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The impact of environmental factors on the diversity of gastropod communities in sinkhole ponds in a coal mining region (Silesian Upland, Southern Poland)

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Abstract: Studies on the diversity of gastropod fauna were carried out in ten sinkhole ponds with varied sediments types, which were located in a coal mining area (Silesian Upland, Southern Poland). The water bodies with different bottom types were distinguished by their dissimilar water properties and the total organic matter in the sediment. A total of 11 gastropod species from four families were identified. Eleven species occurred in sinkhole ponds with a coal shale bottom, while in water bodies with sandy sediments nine species were found. The gastropod diversity and abundance were lower in water bodies with sandy sediments compared to the ponds with a coal shale bottom. Canonical correspondence analysis (CCA) showed the important factors that influence the gastropod distribution in the subsidence ponds that were studied.

Key words: sinkhole ponds; gastropods; environmental factors; Silesian Upland

Introduction

Water bodies that are established in a coal basin are a characteristic element of the surface hydrographic network of an area in which there is underground coal mining exploitation. They are distributed in wastelands, forest complexes and highly urbanised and industrialised areas (Machowski 2010). Their surfaces and depth are different because of the local environmental conditions and the length of the period of surface subsidence. The ways in which water supplies and the land have been used have an impact on the water properties and permanency of these reservoirs (Jankowski et al. 2005; Rzętała 2008; Machowski 2010).

Researches on water invertebrates in subsidence ponds are rarely undertaken in Poland although this type of reservoirs very commonly occurs in the Silesian Upland, which is completely devoid of natural lakes. Previously, the occurrence of 18 gastropod species (Strzelec & Serafiński 2004), 9 leech species (Krodkiewska 2003) and 23 oligochaete species (Dumnicka & Krodkiewska 2003; Krodkiewska 2006; Krodkiewska & Królczyk 2012) has been demonstrated in these reservoirs, which are often defined as hydrological wastelands. These ponds are often valuable refuges for rare or vulnerable plant and animal species and act as the recipient area for alien species and invasive species among others (Lewin & Smoliński 2006; Strzelec 2011; Lewin 2012; Skowrońska-Ochmann et al. 2012; Spyra & Krodkiewska 2013).

Previous studies on the diversity of freshwater gastropods in sinkhole ponds have been concerned with the impact of some physical and chemical water properties, the presence of aquatic macrophytes, the effect of the introduction of alien species and the importance of sinkhole ponds in maintaining the biodiversity in industrial areas (Strzelec 2005; Lewin & Smoliński 2006; Michalik-Kucharz 2008; Lewin 2012). However, the sinkhole ponds that were studied were characterised by a homogenous type of bottom sediments, which were composed of mud and mud with a layer of leaf deposits in different stages of decomposition or mud with a layer of the remains of aquatic plants. They were different in terms of age, their permanence, the diversity of aquatic plants and the way in which water was utilised.

To date no research has been carried out in sinkhole ponds with a coal shale bottom. Therefore, the main aim of this study was to estimate the impact of environmental conditions, including the type of bottom substratum, on the gastropod communities. Additionally, we also attempted to show the significance of the location of the ponds in the dispersal process of gastropods.

Material and methods

The studies were carried out in ten subsidence ponds that are located in two complexes (Figs 1A–D) in a coal mining region in Sosnowiec (19°08′ E 50°17′ N) (eastern part

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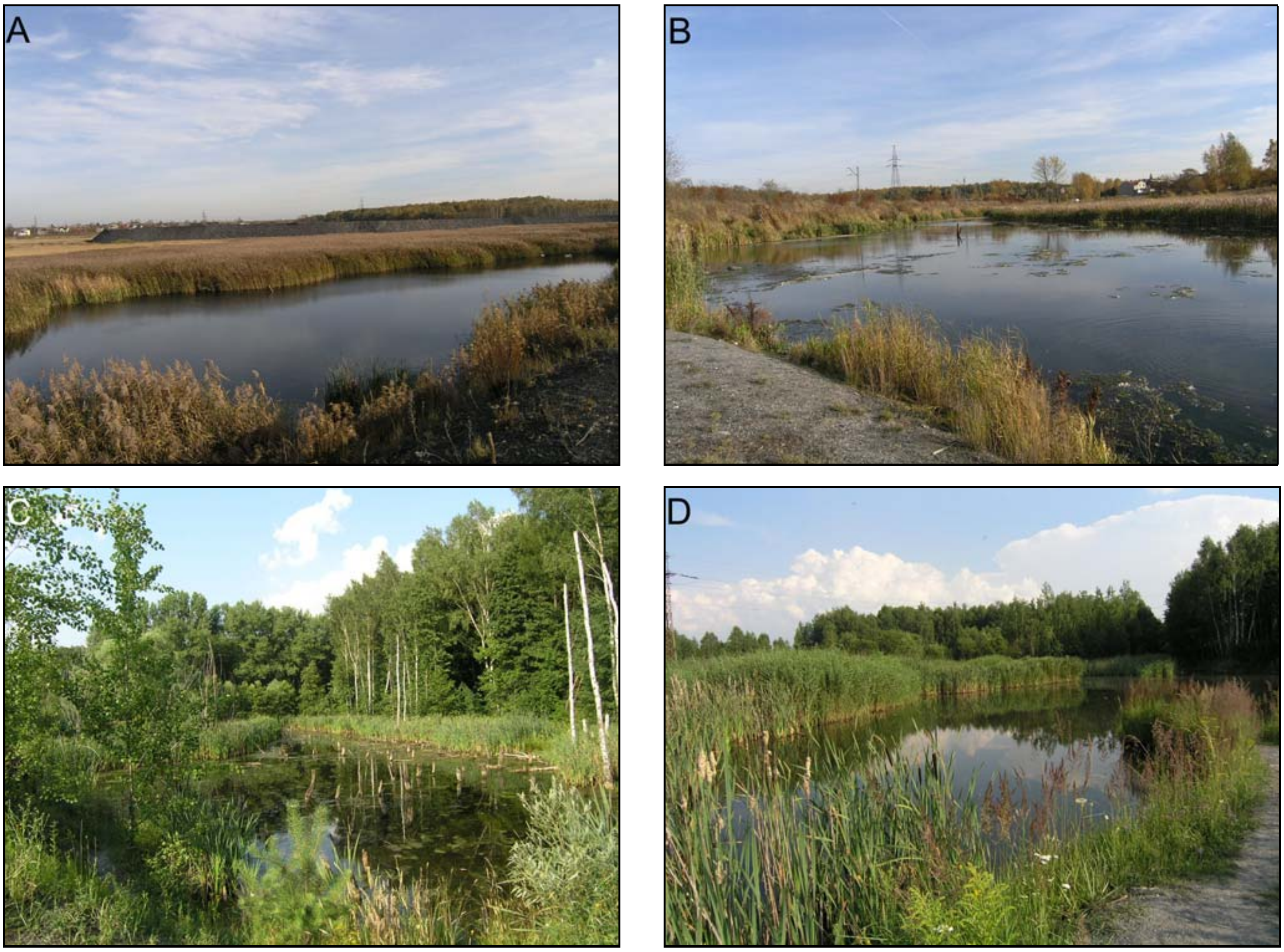

Fig. 1. Water body of the first complex (A, B) and water body of the second complex (C, D).

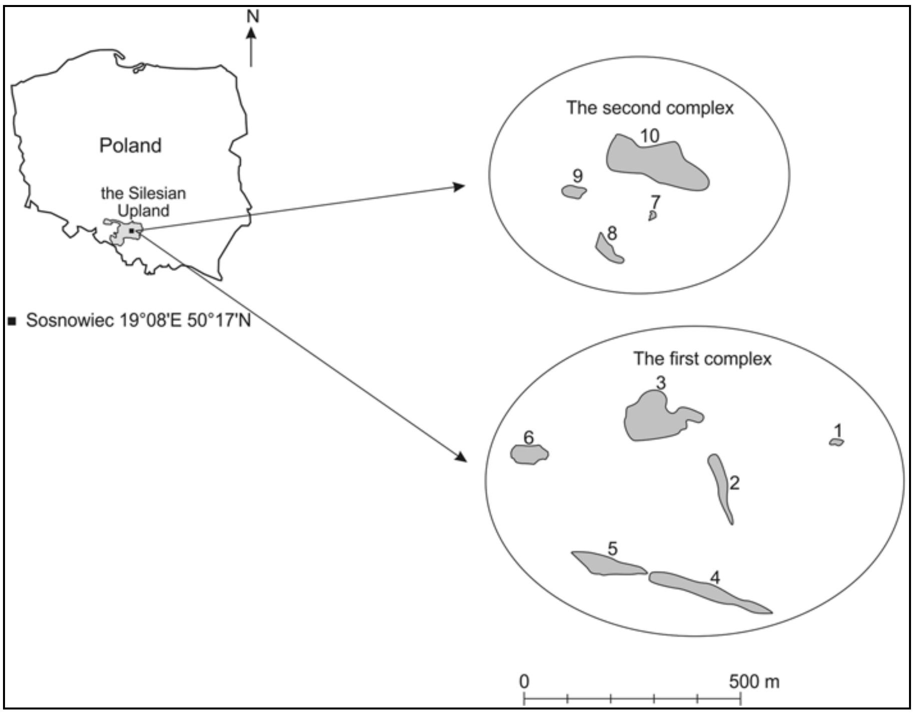

Fig. 2. Location of the subsidence ponds studied.

Table 1. Description of the water bodies studied.

Pond number	Area (ha)	Max. depth (m)	Bottom type*	Immediate surroundings of the pond	Plants**
1	0.07	1.0	A	wasteland	1,2,3,4,5, 6,7,9,12,13
2	0.6	1.8	B	a mine dump, swampy wasteland	2,4, 6,8,9,10,13,14
3	1.7	1.8	A	swampy wasteland	6,8,9, 10,13,14
4	1.1	1.7	B	a reclaimed mine dump, wasteland, housing estate	1,6,9,10,11
5	0.5	1.7	B	a reclaimed mine dump, wasteland, housing estate	1, 6, 9, 10, 11
6	0.3	1.5	A	swampy wasteland	1,6,7,8,9,13
7	0.05	1.0	A	a reclaimed mine dump, a birch-alder forest	4,8,10,16
8	0.3	1.2	B	a mine dump, a birch-alder forest	1,4,6,9,10,15
9	0.2	2.0	B	wasteland	4,6,10,13
10	2.5	1.5	A	a reclaimed mine dump, wasteland, a birch-pine forest	4,5, 6,10

Explanations. *Bottom substratum type: A – sand with detritus; B – coal shale with detritus. **Plants: 1 – *Alisma plantago-aquatica* L.; 2 – *Elodea canadensis* Michx.; 3 – *Potamogeton natans* L.; 4 – *Juncus* sp.; 5 – *Eleocharis palustris* (L. Roem. & Schult.); 6 – *Phragmites australis* (Cav.)Trin. ex Steud.; 7 – *Sparganium erectum* Huds.; 8 – *Lemna trisulca* L.; 9 – *Lemna minor* L; 10 – *Typha latifolia* L.; 11 – *Rumex hydrolapathum* Huds.; 12 – *Batrachium aquatile* (L.) Dumort; 13 – *Ceratophyllum demersum* L.; 14 – *Myriophyllum spicatum* L.; 15 – *Lysimachia thyrsiflora* L.; 16 – *Lysimachia vulgaris* L.

of Silesian Upland, Southern Poland) (Fig. 2). They were created in the 1960s and 1970s.

The sinkhole ponds studied were characterised by a small surface area (up to 2.5 ha) and shallow depth (up to 2.0 m). Their bottom was composed of sand and detritus or coal shale and detritus (Table 1).

Material for the studies was gathered from all of the ponds once at month from May 2001 to April 2002. Samples were only taken from the bottom without vegetation using an Ekman grab (256 cm^2 sampling area). One sample included four replicates using the grab. In total, 12 samples were collected from each of the sinkhole ponds.

In the laboratory the samples were sieved through a 0.23 mm sieve. The macroinvertebrates were sorted under a stereoscopic microscope and preserved in 70% ethanol. Gastropoda were identified at the species level using the Glöer & Meier – Brook key (1998). The identification of *Radix auricularia* and *Radix balthica* was carried out on the grounds of morphological characteristics, mantle pigmentation and the characteristics of the reproductive organs (Jackiewicz 2000). Other macroinvertebrates were identified at the family level using the key by Kołodziejczyk & Koperski (2000).

In addition to the biological samples, water samples were collected for analyses four times (once during the spring, summer, autumn and winter) from all of the ponds. The analyses of water properties (e.g., chlorides, sulphates, phosphates, iron, alkalinity, total hardness, calcium and magnesium) were carried out using standard methods according to Hermanowicz et al. (1999). Water temperature, pH and conductivity were measured in the field using Hanna Instruments portable meters. In addition to water samples, sediment samples were gathered in order to analyse the organic matter content. The total organic matter content was determined according to the loss-on-ignition technique by combusting the sediment at 550°C for 4 h.

The zoocenological studies of the gastropod communities were conducted on the grounds of the following indices: domination (D %), constancy (C %) and the Shannon-Wiener index.

Statistics

Correspondence analysis (CA) was conducted using the software program Canoco ver. 4.5 in order to distinguish the most representative environmental variables and the trends of habitat distribution among the different subsidence ponds.

The *t*-test was performed to evaluate the differences in the water parameters, the content of the sediment organic matter, the gastropod density, the snail taxa number, the diversity of the gastropod communities and the density of gastropod species among the ponds of different bottom types using the program Statistica for Windows ver. 9.0.

The relationships between gastropod species and environmental variables were tested using ordination techniques with the program Canoco. The data were analysed using unimodal analysis (Canonical Correspondence Analysis) because the species data showed a unimodal response (the length of the gradient in the DCA exceeded 3 SD). Species that constituted less than 5% of the collection were omitted from the analysis. The statistical significance of the analysis was determined using the Monte Carlo permutation test. The species data and environmental data were also log-transformed in the analysis. The results from the CCA were displayed graphically in an ordination diagram using the software program CanoDraw ver. 4.12.

Results

The correspondence analysis (CA) showed a division of the subsidence ponds into two groups. The first group, which is located on the right side of the first axis, was formed by reservoirs with sandy bottoms. The second group of reservoirs, which are on the left side of the diagram, are characterised by bottoms with coal shale (Fig. 3).

The subsidence ponds with different bottom types are distinguished by dissimilar water properties and total organic matter in the sediment. A higher mineralisation of water, total hardness, total alkalinity and a greater concentration of chlorides, calcium and magnesium was found in reservoirs with a coal shale bottom. The organic matter content in sediments was also higher in this type of reservoirs. These differences were significant (Table 2).

The fauna of sinkhole ponds was composed of 35 families, including 23 families on both types of bottom, among which, Naididae and Chironomidae predominated. Most of the families constituted under 0.1%

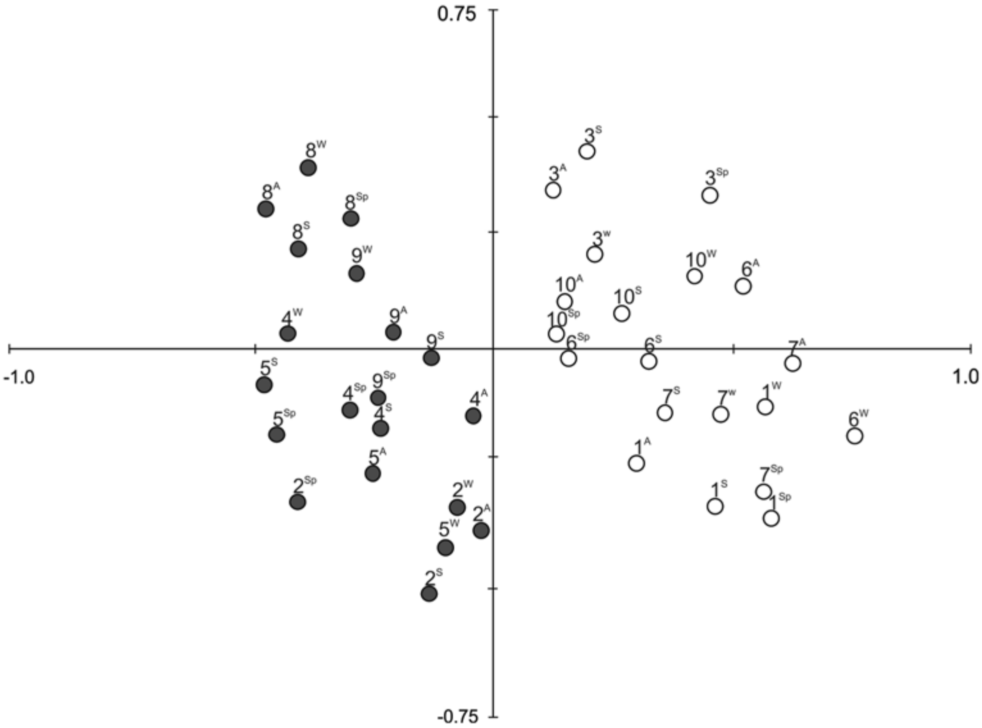

Fig. 3. Correspondence analysis (CA) ordination diagram with only plotted samples. ● coal shale bottom, ○ sandy bottom, Sp – spring, S – summer, A – autumn, W – winter.

Table 2. Water parameters and the content of sediment organic matter in the subsidence ponds studied.

Parameter	Bottom type		t-test df = 38	P
	Sand with detritus (range)	Coal shale with detritus (range)		
Temperature (℃)	4.0–28.0	3.6–27.5	0.149	< 0.05
pH	6.5–9.0	7.0–8.5	0.543	< 0.05
EC (µS cm^{-1})	199.0–1128.0	208.0–1923.0	2.901	> 0.05
Cl (mg L^{-1})	14.0–168.0	20.0–436.0	3.693	>0.05
SO_4 (mg L^{-1})	25.0–240.0	25.0–240.0	0.534	< 0.05
PO_4 (mg L^{-1})	0.01–0.47	0.01–0.45	1.500	< 0.05
Alkalinity (mg $CaCO_3$ L^{-1})	70.0–255.0	115.0–320.0	1.851	< 0.05
Total hardness (mg $CaCO_3$ L^{-1})	130.3–409.4	252.8–528.6	4.109	> 0.05
Ca (mg L^{-1})	44.0–110.0	56.0–122.0	3.647	> 0.05
Mg (mg L^{-1})	5.6–31.7	17.7–43.2	3.714	> 0.05
Fe (mg L^{-1})	0.1–0.5	0.1–1.2	2.909	> 0.05
Organic matter content in the sediment (%)	1.3–6.5	10.3–25.4	4.952	> 0.05

of the collection in both the ponds with a sandy bottom and a coal shale bottom (Table 3).

A total of 11 gastropod species from four families were identified in the ponds that were studied, among which six species occurred abundantly but infrequently. All of the collected species of Gastropoda were distributed in the ponds with a coal shale bottom. *Bithynia tentaculata* and *Planorbis planorbis* were only observed in this type of ponds (Table 4). Eurytopic species, *Radix balthica*, *Gyraulus crista*, *Gyraulus albus* and *Planorbarius corneus,* dominated the communities with both types of bottom. In addition to these species, other species that occurred numerously in the subsidence ponds with a coal shale bottom were *Physella acuta* and *Segmentina nitida* (Table 4). The gastropod communities were worse off in terms of the taxa number, the abundance, the mean density and the diversity expressed in Shannon-Wiener index in the ponds with a sandy bottom (Table 4)

Differences related to the gastropod density ($t = 1.4$, df = 118, $P > 0.05$), the taxa number ($t = 2.48$, df = 118, $P > 0.05$) and the Shannon-Wiener index ($t = 2.35$, df = 118, $P > 0.05$) among the ponds with different bottom types were statistically significant.

The canonical correspondence analysis (CCA) showed a group of important factors that influence the occurrence of gastropods in the subsidence ponds that were studied. The important factors for *R. balthica*, *P. acuta* and *S. nitida* were the condictivity, the alkalinity, the hardness of the water and the concen-

Table 3. Macroinvertebrate fauna in the sinkhole ponds with different bottom types.

Taxon	Family	Bottom type: Sand with detritus D (%)	Sand with detritus C (%)	Coal shale with detritus D (%)	Coal shale with detritus C (%)
Oligochaeta	Lumbriculidae	1.3	36.7		
	Enchytraeidae	0.2	16.7	0.1	16.7
	Naididae	53.9	100	58.5	100
Hirudinea	Glossiphoniidae	1.2	25.0	3.1	46.7
	Hirudinidae	0.02	1.7		
	Erpobdellidae	0.3	15.0	0.4	35
Crustacea	Asellidae	0.1	6.7	0.3	12.5
Odonata	Lestidae	0.07	1.7	0.01	3.3
	Coenagrionidae	0.4	23.3	0.05	8.3
	Corduliidae	0.05	5.0		
	Libellulidae	0.03	3.3	0.04	5.0
Ephemeroptera	Ephemerellidae			0.01	1.7
	Baetidae	0.6	18.3	0.2	8.3
	Caenidae	9.5	71.7	1.3	48.3
Megaloptera	Sialidae	0.1	8.3	0.05	6.7
Coleoptera	Haliplidae	1.0	21.7	0.1	11.7
	Dytiscidae	0.1	8.3	0.06	10.0
	Hydrophilidae			0.02	1.7
Trichoptera	Leptoceridae	0.7	26.7	0.8	43.3
	Phryganeidae	0.03	1.7		
	Polycentropodidae	0.05	3.3	0.05	5.0
Heteroptera	Corixidae	1.2	21.7	4.6	31.7
	Pleidae	0.07	5.0		
	Nepidae			0.01	3.3
	Naucoridae	0.02	1.7		
Diptera	Chironomidae	15.6	86.7	24.1	93.3
	Ceratopogonidae	5.4	61.7	1.4	61.7
	Athericidae	0.05	5.0		
	Ptychopteridae	0.02	1.7		
Gastopoda	Viviparidae	0.03	3.3	0.05	8.3
	Bithynidae			0.01	1.7
	Lymnaeidae	0.6	25.0	1.0	50.0
	Planorbidae	5.5	51.7	2.9	46.7
	Physidae	0.1	8.3	0.4	13.3
Bivalvia	Sphaeriidae	1.4	25.0	0.1	11.7
Mean density of macroinvertebrates (ind. m^{-2})		1027 ± 866		2359 ± 833	
Taxa number in ponds differing in bottom type		31		27	
Taxa number only in one type of bottom		8		3	

tration of chlorides and calcium in the water, which explained their numerous occurrence on the surface of the ponds with a coal shale bottom. By contrast, *G. albus* and *G. crista* were found abundantly on the ponds with a sandy bottom (Fig. 4). The first two ordination axes of the CCA analysis with the best explanatory variables explained a 44.3% variance in the species data and a 65% species – environmental relation. The Monte Carlo permutation test showed that the results of the analysis are statistically significant (Table 5).

The studies demonstrated that the mean density of *P. acuta*, *R. balthica*, *R. auricularia* and *S. nitida* was statistically higher on the surface of the ponds with a coal shale bottom than on the surface of those with a sandy bottom (Table 6).

The studies also showed that the location of the water bodies and their proximity to each other influenced the diversity of the gastropod communities. In the ponds of the first complex, the gastropod communities differed from those in the ponds of the second complex in terms of their density (Table 7) and diversity

Table 4. The domination structure (D%) and constancy (C%) of the gastropod communities in sinkhole ponds with different bottom types.

Species	Bottom type					
	Sand with detritus		Coal shale with detritus		In all	
	D (%)	C (%)	D (%)	C (%)	D (%)	C (%)
Viviparus contectus (Millet, 1813)	0.3	1.7	1.2	8.3	0.9	5.0
Bithynia tentaculata (L., 1758)			0.2	1.7	0.1	0.8
Physella acuta (Draparnaud, 1805)	2.2	8.3	9.2	13.3	6.5	10.8
Radix balthica (L., 1758)	8.5	20.0	18.5	43.3	14.6	3.7
Radix auricularia (L., 1758)	0.3	1.7	3	15	2.0	8.3
Lymnaea stagnalis (L., 1758)	1.1	5.0	0.7	5.0	0.9	5.0
Planorbis planorbis (L., 1758)			1.2	5.0	0.8	2.5
Segmentina nitida (O.F. Müller, 1774)	4.2	16.7	33.4	20.0	22.1	16.7
Gyraulus crista (L., 1758)	57.1	40.0	18.8	33.3	33.5	36.7
Gyraulus albus (O.F. Müller, 1774)	20.2	18.3	6.7	21.7	11.9	20.0
Planorbarius corneus (L., 1758)	6.0	8.3	7.1	31.7	6.6	20.0
N of samples	60		60		120	
N of specimens	3905		6225		10130	
N of species	9		11		11	
Min. species number per pond	3		3			
Max. species number per pond	6		10			
Mean density of gastropods (ind. m^{-2})	65.1 ± 130.6		103.7 ± 172.9		84.4 ± 153.8	
Mean value of Shannon-Wiener index	0.33 ± 0.55		0.63 ± 0.81		0.45 ± 0.68	

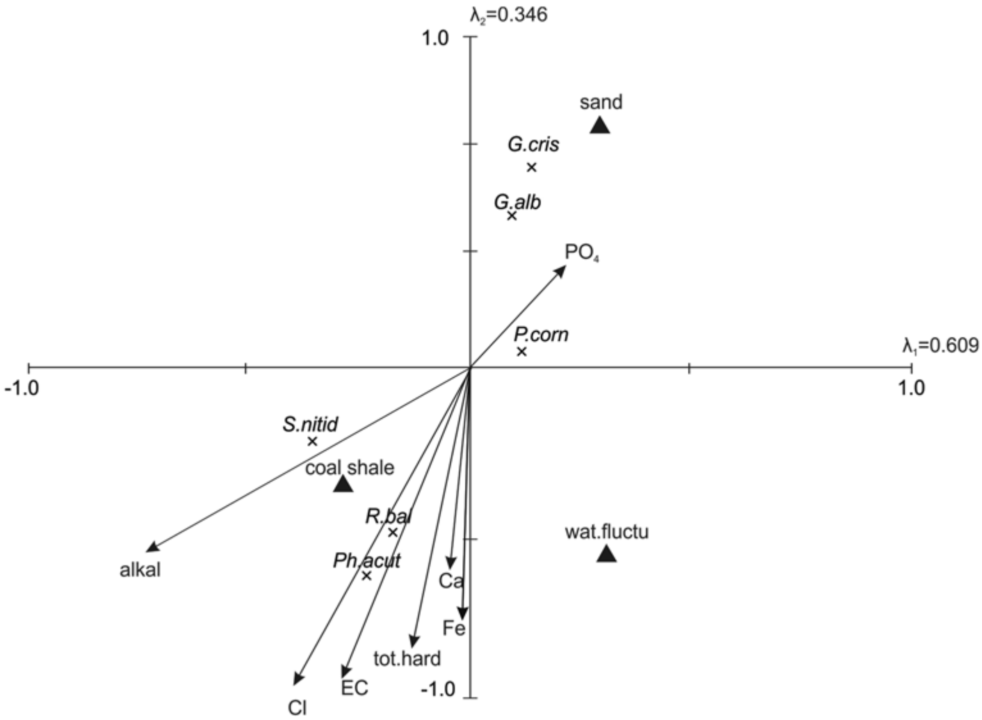

Fig. 4. Canonical correspondence analysis (CCA) ordination diagram based on the abundance of gastropod species and the best explanatory variables. λ_1 – the eigenvalue of the first axis, λ_2 – the eigenvalue of the second axis, P.corn –*Planorbarius corneus*, G.alb – *Gyraulus albus*, R.bal – *Radix balthica*, Ph.acut – *Physella acuta*, S.nitid – *Segmentina nitida*, G.cris – *Gyraulus crista*, alkal – alkalinity, CI – chlorides, EC – conductivity, tot.hard – total hardness, Fe – iron, Ca – calcium, wat.fluctu – water fluctuation, PO_4 – phosphates.

(Fig. 5). Five gastropods species occurred numerously in each of the ponds of the first complex, whereas only *G. crista* was collected abundantly in the second complex. In addition to *G. crista*, another species, *R. balthica*, occurred numerously but not in all of the ponds (Table 7).

Discussion

The composition of bottom sediments is one of the important abiotic factors that influence species diversity and the community structure of macrofauna (Pinel-Alloul et al. 1996). As was shown previously by Oertli

Table 5. Summary of CCA analysis carried out on the abundance of gastropod species and the best explanatory environmental variables.

Axes	1	2	3	4	Total inertia
Eigenvalues	0.609	0.346	0.293	0.127	2.156
Species – environment correlations	0.922	0.870	0.811	0.678	
Cumulative percentage variance:					
of species data	28.3	44.3	57.9	63.8	
of species – environment relation	41.5	65.0	85.0	93.6	
Sum of all eigenvalues					2.156
Sum of all canonical eigenvalues					1.469
Summary of the Monte Carlo test:					
Test of significance of first canonical axis: eigenvalue = 0.609					
F-ratio = 11.851					
P-value = 0.002					
Test of significance of all canonical axes:trace = 1.469					
F-ratio = 3.521					
P-value = 0.002					

Table 6. The value of t-test for the gastropod species density on the bottom types studied.

Species	t-test df = 118	The significance level
V. contectus	1.64	$P < 0.05$
P. acuta	2.02	$P > 0.05$
R. balthica	2.82	$P > 0.05$
R. auricularia	2.59	$P > 0.05$
L. stagnalis	0.00	$P < 0.05$
S. nitida	2.31	$P > 0.05$
G. crista	1.24	$P < 0.05$
G. albus	1.03	$P < 0.05$
P. corneus	0.95	$P < 0.05$

Table 7. The domination structure (D%) and constancy (C%) of the gastropod communities in the pond complexes studied.

Species	The first complex		The second complex	
	D (%)	C (%)	D (%)	C (%)
V. contectus	1.1	8.3		
B. tentaculata	0.1	1.4		
P. acuta	8.3	18.0		
R. balthica	15.2	40.3	12.4	18.7
R. auricularia	1.8	9.7	2.6	6.3
L. stagnalis	0.8	5.5	1.0	4.2
P. planorbis	1.0	4.2		
S. nitida	27.5	27.8	2.1	4.2
G. crista	21.6	37.9	78.3	33.3
G. albus	14.5	30.5	2.1	4.2
P. corneus	8.0	27.8	1.6	6.3
$\sum$ of specimens	8003		2127	
$\sum$ of species	11		7	

(1995), the preference of a species to the type of substrate is not expressed in their presence or their absence but rather in their abundance. Our studies established a preference for a coal shale bottom with silt for Chironomidae, Caenidae and primarily Naididae, among which these species were ubiquitous (Krodkiewska & Królczyk 2012).

Previous studies documented the impact of bottom sediments on the occurrence and diversity of gastropods (Strzelec 1993; Chertoprud & Udalov 1996; Collier et al. 1998). The results of our studies showed that Gastropoda only constituted a few percent of the macrofauna on both types of sediments (6.2% on a sandy bottom and 4.4% on a coal shale bottom, respectively). The data obtained by Spyra (2011) in a few anthropogenic water bodies with bottoms that were covered by leaf deposits indicated that gastropods occur abundantly in benthic macrofauna. On the other hand, according to Lodge (1985, 1986), gastropods avoid sediments that are covered by detritus that is composed mostly of leaves from waterside trees.

Our research showed that sinkhole ponds are characterised by a low diversity of gastropod fauna as compared to other types of anthropogenic water bodies (Michalik-Kucharz 2008). To date, 18 gastropod species

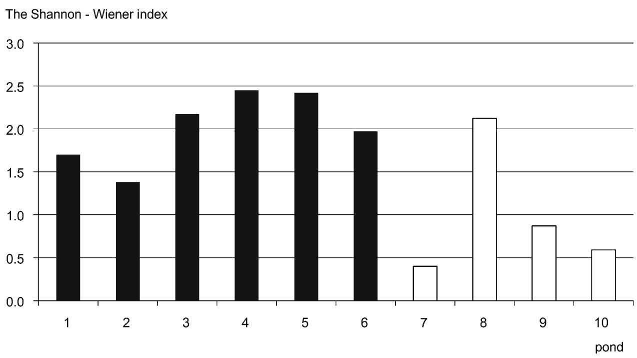

Fig. 5. The Shannon-Wiener index of the communities of gastropods in the sinkhole ponds studied. ■ the first complex, □ the second complex.

have been observed in sinkhole ponds in the area that was studied in this research. In particular, from one to nine species were found in the water bodies (Strzelec & Serafiński 2004). Previously, a large number of studies were carried out in which the positive impact on the sediment-dwelling fauna in an area with an occurrence of aquatic macrophytes was repeatedly underlined (Lodge & Kelly 1985; Brönmark 1989; Kornijów 1989; Collinson et al. 1995; Costil & Clement 1996). Although our sampling sites were located outside the zone of the occurrence of macrophytes, we found from three to ten gastropod species. Their abundance differed from those that were shown by Strzelec & Serafiński (2004), Lewin & Smoliński (2006), Michalik-Kucharz (2008). Our research showed that in the sinkhole ponds that were studied regardless of the sediment type, only a few gastropod species occurred abundantly. Similar observations were made in the investigations of Strzelec (1993), who observed an increased number under adverse conditions in only certain species, which due to adaptations and the lack of predators allowed them to create an ecological niche. In water bodies with sandy sediments covered by detritus *G. crista*, *G. albus*, *P. corneus* and *R. balthica* occurred more numerously, whereas in sinkhole ponds with a coal shale bottom besides the above-mentioned species, *P. acuta* and *S. nitida* occurred more abundantly in the gastropod communities. However, only *G. crista* was observed in each of the water bodies independent of the composition of the sediments. *R. balthica* was found in all of the sinkhole ponds with a coal shale bottom, which according to Strzelec (1993) is one of the first colonisers of anthropogenic water bodies. It is a constant element of macrofauna in sinkhole ponds (Adams & Robin 1988; Strzelec 1993). According to Lassen (1975), *R. balthica*, *G. crista* and *G. albus* are also early immigrants to emergent water bodies. They are species that are characterised by low ecological requirements and that occur in various water environments (Strzelec & Serafiński 2004). In the opinion of Pip (1986), a high degree of variations in the structure of mollusc communities is observed on man-made water bodies during the first period of settlement.

The water bodies that were studied here are about the same age and vary only slightly in their surface areas, which demonstrates that differences in the taxa number and benthos density that were observed are not associated with these factors. A similar result was obtained by Wood et al. (2001). Data from their survey showed the lack of a relationship between the abundance of macrofauna and the age and size of industrial ponds in England. According to Adams & Robbins (1988), only the largest sinkhole ponds are characterised by the occurrence of most macroinvertebrates groups. An opposite result was obtained by Oertli et al. (2002), who found that the size of water bodies had an impact on the occurrence of a certain benthos taxa. Our studies did not demonstrate any influence of this factor on the diversity of the snail fauna.

Sinkhole ponds are an example of isolated, patchily distributed environments. According to Zealand & Jeffries (2009), the distance between water bodies is one of the factors that affect the differences in gastropod communities. In their opinion, snail communities become more similar in ponds that are located close to each other. A connection between water bodies simplifies the active dispersal of snails (Wilmer et al. 2008). In the case of isolated ponds that are closer together, birds may also take part in gastropods dispersal process (Boag 1986; Van Leeuwen et al. 2012a, b,c). It cannot be excluded that snails may also be unintentionally or intentionally introduced to a new site by humans. Our studies showed that the geographic proximity of the ponds that were studied had an influence on the similarity of the gastropod fauna. In all of the ponds of the first complex, *R. balthica*, *S. nitida*, *G. crista*, *G. albus* and *P. corneus* were found in the gastropod communities, whereas at the second complex, only *G. crista* occurred in all of the ponds. According to Beran (2002), *G. crista* is a characteristic species for eutrophic water bodies.

P. acuta, which is an alien species in Poland, was found in sinkhole ponds of the first complex. In the opinion of Früh et al. (2012), degraded water bodies are very often at risk of the occurrence of alien species. Our results showed that *P. acuta* prefers a higher mineralisation of water and a greater concentration of chlorides and iron. Früh et al. (2012) observed that a higher chloride content in water is one of the main variables that also increases the risk of biological invasions including snails.

No rare snail species were found during our survey. An opposite result was obtained, among others, by Lewin & Smoliński (2006) and Michalik-Kucharz (2008). The data from their survey showed that snail species that are on the Polish Red List of Species occurred in the subsidence ponds in the Silesian Upland.

Sinkhole ponds are convenient objects of hydrobiological studies, as they allow the succession of gastropods from creation of the ponds until any possible water loss to be followed. Earlier investigations showed that highly specialized species do not reach colonisation success in these environments (Michalik-Kucharz 2008). Our research indicated that studies on the diversity of gastropod fauna in anthropogenic water bodies should focus on bottom sediments specifically because they are known to act as a reservoir of nutrients, organic compounds and different solutes due to the accumulation of autochthonous and allochthonous organic matter (Boyd 1995).

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References

Adams J. & Robin H. 1988. The fauna of mining subsidence pools in Northumberland. Transactions of the Natural History Society of Northumberland, Durham, and Newcastle-upon-Tyne **55:** 28–38.

Beran L. 2002. Vodní měkkýši České republiky – rozšíření a jeho změny, stanoviště, šíření, ohrožení a ochrana, červený seznam. Sborník Přírodovědného Klubu v Uh. Hradišti, Suppl. 10, 258 pp. ISBN: 80-86485-05-6

Boag D. A. 1986. Dispersal in pond snails: potential role of waterfall. Canad J. Zool. **64 (4):** 904–905. DOI: 10.1139/z86-136

Boyd C.E. 1995. Bottom Soils, Sediments and Pond Aquaculture. Chapman and Hall, New York, 348 pp. ISBN: 978-1-4615-1785-6

Brönmark C. 1989. Interaction between epiphytes, macrophytes and freshwater snails: a review. J. Mollus. Stud. **55 (2):** 299–311. DOI: 10.1093/mollusc/55.2.299

Chertoprud M. V. & Udalov A. A. 1996. Ecological group of freshwater Gastropods in the central part of European Russia. The influence of the type water body and substrate. Zool. Zh. **75 (5):** 644–676.

Collier K.J., Willcock R.J. & Meredith A. 1998. Influence of substrate type and physicochemical conditiond on macroinvertebrate faunas and biotic indices of some lowland Waikato, New Zealand, streams. N. Z. J. Mar. Freshwater Res. **32:** 1–19. DOI: 10.1080/00288330.1998.9516802

Collinson N.H., Boggs J., Corfield A., Hodson M.J., Walker D., Whitfield M. & Williams P.J. 1995. Temporary and permanent ponds: an assessment of the effects of drying out on the conservation value of aquatic macroinvertebrate communities. Biol. Conserv. **74 (2):** 125–133. DOI: 10.1016/0006-3207(95)00021-U

Costil K. & Clement B. 1996. Relationship between freshwater gastropods and plant communities reflecting various trophic levels. Hydrobiologia **32 (1):** 7–16. DOI: 10.1007/BF00018672

Dumnicka E. & Krodkiewska M. 2003. Studies on freshwater Oligochaeta in the Upper Silesia region (Southern Poland). Biologia **58 (5):** 897–902.

Früh D., Stoll S. & Haase P. 2012. Physico-chemical variables determining the invasion risk of freshwater habitats by alien mollusks and crustaceans. Ecol. Evol. **2 (11):** 2843–2853. DOI: 10.1002/ece3.382

Glöer P. & Meier-Brook C. 1998. Süsswassermollusken. Ein Bestimmungsschlüssel für die Bundesrepublik Deutschland. Deutscher Jugendbund für Naturbeobachtung DJN, Hamburg, 134 pp. ISBN: 3923376022, 9783923376025

Hermanowicz W., Dojlido J., Dożańska W., Koziorowski B. & Zerbe J. 1999. Fizyczno – chemiczne badanie wody i ścieków. Arkady, Warszawa, 555 pp. ISBN: 83-213-4067-9_2000

Jackiewicz M. 2000. Błotniarki Europy (Gastropoda: Pulmonata: Lymnaeidae). Wydawnictwo Kontekst, Poznań, 115 pp. ISBN: 83-911523-4-0

Jankowski A.T., Molenda T., Rzętała M., Bebek M. & Mitko K. 2005. Heavy metals in bottom deposits of anthropogenic water reservoirs (a case study of settlement tanks of mine waters). Limnol. Rev. **5:** 101–105.

Kołodziejczyk A. & Koperski P. 2000. Bezkręgowce słodkowodne Polski. Klucz do oznaczania oraz podstawy biologii i ekologii makrofauny. Wydawnictwo Uniwersytetu Warszawskiego, Warszawa, 250 pp. ISBN: 8323501920, 9788323501923

Kornijów R. 1989. Macrofauna of elodeids of two lakes of different trophy. I. Relationships between plants and structure of fauna colonizing them. Ekol. Pol. **37:** 31–48.

Krodkiewska M. 2003. Leech (Hirudinea) communities of post-exploration water bodies in industrial region (Upper Silesia, Poland). Pol. J. Ecol. **51 (1):** 101–108.

Krodkiewska M. 2006. Freshwater Oligochaeta in mining subsidence ponds in the Upper Silesia region of Southern Poland. J. Freshwater Ecol. **21 (1):** 177–179. DOI: 10.1080/02705060.2006.9664111

Krodkiewska M. & Królczyk A. 2012. Impact of environmental conditions on bottom oligochaete communities in subsidence ponds (The Silesian Upland, Southern Poland). Int. Rev. Hydrobiol. **96 (1):** 48–57. DOI: 10.1002/iroh.201011284

Lassen H.H. 1975. The diversity of freshwater snails in view of the equilibrium theory of island biogeography. Oecologia **19 (1)**: 1–8. DOI: 10.1007/BF00377585

Lewin I. 2012. Occurrence of the invasive species *Potamopyrgus antipodarum* (Prosobranchia: Hydrobiidae) in mining subsidence reservoirs in Poland in relation to environmental factors. Malacologia **55 (1):** 15–31. DOI: 10.4002/040.055.0102

Lewin I. & Smoliński A. 2006. Rare and vulnerable species in the mollusc communities in the mining subsidence reservoirs of an industrial area (The Katowicka Upland, Upper Silesia, Southern Poland). Limnologica **36 (3):** 181–191. DOI: 10.1016/j.limno.2006.04.002

Lodge D.M. 1985. Macrophyte – Gastropod associations: observations and experiments on macrophyte choice by gastropods. Freshwater Biol. **15 (6):** 695–708. DOI: 10.1111/j.1365-2427.1985.tb00243.x

Lodge D.M. 1986. Selective grazing on periphyton: A determinant of freshwater gastropod microdistributions. Freshwater Biol. **16 (6):** 831–841. DOI: 10.1111/j.1365-2427.1986.tb01020.x

Lodge D.M. & Kelly P. 1985. Habit distribance and the stability of freshwater gastropods population. Oecologia **68 (1):** 111–117. DOI: 10.1007/BF00379482

Machowski R. 2010. Przemiany geosystemów zbiorników wodnych powstałych w nieckach osiadania na Wyżynie Katowickiej. In: Jankowski A.T. (ed.), Seria: Nauki o Ziemi, Wydawnictwo Uniwersytetu Śląskiego, Katowice, 178 pp. ISBN: 978-83-226-1980-4

Michalik-Kucharz A. 2008. The occurrence and distribution of freshwater snails in a heavily industrialised region of Poland (Upper Silesia). Limnologica **38 (1):** 43–55. DOI: 10.1016/j.limno.2007.09.003

Oertli B. 1995. Spatial and temporal distribution of the zoobenthos community in a woodland pond (Switzerland). Hydrobiologia **300-301 (1):** 195–204. DOI: 10.1007/BF00024461

Oertli B., Joye D.A., Castella E., Juge R., Cambin D. & Lachavanne J.B. 2002. Does size matter? The relationship between pond area and biodiversity. Biol. Conserv. **104 (1):** 59–70. DOI: 10.1016/S0006-3207(01)00154-9

Pinel-Alloul B., Méthot G., Lapierre L. & Willsie A. 1996. Macroinvertebrate community as a biological indicator of ecological and toxicological factors in Lake Saint-François (Québec). Envir. Poll. **91 (1):** 65–87. DOI: 10.1016/0269-7491(95)00033-N

Pip E. 1986. A study of pond colonization by freshwater molluscs. J. Mollusc. Stud. **52 (3):** 214–224. DOI: 10.1093/mollus/52.3.214

Rzętała M. 2008. Funkcjonowanie zbiorników wodnych oraz przebieg procesów limnicznych w warunkach zróżnicowanej antropopresji na przykładzie regionu górnośląskiego. Prace Naukowe Uniwersytetu Śląskiego w Katowicach, 2643, 172 pp. ISBN: 8322618093, 9788322618097

Skowrońska-Ochmann K., Cuber P. & Lewin I. 2012. The first record and occurrence of *Stagnicola turricula* (Held, 1836) (Gastropoda: Pulmonata: Lymnaeidae) in Upper Silesia (Southern Poland) in relation to different environmental factors. Zool. Anz. **251 (4):** 357–363. DOI: 10.1016/j.jcz.2011.11.001

Spyra A. 2011. Autochthonic and allochthonic plant detritus as zoobenthos habitat in anthropogenic woodland ponds. Oceanol. Hydrobiol. Stud. **40 (1):** 27–35. DOI: 10.2478/s13545-011-0004-9

Spyra A. & Krodkiewska M. 2013. The significance of woodland ponds in the conservation of rare species: A case study of *Placobdella costata* (F.Müller, 1846) (Hirudinida: Glossiphoniidae). Pol. J. Ecol. **61 (3):** 613–619.

Strzelec M. 1993. Slimaki (Gastropoda) antropogenicznych srodowisk wodnych Wyżyny Ślaskiej. Prace Naukowe Uniwersytetu Śląskiego w Katowicach, 1358, 103 pp.

Strzelec M. 2005. Impact of the introduced *Potamopyrgus antipodarum* (Gastropoda) on the snail fauna in post-industrial ponds in Poland. Biologia **60 (2):** 159–163.

Strzelec M. & Serafiński W. 2004. Biologia i ekologia ślimaków w zbiornikach antropogenicznych. Centrum Dziedzictwa Przyrody Górnego Śląska, Katowice, 91 pp. ISBN: 839069106X, 9788390691060

Wilmer J.W., Elkin C., Wilcox C., Murray L., Niejalke D. & Possingham H. 2008. The influence of multiple dispersal mechanism and landscape structure on population clustering and connectivity in fragmented artesian spring snail population. Mol. Ecol. **17 (16):** 3733–3751. DOI: 10.1111/j.1365-294X.2008.03861.x

Wood P.J., Greenwood M.T., Barker S.A. & Gunn J. 2001. The effects of amenity management for angling on the conservation value of aquatic invertebrate communities in old industrial ponds. Biol. Conserv. **102 (1):** 17–29. DOI: 10.1016/S0006-3207(01)00087-8

Van Leeuwen C.H.A., Tollenaar M.L. & Klaassen M. 2012a. Vector activity and propagule size affect dispersal potential by vertebrates. Oecologia **170 (1):** 101–109. DOI: 10.1007/s00442-012-2293-0.

Van Leeuwen C.H.A., Van Der Velde G., Groenendael J.M. & Klaassen M. 2012b. Gut travellers: internal dispersal of aquatic organisms by waterfowl. J. Biogeograph. **39 (11):** 2031–2040. DOI: 10.1111/jbi.12004

Van Leeuwen C.H.A., Van Der Velde G., Van Lith B. & Klaassen M. 2012c. Experimental quantification of long distance dispersal potential of aquatic snails in the gut of migratory birds. PLoS ONE **7:** e32292. DOI: 10.1371/journal.pone.0032292.

Zealand A.M. & Jeffries M.J. 2009. The distribution of pond snails communities cross a landscape: separating out the influence of spatial position from local habit quality for ponds in south-east Northumberland, UK. Hydrobiologia **632 (1):** 177–187. DOI: 10.1007/s10750-009-9837-2

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