mm mesh sieve. The samples of molluscs were preserved in 75% ethanol. The species of molluscs were identified according to Glöer &

Meier-Brook (1998). The density of molluscs was estimated as the number of individuals per square meter. Immediately prior to mollusc sampling, water samples were collected from each sample site. The analyses of the physical and chemical parameters of the water, e.g. conductivity, total dissolved solids, pH, dissolved oxygen, nitrates, phosphates, total phosphorus, total hardness, calcium, chlorides, alkalinity, sulphates and iron were carried out according to Hermanowicz, Dożańska, Dojlido, and Koziorowski (1976). The samples were taken twice each year, in April and August.

Macrophyte species were recorded on the same visit as mollusc sampling. If macrophyte species could not be identified to species in the field, they were taken to the laboratory, dried between sheets of filter paper and, after drying, mounted as ordinary herbarium species. Macrophytes were identified to species according to Szafer, Kulczyński, and Pawłowski (1986).

The mineralogical analyses of the bottom sediments were carried out using a Siemens D 5,000 powder diffractometer.

The zoocenological study of the mollusc communities was carried out using the following indices:

1. Domination (D%)

   $D = n_a/n \times 100$,

   where n_a is the number of individuals of species a and n the total number of individuals in a sample.

   The value of the domination index D was divided into five classes according to Górny and Grüm (1981): eudominants $>10.0\%$ of sample, dominants 5.1–10.0% of sample, subdominants 2.1–5.0% of sample, recedents 1.0–2.1% of sample and subrecedents $<1.0\%$ of sample.
2. The Shannon–Wiener index (Cao, Bark, & Williams 1996; Mouillot & Lepretre 1999):

   $H' = -\sum(P_i)(\log_2 P_i)$,

   where $P_i = N_i/N$ the proportion of individuals belonging to species i.

   The analysis of mollusc frequency in particular reservoirs in terms of bottom sediments and macrophyte abundance was calculated by means of a chi-squared (χ^2) association test (Fovler, Cohen, & Jarvis 1998).

Principal component analysis (PCA)

The studied data set contains measurement values of 12 various biological, physical and chemical parameters of eight samples collected at the sampling sites in each of the mining subsidence reservoirs. The measured parameters are as followed: mollusc density, number of species, dissolved oxygen, pH, conductivity, total dissolved solids, nitrates, phosphates, total phosphorus, total hardness, chlorides and akalinity. The data are organized in a matrix **X** (8×12). Each row of the matrix **X** represents one sample site, described by 12 parameters. As the measured parameters significantly differ in their ranges, the data set is standardized according to the formula:

$$x_{ij} = \frac{(x_{ij} - \bar{x}_j)}{s_j},$$

where $\bar{x}_j, s_j$ denote the mean of the jth column and its standard deviation, respectively.

The most popular technique of exploratory analysis of mutlivariate data sets is PCA (Jolliffe 1986; Vandeginste et al. 1998; Wold 1987). It can be applied to the reduction of data dimensionality, the reduction of experimental error, data visualization and the interpretation of the objects and variables relationships. PCA analysis was performed using Matlab 6.0 version.

Results

The physical and chemical parameters of the waters

Table 1 shows the physical and chemical parameters of the waters. The lowest values for conductivity, the total dissolved solids, nitrates, phosphates and total phosphorus occurred in reservoir 7. Most of the physical and chemical parameters were highest in the reservoirs which received mining waters (reservoirs 1, 2, 3 and 4). The Mleczna River is periodically polluted by domestic and industrial sewage. This results in high values of conductivity, total dissolved solids, chlorides and total hardness (Table 1). Regarding total hardness, the waters are soft (reservoir 7), soft and medium hard (reservoirs 5, 6), medium hard and hard (reservoirs 1–4) and in the Mleczna River.

The bottom sediments

The qualititative analysis of mineralogy showed that quartz was the main component. Nimite, kaolinite, illite, albite and strontium oxide were present in smaller amounts.

Macrophytes

Eighteen macrophyte species occurred in the mining subsidence reservoirs (Table 2). Most of the reservoirs were dominated by *Glyceria maxima*, *Typha latifolia* and *Lemna minor*. *Nuphar lutea*, such as nymfeid, is legally protected in Poland (Dziennik Ustaw 2001a). *Najas marina* rarely occurs in the reservoirs of the Katowicka

Table 1. The physical and chemical parameters of water and their values (1993–2005)

Parameter	The Mleczna River (main runoff)	Reservoirs with flowing water	Reservoirs with non-flowing water	
Reservoirs	No. 8	Nos. 1, 2, 3, 4	Nos. 5, 6	No. 7
Conductivity (μS/cm)	1875–3240	710–2160	290–1500	380–527
Total dissolved solids (mg/l)	970–1620	740–1070	140–750	130–210
pH	7.0–7.9	7.0–8.1	7.1–8.4	7.1–8.3
Dissolved oxygen (mg O_2/l)	2.4–10.8	4.2–11.0	3.5–8.8	6.3–11.3
Nitrates (mg NO_3/l)	0.3–7.7	1.0–17.8	3.3–7.3	1.3–3.0
Phosphates (mg PO_4/l)	0.41–2.74	0.21–2.74	0.04–2.10	0.05–0.65
Total phosphorus (mg P/l)	0.13–0.89	0.08–0.89	0.01–0.68	0.02–0.21
Total hardness (mg $CaCO_3$/l)	270–450	218–340	91–246	35–143
Calcium (mg Ca/l)	48–154	40–105	36–82	25–88
Chlorides (mg Cl/l)	268–690	67–390	20–190	20–88
Alkalinity (mg $CaCO_3$/l)	170–405	190–395	75–310	70–105
Sulphates (mg SO_4/l)	120–350	120–350	50–300	50–75
Iron (mg Fe/l)	0.2–1.5	0.2–1.0	0.05–1.39	0.01–0.4

Table 2. Macrophyte occurrence in the mining subsidence reservoirs in Czułów, near Katowice

Species	Reservoirs with flowing water				Reservoirs with non-flowing water		
	No.1	No. 2	No. 3	No. 4	No. 5	No. 6	No. 7
Acorus calamus L.	+						
Alisma plantago-aquatica L.	+						+
Ceratophyllum demersum L.	+	+			+	+	
Eleocharis palustris (L.) Roem. & Sm.	+						
Elodea canadensis Michx.	+	+			+	+	
Glyceria maxima (Hartm.) Holmb.	+	+	+	+	+	+	+
Iris pseudoacorus L.	+	+					+
Lemna minor L.	+	+	+	+	+	+	
Lemna trisulca L.	+	+					
Myriophyllum spicatum L.	+						
Najas marina All.							+
Nuphar lutea (L.) Sibth. & Sm.	+					+	
Potamogeton crispus L.	+		+			+	+
Riccia fluitans L.	+			+			
Rumex hydrolapathum Huds.	+			+	+	+	+
Sparganium erectum L. EM. RCHB.	+	+	+				
Typha latifolia L.	+	+	+	+			+
Utricularia vulgaris L.		+					+
$\sum$ of species	16	9	5	5	5	7	8

Upland. This species was present in a single mining subsidence reservoir, which had the largest area and the cleanest water. *Utricularia vulgaris* occurred in two reservoirs (Table 2).

The zoocenological study of the mollusc communities

From 1993–2005, 23 species were observed (Table 3). In the reservoirs with flowing water, 22 species were recorded. In the reservoirs with non-flowing water *Bithynia tentaculata* was eudominant (Table 3) and varied in density from 2 to 98 individuals/m^2. *Potamopyrgus antipodarum*, whose density varied from 2 to 2422 individuals/m^2 occurred as eudominant in the reservoirs with flowing water (Table 3). From 1997 to the present, a great invasion of *Potamopyrgus antipodarum*, the only alien parthenogenetic gastropod species in Europe, was observed. A bivalve species: *Musculium lacustre* was found both in reservoirs with

Table 3. The values of the domination ($D\%$) index of the mollusc communities

Species	1993	1995	1996	1997	2000	2001	2002	2003	2004	2005
Viviparus contectus (Millet, 1813)			6.6[a] 1.6[b]	0.4[a]	0.8[a] 10.7[b]	2.9[a] 0.8[b]	2.4[a] 5.6[b]	3.4[a] 6.3[b]	5.5[a] 5.0[b]	0.6[a] 6.4[b]
Potamopyrgus antipodarum (Gray, 1843)				83.0[a]	51.5[a]	66.4[a]	38.4[a]	40.5[a]	43.5[a]	81.4[a]
Bithynia tentaculata (Linnaeus, 1758)					7.2[a] 14.0[b]	2.2[a] 19.5[b]	3.1[a] 36.9[b]	3.5[a] 19.8[b]	9.2[a] 17.6[b]	3.9[a] 21.3[b]
Acroloxus lacustris (Linnaeus, 1758)	36.4[a]	31.6[a]	1.9[a]	0.1[a]	7.6[a] 10.8[b]	0.7[a] 3.1[b]	0.6[b]	1.5[a] 0.6[b]	1.6[a] 1.8[b]	0.3[a] 2.1[b]
Lymnaea stagnalis (Linnaeus, 1758)	13.2[a] 14.3[b]	14.6[a] 21.7[b]	1.9[a] 5.0[b]	0.9[a] 7.9[b]	1.6[a]	3.6[a] 8.6[b]	7.9[a] 10.5[b]	16.2[a] 3.6[b]	4.4[a] 8.0[b]	0.5[a] 5.7[b]
Stagnicola palustris (O. F. Müller, 1774)			3.8[a]	0.4[a]						
Stagnicola corvus (Gmelin, 1791)			1.9[a]	0.5[a]						
Radix auricularia (Linnaeus, 1758)					4.0[a] 7.5[b]	1.6[b]	1.8[a] 2.0[b]	0.4[a] 3.4[b]	1.0[a] 6.0[b]	0.1[a] 7.8[b]
Radix peregra (O. F. Müller, 1774)	24.5[a]	24.7[a]	22.6[a] 3.5[b]	1.6[a] 8.8[b]	4.8[a] 3.2[b]	1.9[a] 4.7[b]	4.3[a] 2.0[b]	3.2[a] 3.6[b]	12.6[a] 3.0[b]	1.0[a] 6.4[b]
Anisus spirorbis (Linnaeus, 1758)			3.8[a]	2.3[a]		0.5[a]				
Bathyomphalus contortus (Linnaeus, 1758)				0.1[a]				5.5[b]	0.3[a] 5.0[b]	2.1[b]
Gyraulus albus (O. F. Müller, 1774)	6.0[a]	7.0[a]	3.8[a]	1.2[a]	8.8[a] 18.3[b]	2.2[a] 10.2[b]	6.7[a] 7.2[b]	3.2[a] 22.9[b]	2.4[a] 4.5[b]	0.3[a] 7.1[b]
Gyraulus crista(Linnaeus, 1758)	1.3[a] 6.1[b]	6.3[a] 5.0[b]	79.9[b]	0.2[a] 26.3[b]	1.6[a] 5.4[b]	2.3[b]	3.7[a] 1.3[b]	1.8[a] 0.4[b]	7.8[a] 0.8[b]	4.2[a] 1.4[b]
Hippeutis complanatus (Linnaeus, 1758)			15.1[a] 0.6[b]	5.3[a] 10.5[b]	2.0[a] 2.2[b]	4.1[a] 21.9[b]	6.7[a] 14.1[b]	2.4[a] 9.2[b]	2.3[a] 2.5[b]	2.0[a] 2.1[b]
Segmentina nitida (O. F. Müller, 1774)	12.0[a] 6.1[b]	12.0[a] 3.3[b]	13.2[a] 0.6[b]	1.0[a] 5.3[b]	3.2[b]	3.4[a]	9.2[a]	3.7[a] 6.9[b]	4.1[a] 19.3[b]	3.3[a] 4.2[b]
Planorbarius corneus (Linnaeus, 1758)	6.6[a] 65.3[b]	3.8[a] 63.3[b]	16.0[a] 3.8[b]	0.7[a] 41.2[b]	9.7[a] 3.2[b]	6.0[a] 15.6[b]	6.7[a] 8.5[b]	13.2[a] 9.9[b]	3.4[a] 20.8[b]	0.4[a] 15.6[b]
Ferrissia wautieri (Mirolli, 1960)					21.5[b]	11.7[b]	1.8[a] 11.4[b]	0.3[a] 7.4[b]	2.0[b]	10.6[b]
Physella acuta (Draparnaud, 1805)		6.7[b]	9.4[a] 5.5[b]	2.4[a]			1.8[a]	0.3[a]		0.5[a]
Aplexa hypnorum (Linnaeus, 1758)	8.2[b]								0.4[a]	0.2[a]
Anodonta anatina (Linnaeus, 1758)									0.6[a]	0.2[a]
Sphaerium corneum (Linnaeus, 1758)									2.8[b]	4.2[b]
Musculium lacustre (O. F. Müller, 1774)						4.83[a]	3.1[a]	2.1[a]	0.4[a] 0.8[b]	0.2[a] 2.8[b]
Pisidium casertanum (Poli, 1791)						1.21[a]	2.4[a]	4.3[a]	0.7[a]	0.9[a]
∑ specimens	151[a] 49[b]	158[a] 60[b]	106[a] 318[b]	1726[a] 114[b]	249[a] 93[b]	414[a] 128[b]	164[a] 306[b]	677[a] 524[b]	70[a] 398[b]	3188[a] 141[b]

[a]Reservoirs with flowing water.
[b]Reservoirs with non-flowing water.

flowing and non-flowing water. Density of this species varied from 3 to 4 individuals/m^2 in the reservoirs with non-flowing water, and from 2 to 15 individuals/m^2 in the reservoirs with flowing water. *Anodonta anatina* occurred with a density of 4–5 individuals/m^2 in the reservoirs with flowing water only.

From 1993–1995, *Planorbarius corneus* was the only species found in reservoir 7. In this reservoir, in the following years, the number of mollusc species increased from 1 to 10 up to 2003 and to 15 species up to 2005. The only permanent population of *Ferrissia wautieri* was in reservoir 7. The density of *Ferrissia wautieri* varied from 5 to 24 individuals/m^2. In the whole period of the survey, *Gyraulus crista* and *Planorbarius corneus* were found in the reservoirs with non-flowing water, whereas *Lymnaea stagnalis*, *Radix peregra*, *Gyraulus albus* and *Planorbarius corneus* were present in the reservoirs with flowing water (Table 3). In the reservoirs with non-flowing water, from 1995–1996 *Physella acuta* was subdominant or dominant in the mollusc communities and occurred periodically, whereas *Aplexa hypnorum* occurred periodically in 1993 (Table 3). Density of *Physella acuta* ranged from 4 to 16 individuals/m^2 in the reservoirs with non-flowing water, and from 2 to 34 individuals/m^2 in the reservoirs with flowing water, whereas the density of *Aplexa hypnorum* in the reservoirs ranged from 1 to 4 and from 3–8 individuals/m^2, respectively. A similar periodical occurrence of *Stagnicola palustris*, *Stagnicola corvus*, *Anisus spirorbis* and *Bathyomphalus contortus* was observed in the reservoirs with flowing water.

In 2000, the number of species decreased and after 1 year the number of species increased in the reservoirs with flowing water. From 1993 to 2005 the number of species increased from 7 to 17 in the reservoirs with flowing water, whereas the number of species increased from 5 to 15 in the reservoirs with non-flowing water (Table 3). *Viviparus contectus*, *Radix auricularia*, *Bathyomphalus contortus*, *Gyraulus crista* or *Ferrissia wautieri* showed a greater density in the reservoirs with non-flowing water compared to the reservoirs with flowing water. Density of *Gyraulus crista*, for example, reached 254 individuals/m^2 in the reservoirs with non-flowing water, whereas there were 129 individuals/m^2 in the reservoirs with flowing water.

The Shannon–Wiener index values calculated for mollusc communities in the reservoirs ranged from 1.22 (1996) to 3.51 (2005) in the reservoirs with non-flowing water, and from 1.18 (1997) to 3.22 (1996) in the reservoirs with flowing water. The maximum value of $H' = 3.51$ was calculated for the mollusc communities which occurred in the reservoirs with non-flowing water in 2005. Up to 2005, in the Mleczna River, only a few mollusc species were found, e.g.: *Potamopyrgus antipodarum*, *Radix peregra*, *Physella acuta* and *Sphaerium corneum.*

The frequency analysis of the mollusc communities

The result of the frequency analysis showed a statistically significant positive association, a negative one or a lack of association between certain mollusc species and the substratum, e.g. *Bithynia tentaculata*, *Segmentina nitida*, *Gyraulus albus* and *Bathymophalus contortus. Bithynia tentaculata* was positively associated with a stony bottom; *Gyraulus albus* was positively associated with a fine-particulated bottom sediment; *Bathyomphalus contortus* was positively associated with *Glyceria maxima*, whereas *Segmentina nitida* was negatively associated with a stony bottom ($\chi^2_9 = 105.17$, $p < 0.01$).

PCA results

To explore the studied data set and to examine the similarities of the samples, PCA was used. As this data set contains measurements performed within different magnitude ranges, the PCA model was constructed for the centered and standardized data. For determination of the number of significant components (PCs) of this data set, the percent of modeled variance (Wold 1987), residual variance (Cattel 1966), Malinowski's *F*-test (Malinowski 1988) and the root mean square error of cross-validation (RMSCV) (Wold 1978) were used. The PCA model, with five significant principal components, describes 98% of data variance. Score plots and loading plots, which were obtained as a result of this analysis, are presented in Fig. 2.

PC1 reflects the difference between sample sites 6, 7 and 8 and all the remaining samples sites. Based on the loading plots, we can conclude that these differences are mainly due to the relatively higher values of variables 1, 2 and 4 (which represent mollusc density, number of species and pH, respectively) and very low values of the remaining parameters observed for sample sites 6, 7 and 8. PC2 is constructed mainly due to the difference between sample sites 8 and 4. Sample site 8 is characterized by the highest concentration of dissolved oxygen (parameter 3), whereas sample site 4 is characterized by the highest concentration of phosphates (parameter 8). The third factor (PC3) reveals the difference between sample sites 1, 2, 3 and 5. These differences are possibly due to the highest concentration of nitrates (parameter 7) observed for sample sites 1, 2 and 3. Sample site 5 is characterized by a relatively higher pH (parameter 4). PC4 reveals the uniqueness of sample site 5 and sites 4, 8, mainly due to the highest value of pH (parameter 4) observed for object no. 5 and a relatively higher value of mollusc density (parameter 1) observed for sample sites 4 and 8, whereas PC5 additionally reveals the uniqueness of sample site 3 due to

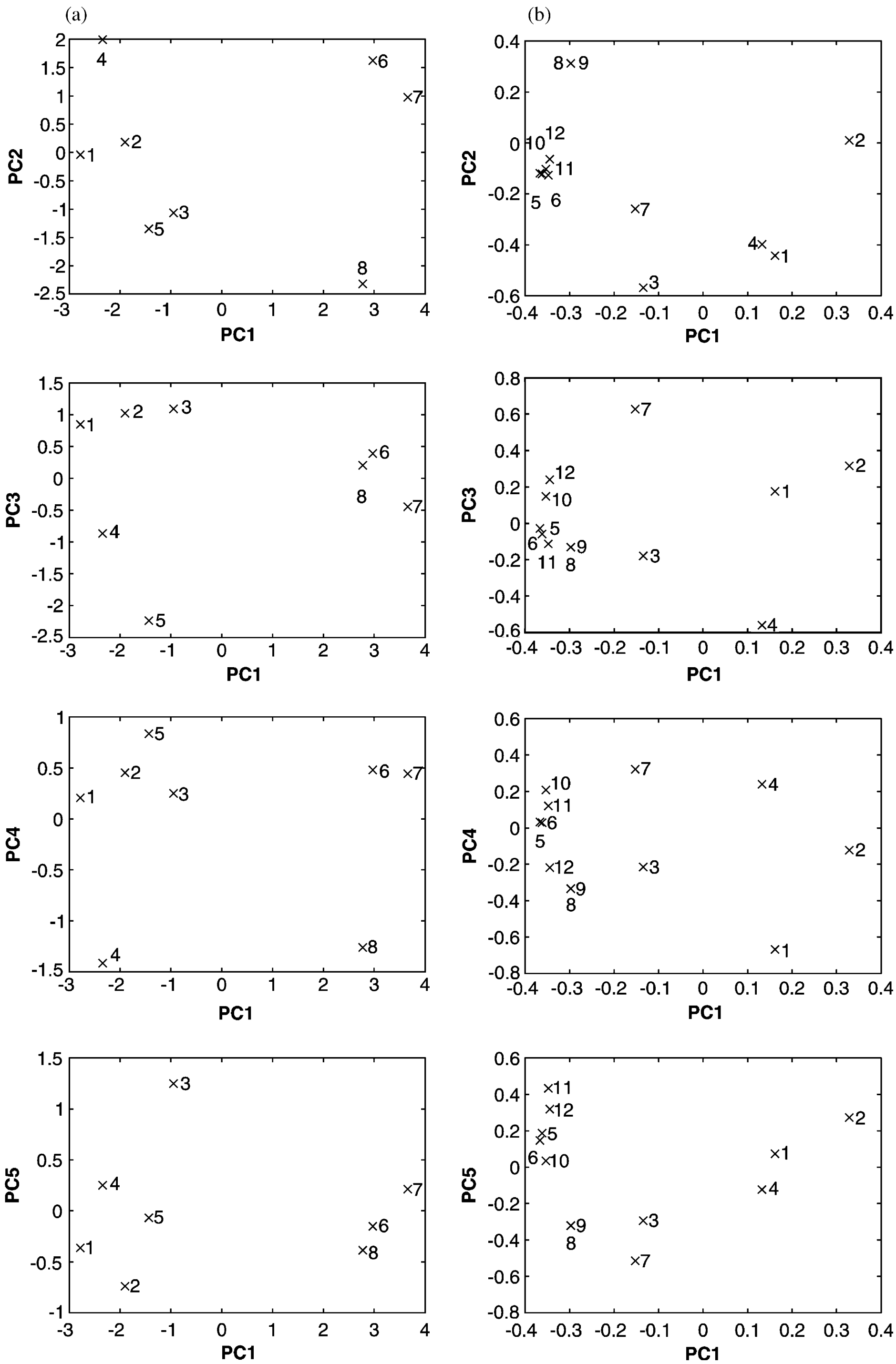

Fig. 2. (a) Score plots and (b) loading plots as a result of PCA for centered and standardized data X (8 × 12).

the high value of the concentration of chlorides, alkalinity and the number of species (parameters 11, 12 and 2).

Loading plots reveal a high correlation between parameters 11, 10, 12, 5 and 6 (i.e. between the concentration of chlorides, the total hardness, alkalinity, conductivity and total dissolved solids) and among parameters 1 and 4 (i.e. mollusc density and pH). It also reveals a negative correlation between parameter 2 (number of species) and the whole group of parameters 11, 10, 12, 5 and 6 (i.e. between the concentration of chlorides, the total hardness, alkalinity, conductivity and total dissolved solids) and between parameters 8 and 1 (concentration of phosphates and mollusc density) and parameters 8 and 4 (concentration of phosphates and pH).

Discussion

In the mining subsidence reservoirs in Czułów, a few rare species are found in the Katowicka Upland, including *Acroloxus lacustris*, *Viviparus contectus*, *Physella acuta*, *Hippeutis complanatus*, *Anodonta anatina.* Mollusc species such *Radix auricularia*, *Bithynia tentaculata*, *Musculium lacustre*, *Segmentina nitida* or *Pisidium casertanum* are considered as uncharacteristic species of this type of water environment. According to the Polish Red List of Species, *Bithynia tentaculata*, *Hippeutis complanatus*, *Ferrissia wautieri*, *Musculium lacustre* and *Pisidium casertnum*, which were found in Czułów, have become a vulnerable species (VU) in Upper Silesia (Serafiński, Michalik-Kucharz, & Strzelec 2001). Our survey showed the occurrence of *Bithynia tentaculata*, *Radix auricularia*, *Stagnicola palustris*, *Hippeutis complanatus* and *Ferrisia wautieri* in the mining subsidence reservoirs of Upper Silesia for the first time (Strzelec & Serafiński 2004).

Physella acuta, an alien species in Poland, and *Aplexa hypnorum* were very rarely and not numerously found in the freshwater environments of the Upper Silesian Upland (southern Poland). In Czułów, they varied in density from 2 to 24 individuals/m^2 and from 3 to 8 individuals/m^2, respectively, whereas according to Strzelec (1993), the density of *Physella acuta* and *Aplexa hypnorum* varied from 2 to 6 individuals/m^2 and from 7 to 11 individuals/m^2 in the mining subsidence reservoirs, respectively.

In Czułów, from 1997–2005 *Potamopyrgus antipodarum* has been eudominant in the mollusc communities of the reservoirs with flowing water. The first time this species was found was in 1997. *Potamopyrgus antipodarum* was found in the submerged part of *Glyceria maxima* and on the concrete lining of waterbanks. Our results confirmed that there had been an invasion of *Potamopyrgus antipodarum* into the reservoirs and rivers of Upper Silesia (Strzelec & Serafiński, 1996; Michalik-Kucharz et al. 2000), as well as into mining subsidence reservoirs (Strzelec & Krodkiewska 1994; Strzelec & Serafiński 2004). Our study found that *Potamopyrgus antipodarum* is present in the reservoirs with flowing water, which are characterized by greater conductivity values compared to the reservoirs with non-flowing water. Costil, Dussart, and Daguzan (2001) also considered *Potamopyrgus antipodarum* as a species characteristic of water with significant conductivity values. The density of *Potamopyrgus antipodarum* varied from 2 to 2422 individuals/m^2 in the mining subsidences in Czułów and from 220 to 28,500 individuals/m^2 in the reservoirs in the northern part of Poland (Brzeziński & Kołodziejczyk 2001), whereas tens of thousands of individuals per m^2 occur on submerged macrophytes, stones and soft substrata in the reservoirs and rivers in New Zealand (Cope & Winterbourn 2004).

From 2000 to 2005 *Ferrissia wautieri* was found in the mining subsidence reservoirs. The first permanent population of this species was found in the north-eastern part of Poland in submerged leaves of *Typha latifolia* (Strzelec & Lewin 1996). In the mining subsidence reservoir *Ferrissia wautieri* was also present in the submerged leaves of *Glyceria maxima*, as well as on stony bottoms.

The mollusc communities of the reservoirs in Czułów have changed in terms of the numbers of species and their densities. The periodic elimination of macrophytes and various regulations of the reservoir's output might have led to these changes, as well as the presence of fish: *Tinca tinca*, *Carassius auratus gibelio*, *Carassius auratus*, *Cyprinus carpio* and *Rutilus rutilus*, which eat invertebrates. Wood, Greenwood, Barker, and Gunn (2001) showed that in reservoirs which have been stocked with fish, cyprinids have a great impact on macroinvertebrate and mollusc distributions. Cyprinids showed an omnivorius tendency and modified the bottoms by removing macrophytes. According to Aldridge (2000), elimination of macrophytes including helophytes, removed about 3% of population of *Anodonta anatina.* In Czułów, the occurrence of *Anodonta anatina* is doubtlessly connected with reservoirs which have been stocked with fish, e.g. *Tinca tinca*, *Rutilus rutilus*, *Perca fluviatilis*. These fish species are suitable as a host for *Anodonta anatina* (Weber 2005). *Anodonta anatina*, subrecedents in the mollusc communities, was the only species among Unionidae found in reservoir 1, which received mining waters. *Anodonta* species are less sensitive to phenomena of eutrophication compared to *Unio* species (Weber 2005).

Our survey showed that in the reservoirs of Czułów, the mollusc communities are considerably diverse, and in one of the reservoirs 15 species occurred. An opposite result was obtained by Strzelec (1993), Strzelec & Serafiński (2004). Data of their survey showed that the mining subsidence reservoirs of the Upper Silesia are poor in terms of the numbers and densities of mollusc species. They found only single specimens of *Gyraulus crista*, *Viviparus contectus*, *Acrloxus lacustris* or *Segmentina nitida*. According to Strzelec, 19 mollusc species occurred in this type of reservoir and varied in the number of mollusc species from 1 to 5 in particular reservoirs.

The basement complex and substratum can influence the mollusc communities. The mineralogical analysis of the bottom sediments of the mining subsidence reservoirs in Czułów showed mainly the presence of quartz, clay mineral and feldspar. On this type of bottom, 17 mollusc species were present in the reservoirs with flowing water, whereas there were 15 mollusc species in the reservoirs with non-flowing water. For comparison, Strzelec (1999) recorded nine gastropod species on the dolomite bottom in the mining subsidence reservoirs of the Katowicka Upland and 1–4 species in various other reservoirs. Strzelec also found 18 gastropod species on shell limestone bottoms and in various other reservoirs, the number of species varied from 3–9.

The results of the χ^2 test showed that in the mining subsidence reservoirs in Czułów, *Bithynia tentaculata* was associated with a stony bottom. This confirmed surveys by Soszka (1975) and Dussart (1976) that *Bithynia tentaculata* occurs mainly in bottom sediments and to a lesser degree is associated with macrophytes. According to Stańczykowska (1960), Dvořák & Best (1982), *Gyraulus albus* is a phytophilous species. However, our survey did not confirm this result. Our survey showed a statistically significant association between *Gyraulus albus* and fine-particulated bottom sediment, which contained quartz, clay minerals and stony bottoms.

The influence of the physical and chemical parameters of water on mollusc communities has frequently been documented. Our investigations of the influence of pH on the mollusc communities were similar to results of many authors. For example, Clarke & Scruton (1997) observed that the distribution of the Gastropoda in the water environments they had been observing depended on pH value ($p = 0.018$). This result confirmed earlier investigations by Økland (1983) and Herrmann et al. (1993). Økland observed an increase in the number of species and their densities above pH 7.0. The same result was obtained by Bendell & McNicol (1993). Clenaghan, Giller, O'Halloran, and Herman (1998) showed a significant positive correlation among mollusc density, conductivity ($r_s = 0.75$) and calcium ($r_s = 0.74$). Our research confirmed findings by Lewin (2001). She showed a positive correlation between gastropod density and alkalinity or chlorides in the anthropogenic reservoirs. Various studies have shown that the increasing alkalinity of a water environment results in an increase in the food resource of gastropods, typically periphyton. Accordingly, the alkalinity of mining subsidence reservoirs influences periphyton development, which in turn influences gastropod densities. This does not apply to detritivores and other omnivorous species in the reservoirs with flowing water and reservoirs with non-flowing water in Czułów. Russel-Hunter (1978) claimed that the number of gastropod species and specimens are greater in eutrophic reservoirs compared to oligotrophic reservoirs. Clarke, Knoechel, and Ryan (1997) showed that there was a relationship between biogenic elements and the density of molluscs. This was confirmed by our own survey, which showed a correlation between mollusc density and phosphate concentration. Savage and Gazey (1987) observed a statistically significant correlation between the number of gastropods, conductivity ($r = 0.58$, $p<0.001$) and alkalinity ($r = 0.69$, $p<0.001$). Our investigation did not confirm this because the mollusc density, not the number of species, was correlated with water parameters.

The results of our survey showed that *Typha latifolia* was present in the reservoirs with flowing water, mainly where mining water contained large amounts of mineral matter. According to Kłosowski and Tomaszewicz (1984), Zarzycki et al. (2002), *Typha latifolia* inhabits considerably more nutritious water and organic-mineral bottoms compared to *Typha angustifolia. Typha latifolia* is a bioindicator of nutritious water, characterized by a broad range of environmental factors, for example ammonium nitrogen, phosphates, chlorides and iron. Our results confirmed the survey of Kłosowski and Tomaszewicz (1984), Zarzycki et al. (2002). *Acorus calamus*, a bioindicator of high concentration nitrates in water, occurred in reservoir 1 only, which received mine waters. *Glyceria maxima* was found in the part of reservoir 3 where mining waters flowed directly in. Our results confirmed the Ciecierska (1997) survey, which showed that *Glyceria maxima* is a bioindicator of reservoirs influenced by a particularly high anthropopressure, where they form congeneric agglomerations. The congeneric agglomerations of *Glyceria maxima* were typical of reservoir 3 into which mining waters flow.

During our survey freshwater sponges were found. We also observed many species of wildfowl, birds of prey, amphibians and reptiles, e.g. *Vipera berus* (L.), *Lacerta agilis* (L.) in the reservoirs and on the waterbanks. Amphibians and reptiles are legally protected in Poland (Dziennik Ustaw 2004). Up until 2004, all bivalve species were legally protected, excluding *Anodonta anatina* (Dziennik Ustaw 2001b, 2004). Because of the distinctive environmental features of the mining subsidence reservoirs in Czułów, the research area, which is not so degraded, has provided a refuge for wildlife, e.g. *Nuphar lutea*, *Musculium lacustre*, *Pisidium casertanum*, *Vipera berus*, *Lacerta agilis* as well as many rare and vulnerable mollusc species.

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