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ABIOTIC PARAMETERS DETERMINING FAUNA COMPOSITION IN KARSTIC SPRINGS

ABSTRACT: The biotic diversity of springs is specific, which makes them valuable sites important for nature protection. Springs located in the Krakow-Częstochowa Upland (southern Poland) are characterized by low variability of environmental conditions, but their benthic fauna composition is considerably different. Benthic invertebrates, water chemistry as well as sediment characteristics of 25 springs were studied four times in 2003. The relationships between fauna composition and abiotic parameters were ascertained using multivariate statistical analyses. In total, fifty families or subfamilies and four higher taxa of invertebrates were identified in the springs studied. Only *Gammarus fossarum* (Amphipoda) occurred in all of the springs, whereas crenophilic taxonomic groups such as Turbellaria, Bythinellinae, Nemouridae, Limoniidae, Limnephilidae and Enchytraeidae as well as ubiquitous taxa such as Tubificidae and Chironomidae were very common but not present in all springs. Important factors determining differences in the taxonomic composition (at the family level) of the invertebrate fauna of springs were found to be those connected with their geographical location as well as chemical and discharge parameters, which were different for southern and northern groups of springs.

The taxonomic richness, i.e. the number of invertebrate taxa, was found to be strongly dependent on discharge and the content of organic matter in bottom sediments, whereas specific taxa mentioned above had other abiotic determinants such as alkalinity, NO_3 and temperature.

KEY WORDS: macroinvertebrates, multivariate analysis, springs, crenobiology, Poland

1. INTRODUCTION

Springs are sensitive to various kinds of anthropogenic changes (encasing, tourist impact, water exploitation etc.) which depredate unique benthic fauna communities by destroying their habitats. Springs in Poland are usually protected as inanimate nature monuments (Baścik 2004) but the diversity of their benthic fauna and the occurrence of rare or endangered species have not been taken into account.

Until recently the taxonomic composition of invertebrates living in springs has been largely unknown despite many studies on the fauna inhabiting this environment conducted in both Europe and North America (Botosaneanu 1998). Springs offer unique environmental conditions, in particular reduced fluctuations in water temperature, chemistry and flow regime (Kamp 1995, Cabe 1998, Chełmicki 2001), which influence their faunal composition (Särkkä *et al.* 1997, Hoffsten and Malmqvist 2000, Smith *et* *al.* 2003). Beside crenobionts, less specialized taxa are also typically abundant in springs. The occurrence of ubiquitous taxa results in a relatively high species diversity (e.g. Lindegaard *et al.* 1998, Webb *et al.* 1998, Mori and Brancelj 2006). Responses of the fauna composition of springs to single factors such as their water temperature or discharge (Fumetti *et al.* 2006, Mori and Brancelj 2006) as well as substrate composition (Dumnicka *et al.* 2007) have been studied previously. In recent years multivariate analysis of fauna relationships to abiotic factors have been undertaken more frequently (Williams *et al.* 1997, Lindegaard *et al.* 1998, Smith *et al.* 2001, 2003, Barquin and Death 2004) in various types of springs (e.g. perennial-temporary, polluted-unpolluted).

In Poland, wide-ranging ecological studies on springs were conducted only in the Sudety Mountains (southern Poland) by Michejda (1954), who stressed the effect of some environmental factors on fauna composition. The most detailed zoological studies were performed in a large complex of limnocrene karst springs called Niebieskie Źródła (Blue Springs) in central Poland (Wojtas 1972, Piechocki 2000). They were found to be populated by about 280 species representing 15 taxonomic groups of benthic macroinvertebrates.

Until now the studies including the whole benthic fauna have been performed only in a few springs situated in a large, limestone region in southern Poland known as the Krakow-Częstochowa Upland (Szczęsny 1968, Dratnal 1976). Individual taxonomic groups such as Turbellaria (Dudziak 1954), Trichoptera (Czachorowski 1990), Coleoptera (Kordylas 1994) and Hydracarina (Biesiadka *et al.* 1990) have been studied in a greater number of springs of more diverse characteristics.

The aim of our studies was to determine the relationships between fauna composi-

Table 1. Characteristics of the springs. Spring type: R – rheocrene, L – limnocrene, LR – limnorheocrene, E – encased; sediment organic matter (median). Discharge data (annual average or a single measurement) according to Dynowska (1983) and Chełmicki (2001). Spring number– see Fig. 1.

Number	Type	Discharge	Sediment		Organic
		(L s^{-1})	fine (%)	coarse (%)	matter (%)
1	E	0.6	–	–	–
2	E	1.0–4.4	loamy sand (20)	stones (80)	1.5
3	LR	5.0–5.6	silt (100)		2.9
4	L	0.01	silt loam (90)	stones (10)	3.8
5	R	8.0–9.8	silt loam (10)	stones (90)	2.9
6	R	0.8–1.0	silt (30)	stones (70)	2.1
7	LR	ca. 1.0	silt loam (10)	stones (90)	4.1
8	R	ca. 3.0	silt loam (20)	stones (80)	3.7
9	E/R	5.0–6.0	loamy sand (40)	stones (60)	5.7
10	E/R	0.5	sand (70)	stones (30)	2.4
11	E/R	0.4–2.0	loamy sand (100)	–	4.4
12	E/R	12.5–15	silt (30)	stones (70)	2.2
13	R	4.0–11.0	silt (10)	stones (90)	5.2
14	E	0.5–0.6	sand (10)	stones (90)	4.0
15	R	6.5–13.0	sand (20)	stones (80)	4.1
16	R	115–150	sand (100)	–	0.2
17	R	25.0–35.8	sand (20	stones (80)	0.4
18	R	30	sand (100)	–	0.2
19	R	47.0–109.0	sand (80)	stones (20)	0.5
20	E/R	230–1440	sand (70)	stones (20)	0.8
21	R	30	sand (70)	stones (30)	2.8
22	R	30	loamy sand (10)	stones (90)	0.4
23	LR	20.0–47.0	loamy sand (100)	–	1.4
24	R/E	46–100	sandy silt (30)	stones (70)	2.3
25	R	ca.50	loamy sand (100)	–	0.8

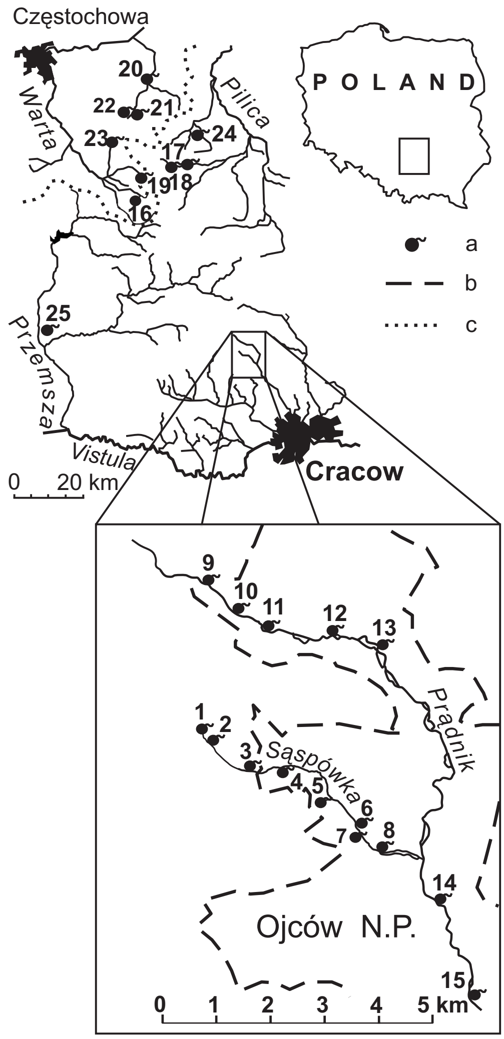

Fig. 1. Location of the area (the Krakow-Częstochowa Upland) and springs under investigation: no. 1–15 – southern group of springs situated along the Sąspówka stream and the Prądnik stream, no. 16–25 – northern group of springs situated in the catchments of the Pilica River, Warta River and Przemsza River; alkaline springs no. 19 and 25, a – springs, b – borders of the Ojców National Park, c – watershed between the Vistula and Oder drainage basins, after Galas (2005).

tion and abiotic parameters in perennial cold springs situated on limestone bedrock. The most important variables differentiating the springs were geographical location, discharge value, water chemistry, character of sediments and their organic matter content. Various methods of multivariate data analysis were employed to establish and prove the existence, direction and strength of these relationships.

2. STUDY AREA

The study area is situated in the Krakow-Częstochowa Upland in southern Poland (50°10'–50°46'N, 19°17'–19°54'E) (Fig. 1). It is composed of Jurassic limestone, whose thickness varies from 20 to 500 m. The Upland is covered by different kinds of deposits. There are quaternary loess and clayey loess in the southern part of the Upland, whereas permeable sands and loamy sands can be found in its northern part (Dynowska 1983). The different types of deposits in turn affect the granulometric composition of spring sediments (Galas 2005). The area abounds in springs situated in the drainage basins of the two main Polish rivers: the Vistula and the Oder. The springs under investigation represent a diversity of depths of the feeding layer; they also differ in discharge value, character of sediments and organic matter content (measured for fine sediments) (Table 1). 25 springs were selected for this study: 15 in the southern part of the Upland and 10 in its northern part (Fig. 1). Springs in the southern part are located in the Ojców National Park (Fig. 1) founded in 1956 to protect karstic forms in the deep valley of the Prądnik stream with its rich flora and fauna. This area has recently been included in the NATURA 2000 system of nature protection. Springs in the southern part are small, situated close to one another, usually along streams, while those in the northern part they are much larger and widely scattered (Fig. 1). Three springs (no. 1, 2, 14) have been strongly modified, and on some others concrete well-heads have been installed (Table 1). Most of the springs selected for the study are rheo-limnocrenes, surrounded by variously used land such as meadows and woodland, or situated within villages (Dumnicka 2006, Dumnicka *et al.* 2007).

3. SAMPLING METHODS

Samples of water, benthic invertebrates and sediments were collected from each spring seasonally in February, May, August and October 2003. Temperature and pH were measured *in situ*, while water samples were taken to determine the oxygen content, conductivity, alkalinity, total hardness, BOD_5 and the concentration of Ca, Mg, Cl, SO_4, NH_4, NO_3 and PO_4. Water chemistry analyses were conducted according to Standard Methods (1992), and their detailed descriptions as well as results were already published by Galas (2005). Two samples of fine sediments were collected with a plastic corer (12.56 cm^2), which was driven into the substrate to a depth of 5 cm. The benthic fauna, organic matter content (% LOI) and granulometric composition (sand 1.0–0.1 mm, silt 0.1–0.002 mm and clay <0.002 mm by aerometric method) of the sediment were determined.

One sample of benthic fauna was also taken from coarse sediments using a bottom scraper (225 cm^2 with 0.2 mm net mesh). The number of samples collected from each spring at the same time was limited to three

Table 2. Median and SD values of abiotic parameters in the springs. Significance of the difference between the two groups of springs:* *P* <0.01, ** *P* <0.005, *** *P* <0.001. Spring number – see Fig. 1.

Parameter	Southern springs (No 1–15) (60 samples)		Northern springs (No 16–25) (40 samples)	
	Median	SD	Median	SD
Water parameters:				
Temperature (°C)	8.9*	0.6	9.2	1.0
pH	7.8	0.2	8.0	0.2
Conductivity (μS cm^{-1})	402.8**	59.7	347.8	90.9
Total hardness (°N)	5.0	0.6	4.1	1.3
Alkalinity mval (L^{-1})	4.3***	0.3	3.2	0.9
Chlorides mg (L^{-1})	0.75**	0.8	1.9	4.0
Sulphates mg (L^{-1})	13.4	8.3	18.9	21.2
Calcium mg (L^{-1})	33.7	3.9	27.9	4.8
Magnesium mg (L^{-1})	0.87	0.7	1.1	3.6
O_2 (%)	84.6	9.2	82.6	22.2
Oxidability mg O_2 (L^{-1})	0.4	0.3	0.4	0.3
BOD_5 mg O_2 (L^{-1})	1.3**	1.0	0.4	1.3
Ammonium mg (L^{-1})	0.2	0.1	0.2	0.6
Nitrates mg (L^{-1})	3.3	1.5	4.3	2.0
Phosphates mg (L^{-1})	0.3	0.1	0.3	0.3
Discharge (L s^{-1})	4.4***	4.5	47.0	51.9
Sediment parameters:				
Silt content (%)	69.5***	22.6	4.5	6.4
Sand content (%)	20.0***	19.4	93.0	8.6
Organic matter (%)	3.3***	2.3	0.6	0.9

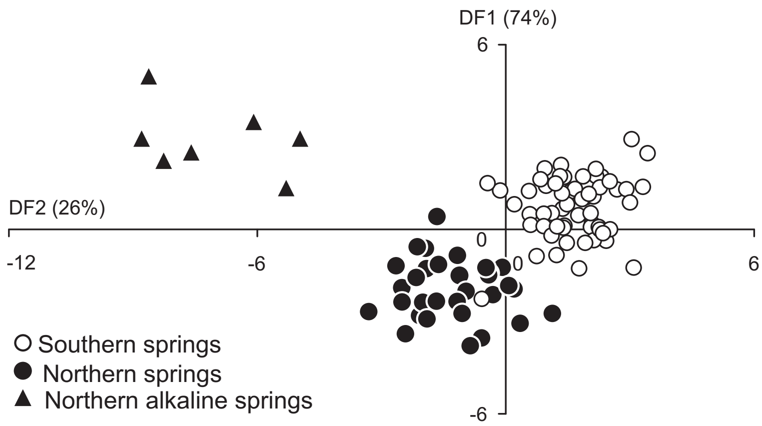

Fig. 2. Results of Discriminant Function Analysis based on the taxonomic (family) composition of invertebrates from the springs classified according to their geographic location (see Fig. 1). Basic differences between the two groups of springs related to conductivity, alkalinity, chloride content, discharge and sediment composition are given in Table 2 and Table 3.

(two corer samples and a scraper one) due to the small bottom surface of the springs. All specimens of benthic fauna from all types of sediment samples were hand-sorted under a stereoscopic microscope, fixed in 4% formaldehyde, preserved in alcohol and counted. For multivariate analysis the family level data were used; however, some taxonomic groups were determined to the species or genus level. These results were partly published (Dumnicka 2005, 2006, Matolicz *et al.* 2006).

4. DATA ANALYSIS

Data on the number of animals were log-transformed and standardized before analysis. DECORANA was used to classify particular samples on the basis of their macrofauna composition, expressed as numerical percentages of the taxa. The analysis of Discriminant Functions (Statistica 6 by Statsoft) was used to test whether the samples could be accurately classified based on the fauna composition (determined to the family level) in terms of their abiotic parameters. The aim of Multiple Regression Analysis was to determine the strength and direction of the relationships between the numbers or percentages of particular taxa and the values of the main abiotic parameters measured in particular springs. The explanatory strength of the model is expressed by the multiple regression coefficient R^2, while the values of the R and Beta parameters represent the strength and direction of relationships between explaining and explained variables, whilst *P* shows their statistical significance.

The significance of differences between abiotic factors in the southern and northern springs was calculated using t-test.

5. RESULTS

Most of the water parameters were found to be similar for the springs situated in both parts of the Upland. Out of 15 parameters under investigation only the values of conductivity, alkalinity and BOD_5 were significantly higher in the southern springs while the chloride concentration was higher in the northern part of the Upland (Table 2). Even though the median values of the other water chemistry parameters were comparable in all springs, the range of fluctuations was greater in the northern group. The main differences between the two regions were found in the discharge value and the type of fine-grained sediment. The sediments differed significantly in their granulometric composition and organic matter content. Silt prevailed in the southern part of the Upland, whereas sand dominated in the northern part (Table 2).

The absolute number of collected invertebrates amounted to 33 200, including approx. 17 500 from the northern springs (Table 3). In total, fifty families or subfamilies and four higher taxa of invertebrates were identified. *Gammarus fossarum* (Koch, in Panzer 1835) (the only representative of the Gammaridae family) was the most frequently collected taxon, occurring in all springs. Taxonomic groups characteristic of springs such as Turbellaria, Bythinellinae, Nemouridae, Limoniidae, Limnephilidae and Enchytraeidae as well as ubiquitous taxa such as Tubificidae and Chironomidae were also very common but not present in all springs (Table 3).

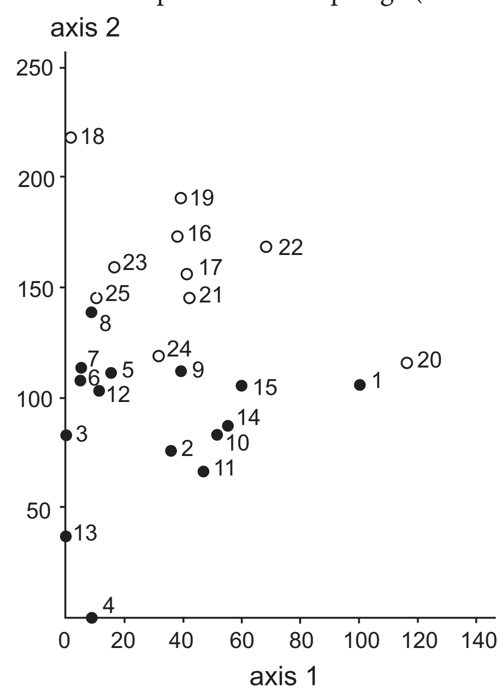

Fig. 3. Results of DECORANA (Detrended Correspondence Analysis) – differences between the group of filled circles (southern springs 1–15) and the group of open circles (northern springs 16–25). Spring number – see Fig. 1. The chemical and discharge differences between the two groups of springs – see Fig. 1 and Table 2.

Table 3. The absolute number of specimens caught in all sediment samples (NI), particular taxons as mean percentages of the entire invertebrate fauna (%) and the frequency of occurrence of particular taxa (the number of springs where a taxon was found – NS) in samples from the southern and northern groups of springs.

Taxa		Southern group (180 samples)			Northern group (120 samples)		
		NI	%	NS	NI	%	NS
Hydrozoa		0	0	0	86	1	1
Turbellaria		234	1	12	401	2	9
Nematoda		181	1	13	31	<1	8
Hydracarina		36	<1	7	73	<1	4
Oligochaeta	Lumbriculidae	86	<1	9	24	<1	7
	Naididae	331	2	12	95	0.5	5
	Tubificidae	994	6	14	197	1	8
	Propappidae	0	0	0	90	<1	1
	Enchytraeidae	71	<1	13	60	<1	8
	Lumbricidae	2	<1	1	2	<1	2
Crustacea	Cyprididae	26	<1	6	6768	39	7
	Ilyocyprididae	676	4	6	4	<1	1
	Candonidae	15	<1	6	3	<1	3
	Gammaridae	3553	23	15	2677	15	10
	Niphargidae	6	<1	4	1	<1	1
	Asellidae	61	<1	3	126	1	3
Ephemeroptera	Baetidae	6	<1	4	26	<1	2
	Heptageniidae	3	<1	2	0	0	0
Plecoptera	Nemouridae	515	3	15	133	1	8
	Perlodidae	3	<1	1	0	0	0
Megaloptera	Sialidae	17	<1	3	2	<1	1
Trichoptera	Rhyacophilidae	0	0	0	1	<1	1
	Hydroptilidae	0	0	0	1	<1	1
	Polycentropodidae	22	<1	5	25	<1	6
	Psychomyidae	1	<1	1	1	<1	1
	Goeridae	0	0	0	52	<1	6
	Apataninae	0	0	0	9	<1	2
	Drusinae	249	2	9	1236	7	10
	Stenophylacini	15	<1	5	0	0	0
	Chaetopterygini	17	<1	8	29	<1	8
	Odontoceridae	0	0	0	1	<1	1
	Sericostomatidae	0	0	0	4	<1	2
Diptera	Limoniidae	32	<1	13	64	<1	10
	Psychodidae	7	<1	5	1	<1	1
	Dixidae	2	<1	1	0	0	0
	Tanypodinae	68	<1	5	185	1	3
	Diamesinae	10	<1	4	3	<1	1
	Prodiamesinae	196	1	10	59	<1	4
	Pseudodiamesinae	2	<1	1	4	<1	2
	Orthocladiinae	286	2	13	441	2	9
	Chironominae	415	3	12	150	1	4
	Ceratopogonidae	49	<1	7	8	<1	3
	Empididae	0	0	0	8	<1	4
	Sciomyzidae	1	<1	1	0	0	0
	Tipulidae	1	<1	1	2	<1	2
	Ptychopteridae	5	<1	2	0	0	0
Coleoptera	Elmidae	155	1	4	175	1	4
	Dytiscidae	3	<1	2	0	0	0
Mollusca	Bythinellinae	6946	44	13	3962	23	10
	Littoridininae	0	0	0	30	<1	1
	Lymnaeidae	4	<1	1	0	0	0
	Planorbidae	0	0	0	166	1	1
	Ancylidae	128	1	5	22	<1	2
	Sphaeriidae	239	1	11	59	<1	4

Table 4. Results of Multiple Regression Analysis explaining relationships between the number of individuals from each taxon (collected in all samples) and the values of particular abiotic parameters: alkalinity, discharge, nitrate concentration, organic matter content or temperature (see Table 2). Only the taxa with significant relationships (P <0.05) revealed in one or more models are presented.

	Alkalinity		Discharge		NO_3		Organic matter		Temperature	
Taxa	R	Beta	R	Beta	R	Beta	R	Beta	R	Beta
Asellidae	0.61	0.35	0.61	-0.30	ns	ns	ns	ns	ns	ns
Gammaridae	0.36	-0.20	ns	ns	0.36	0.22	ns	ns	ns	ns
Orthocladiinae	0.41	-0.25	0.41	0.18	ns	ns	ns	ns	ns	ns
Ceratopogonidae	ns	ns	ns	ns	0.63	0.36	ns	ns	ns	ns
Ilyocyprididae	ns	ns	ns	ns	ns	ns	ns	ns	0.51	0.23
Turbellaria	ns	ns	0.53	0.19	ns	ns	0.53	-0.43	ns	ns
Elmidae	ns	ns	0.67	0.31	ns	ns	ns	ns	ns	ns
Naididae	ns	ns	0.66	-0.32	ns	ns	ns	ns	ns	ns
Tubificidae	ns	ns	ns	ns	0.65	0.40	ns	ns	ns	ns
Goeridae	0.67	0.32	ns	ns	ns	ns	ns	ns	ns	ns
Bythinellinea	ns	ns	0.68	0.36	ns	ns	0.68	-0.36	0.68	0.61
Littoridininae	0.58	0.26	0.58	0.24	ns	ns	ns	ns	ns	ns
Sphaeriidae	0.64	0.34	0.64	-0.24	0.64	-0.44	ns	ns	ns	ns
Family richness	ns	ns	0.88	-0.40	ns	ns	0.88	0.51	ns	ns
R^2	0.77		0.87		0.71		0.86		0.79	

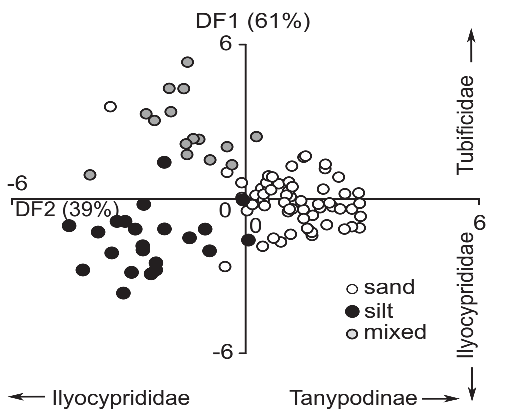

Fig. 4. Results of Discriminant Function Analysis based on the taxonomic (family) composition of invertebrates from the springs classified according to their sediment composition.

A relatively high number of taxa (17) were found exclusively in one or two of the 25 springs. From these families a single or a few specimens were mostly caught, whereas Propappidae, Hydrozoa and Gastropoda (Littoridininae and Planorbidae) were also found in only one spring, albeit abundantly (Table 2). *Bythinella austriaca* (Frauenfeld 1857) (Bythinellinae) dominated in the springs of both parts of the Upland and constituted 44% of the total fauna in the south and 23% in the north. Gammaridae occurred in a similar abundance in both areas. Cyprididae were found more abundantly in the northern part of the Upland.

Three models of Discriminant Function Analysis provided satisfactory results of sample classification. The most important variables in these procedures were geographical and chemical parameters, the type of bottom sediment and the mean discharge value. The first analysis markedly separated the springs into three categories (Fig. 2). The samples from southern springs, northern springs and northern alkaline springs (no. 19 and 25, see Galas 2005) were distinguished with satisfactory accuracy (98, 100 and 100% of samples, respectively). DF1 was found to be strongly positively correlated with the number of Gammaridae, while a strong negative correlation between DF1 and Littoridininae was observed (explaining 74% of variance). Also a strong positive correlation between DF2 and the number of Sphaeriidae and Planorbidae (26%) was found. Based on chemical parameters, mainly alkalinity, three groups of springs were distinguished, and the occurrence of several families was correlated with this division. Based on the mean percentage values of all taxa of benthic invertebrates, only two groups of springs were distinguished by DECORANA (Fig. 3). They clearly show the

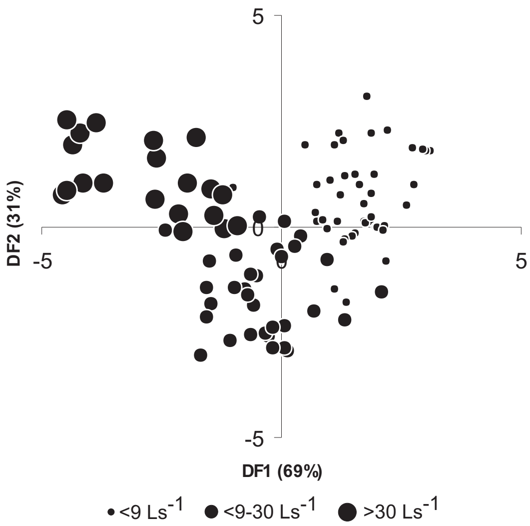

Fig. 5. Results of Discriminant Function Analysis based on the taxonomic (family) composition of invertebrates from the springs classified according to their mean discharge values.

differences between the southern and northern springs.

The Discriminant Function Analysis also separated samples into three groups based on the type of bottom sediment (Fig. 4). The samples from springs with dominant sandy, silty and mixed bottom sediments were classified with 98, 86 and 88% accuracy respectively. DF1 showed a strong positive correlation with the number of Tanypodinae and a strong negative correlation with the number of Ilyocyprididae. DF2 correlated strongly and positively with the number of Tubificidae and negatively with the number of Ilyocyprididae.

Discriminant Function Analysis was also used to differentiate springs into three groups based on discharge (Fig. 5). Samples from springs with low discharge (first quartile of values measured throughout the season) were classified accurately with 89% efficiency, samples from springs with medium discharge (second quartile) with 81% efficiency and those from high discharge springs (third quartile) with 90% efficiency. There was a strong positive correlation between the number of Chironominae and DF1, and a strong negative correlation between the number of Turbellaria and DF1. Moreover, a strong positive correlation was noted between the number of Chironominae and DF2, while the number of Propappidae showed a strong negative correlation with DF2.

The results of Multiple Regression Analysis, explaining relationships between the number of taxa and values of abiotic parameters are presented in Table 4. Only models with significant P (<0.05) and R higher than 0.7 as well as taxa with significant P in one or more models are presented in the results. All other models were omitted as insignificant. Five models of multiple regression analysis were found to be significant, and they involve the following variables (from the highest to the lowest significance): discharge value (high R^2 for 9 factors), organic matter concentration (R^2 also high but significant only for 3 factors), alkalinity (an important abiotic parameter for 6 families), NO_3 concentration (important for 4 families) and water temperature (important for 2 families).The number of Bythinellidae and Sphaeriidae in particular samples correlated significantly with three abiotic parameters. The strongest R^2 coefficients were found for the correlations between diversity at the family level (family richness) and discharge as well as organic matter concentration in bottom sediments (Table 4).

6. DISCUSSION

Although the springs under investigation were located on the same rocky substrate, the sediments were formed in different processes after the glaciation period (Jersak 1973, Lewandowski 1994). This was the cause of slightly different chemical parameters of water and considerably diverse types of bottom sediments in the southern and northern parts of the Upland. Increased values of nitrate and phosphate concentration and their fluctuations suggest the impact of human activity on some of the springs (Galas 2005).

The occurrence of 50 families of macrofauna in the springs studied should be considered as high in comparison to an almost identical number obtained in 110 Danish springs and their outlets (Lindegaard *et al.* 1998). In mountain springs faunal richness was usually smaller, e.g. in the Italian Alps, where 27 families were found (Bonettini and Cantonati 1996), or in karstic springs of the Julian Alps with 33 families

(Mori 2003). However, among the 50 families identified in the Krakow-Częstochowa Upland as many as 17 taxa were found rarely in one or two disparately situated springs. These springs are located very close to a river or within a pond, which results in the occurrence of taxa characteristic of these kinds of water bodies.

Benthic animals with very different ecological requirements co-occurred in the same springs. They ranged from cold stenothermic Turbellaria and Nemouridae through stygobiontic Niphargidae, semiaquatic Limoniidae and Enchytraeidae to ubiquitous taxa. The coexistence of taxa with diverse ecological requirements seems to be typical of springs (Lindegaard *et al.* 1998, Cantonati *et al.* 2006).

In the case of springs situated on a homogenous geological substrate, e.g limestones of the Krakow-Częstochowa Upland or Pennsylvania (Glazier and Gooch 1987), their fauna is diversified by differences in discharge, water chemistry and the type of bottom sediment but not by the location in the catchment area of specific rivers (the Vistula or the Oder in the case of Krakow-Częstochowa Upland). The instability of discharge is considered to be the most important factor determining the taxonomic composition of spring fauna communities (Smith and Wood 2002, Smith *et al.* 2003). When discharge fluctuates, taxonomic composition is not shaped by the chemical parameters of the spring water. In the springs under investigation, only small discharge fluctuations were observed, which had no effect on their benthic fauna composition.

Samples of invertebrates from particular springs were classified with great accuracy into 3 groups differentiated by mean discharge values (3 and 80 L s^{-1} for springs situated in the southern and northern parts of the Krakow-Czestochowa Upland, respectively). The significant influence of this parameter on the fauna composition of perennial springs has been documented in previous studies (Hoffsten and Malmqvist 2000, Ilmonen and Paasivirta 2005, Fumetti *et al.* 2006).

The great importance of the type of bottom sediment as a determinant of the taxonomic composition of benthic fauna has also been shown previously (Ilmonen and Paasivirta 2005, Catonati *et al.* 2006, Dumnicka *et al.* 2007). Samples of invertebrates from particular springs were classified with considerable accuracy into 3 groups depending on the dominant types of sediments. The taxa most important in explaining this division are predominately associated with a soft bottom (Tubificidae, Tanypodinae) or known as typically bentho-planktonic organisms (Ilyocyprididae).

The relationship between water temperature and the number of taxa found in particular springs is difficult to interpret, because the measured range of temperatures was low: 7.2–10.3°C in the southern springs and 8.0–14.4°C in the northern springs (Galas 2005). However, the maximal and minimal temperatures during the whole period of the study may have been considerably higher. Water temperature seems to be an important parameter determining the invertebrate composition of springs as well as the occurrence of individual taxa in cases when it fluctuates in a wide range (e.g. 7.6–22.6°C, Williams *et al.* 1997).

The content of organic matter in sediments has previously been indicated as a parameter which correlates most strongly with the relative number of particular benthic taxa in lakes and rivers (e.g. Ali *et al.* 2002, Scealy *et al.* 2007) but not in springs. In the available literature only Barquin and Death (2004) claim this parameter to be an important predictor of the taxonomic diversity of fauna in springs, and the present study confirms their findings.

It must be emphasized that despite the relative homogeneity of the springs under investigation, their inhabitants were highly diverse. This diversity was noted not only between springs but also between seasons. Even small differences in abiotic parameters between particular springs resulted in a different composition of their benthic fauna. That is why protection of most springs situated in the Krakow-Czestochowa Upland is necessary for preserving the natural composition and high biological diversity of their fauna. To date statistical analyses have not shown any impact of water pollution on the macrofauna composition of springs in this region. Recent chemical analyses, however, have revealed an elevated concentration of nitrates and phosphates in some of them (Galas 2005). That is why a reduction in the inflow of organic pollution and nutrients is required. The use of springs by tourists, as in the case of the Upland, may also lead to diminished biodiversity and a decline in water quality (Barquin and Scarsbrook 2008).

7. REFERENCES

Ali A., Frouz J., Lobinske R.J. 2002 – Spatio-temporal effects of selected physico-chemical variables of water, algae and sediment chemistry on the larval community of nuisance Chironomidae (Diptera) in a natural and a man-made lake in central Florida – Hydrobiologia, 470: 181–193.

Barquin J., Death R.G. 2004 – Patterns of invertebrate diversity in streams and freshwater springs in Northern Spain – Arch. Hydrobiol. 161: 329–349.

Barquin J., Scarsbrook M. 2008 – Management and conservation strategies for coldwater Springs – Aquatic Conserv: Mar. Freshw. Ecosyst. 18: 580–591.

Baścik M. 2004 – Walory krajobrazowe chronionych źródeł Wyżyny Krakowsko-Wiluńskej i Miechowskiej [Landscape values of protected springs of the Kraków-Wieluń and Miechów Uplands]. (In: Zróżnicowanie i przemiany środowiskowa przyrodniczo- kulturowego Wyżyny Krakowsko-Częstiochowskiej [The diversification and transformation of natura and cultural environment of the Kraków-Częstochowa Upland] Ed. J. Partyka) – Ojców 2004. (in Polish).

Biesiadka E., Cichocka M., Warzecha B. 1990 – Water mites (Hydracarina) of the springs in the Kraków – Częstochowa and Miechów Uplands – Acta Hydrobiol. 32: 171–186.

Bonettini A.M., Pavia I., Cantonati M. 1996 – Macroinvertebrate assemblages of springs of the River Sarca catchment (Adamello-Brenta Regional Park, Trentino, Italy) – Crunoecia, 5: 71–78.

Botosaneanu L. (ed.) 1998 – Studies in crenobiology. The biology of springs and springbrooks – Backhuys Publishers, Leiden, 261 pp.

Cabe D.J. 1998 – Biological communities in springbrooks. (In: Studies in Crenobiology the Biology of Springs and Springbrooks, Ed. L. Botosaneanu) – Backhuys Publishers, Leiden, pp. 221–228.

Cantonati M., Gerecke R., Bertuzzi E. 2006 – Springs of the Alps – sensitive ecosystems to environmental change: from biodiversity assessments to long-term studies – Hydrobiologia, 562: 59–96.

Chełmicki W. (ed.) 2001 – Źródła Wyżyny Krakowsko-Wieluńskiej i Miechowskiej. Zmiany w latach 1973–2000 [Springs of the Kraków-Wieluń and Miechów Uplands. Changes between 1973 and 2000] – Jagiellonian University, Kraków, 127 pp. (in Polish).

Czachorowski S. 1990 – Caddisflies (Trichoptera) of the springs of the Kraków – Częstochowa and Miechów Uplands (Poland) – Acta Hydrobiol. 32: 391–405.

Dratnal E. 1976 – Zgrupowania bezkręgowców bentosowych potoku Prądnik w Ojcowskim Parku Narodowym i na terenie przyległym [Benthic invertebrate communities of the Prądnik stream] – Ochrona Przyrody, 41: 281-321. (in Polish).

Dudziak J. 1954 – Obserwacje nad rozmieszczeniem wypławków krynicznych w południowej części Wyżyny Krakowskiej [Observations on the distribution of the Spring Planarians in the southern part of the Cracov Upland] – Pol. Arch. Hydrobiol. 2: 7–30. (in Polish).

Dumnicka E. 2005 – Stygofauna associated with spring fauna in southern Poland – Subterr. Biol. 3: 29–36.

Dumnicka E. 2006 – Composition and abundance of oligochaetes (Annelida: Oligochaeta) in springs of Kraków-Częstochowa Upland (Southern Poland): effect of spring encasing and environmental factors – Pol. J. Ecol. 54: 231–242.

Dumnicka E., Galas J., Koperski P. 2007 – Benthic invertebrates in karst springs: does substratum or location define communities? – Inter. Rev. Hydrobiol. 92: 452–464.

Dynowska I. 1983 – Źródła Wyżyny Krakowsko-Wieluńskiej i Miechowskiej [Springs within the Upland of Cracow-Wieluń and Miechów] – Studia Ośrodka Dokumentacji Fizjograficznej PAN, Kraków, 11, 244 pp.

Fumetti von S., Nagie P., Scheifhacken N., Naltes B. 2006 – Factors governing macrozoobenthic assemblages in perennial springs in north-western Switzerland – Hydrobiologia, 568: 467–475.

Galas J. 2005 – Human impact on physical and chemical properties of springs from Cracow-Częstochowa Upland (Southern Poland) – Pol. J. Ecol. 53: 329–341.

Glazier D.S., Gooch J.L. 1987 – Macroinvertebrate assemblages in Pennsylvania (U.S.A.) springs – Hydrobiologia, 150: 33–43.

Hoffsten P.O., Malmqvist B. 2000 – The macroinvertebrate fauna and hydrogeology of springs in central Sweden – Hydrobiologia, 436: 91–104.

Ilmonen J., Paasivirta L. 2005 – Benthic macrocrustacean and insect assemblages in relation to spring habitat characteristics: patterns in abundance and diversity – Hydrobiologia, 533: 99–113.

Jersak J. 1973 – Lithology and stratigraphy of the loess on the southern Polish Uplands – Acta Geografica Lodzensis, 32: 1–142.

Kamp Van der G. 1995 – The hydrogeology of springs in relation to the biodiversity of spring fauna: A review – J. Kansas Entomol. Soc. 68: 4–17.

Kordylas A. 1994 – An investigation of the water beetles of Polish springs – Latissimus, 4: 9–11.

Lewandowski J. 1994 – Fluvioperiglacial covers of the Częstochowa Upland (Southern Poland) – Przegląd Geologiczny, 42: 1009–1013.

Lindegaard C., Brodersen K.P., Wiberg-Larsen P., Skriver J. 1998 – Multivariate analyses of macrofaunal communities in Danish springs and springbrooks. (In: Studies in Crenobiology the Biology of Springs and Springbrooks, Ed. L. Botosaneanu) – Backhuys Publishers, Leiden, pp. 201–219.

Matolicz A., Iglikowska A., Namiotko T. 2006 – Małżoraczki (Ostracoda) źródeł Wyżyny Krakowsko-Częstochowskiej [Ostracods (Ostracoda) in springs of the Kraków-Częstochowa Upland]. (In: Zastosowanie hydrologii w badaniach biologicznych wód płynących [Hydrology application In biological studiem of running waters] Eds: M. Kłonowska-Olejnik, W. Fiałkowski) – XIII Warsztaty Bentologiczne PTH, Ochotnica-Kraków18–20 maja 2006, 81–82.

Michejda J. 1954 – Analiza stosunków ekologicznych źródeł i potoków Gór Stołowych [An analysis of the ecological conditions in springs and streams of the Góry Stołowe] – Poz. Tow. Przyj. Nauk, Wydz. Mat.-Przyr., Pr. Kom. Biol. 16: 1–110. (in Polish).

Mori N. 2003 – Macroinvertebrate communities of karst springs in the Julian Alps in relation to environmental factors – Natura Sloveniae, 52: 5–17.

Mori N., Brancelj A. 2006 – Macroinvertebrate communities of karst springs of two river catchments in the Southern Limestone Alps (the Julian Alps, NW Slovenia) – Aquat. Ecol. 40: 69–83.

Piechocki A. (ed.) 2000 – The fauna of Niebieskie Źródła Springs – Acta Univ. Lodz., Folia limnol. 7: 3–123. (in Polish).

Särkkä J., Levonen L., Mäkelä J. 1997 – Meiofauna of springs in Finland in relation to environmental factors – Hydrobiologia, 347: 139–150.

Scealy J.A., Mika S.J., Boulton A.J. 2007 – Aquatic macroinvertebrate communities on wood in an Australian lowland river: experimental assessment of the interactions of habitat, substrate complexity and retained organic matter – Mar. Freshwat. Res. 58: 153–165.

Smith H., Wood P., Gunn J. 2001 – The macroinvertebrate communities of limestone springs in the Wye Valley, Derbyshire Peak District, UK – Cave Karst Sci. 28: 67–78.

Smith H., Wood P.J. 2002 – Flow permanence and macroinvertebate community variability in limestone spring systems – Hydrobiologia, 487: 45–58.

Smith H., Wood P.J., Gunn J. 2003 – The influence of habitat structure and flow permanence on invertebrate communities in karst spring systems – Hydrobiologia, 510: 53–66.

Standard Methods 1992 – Standard methods for examination of water and wastewater, 18th ed. APHA, Washington DC.

Szczęsny B. 1968 – Fauna denna potoku Sąspówka na terenie Ojcowskiego Parku Narodowego [The bottom fauna of the stream Sąspówka in the Ojcow National Park] – Ochrona Przyrody, 33: 215–235.

Webb D.W., Wetzel M.J., Reed P.C., Phillippe L.R., Young T.C. 1998 – The macroinvertebrate biodiversity, water quality, and hydrogeology of ten karst springs in the Salem Plateau section of Illinois, USA (In: Studies in Crenobiology the Biology of Springs and Springbrooks, Ed. L. Botosaneanu) – Backhuys Publishers, Leiden, 39–48.

Williams D.D, Williams N.E., Cao Y. 1997 – Spatial differences in macroinvertebrate community structure in springs in southeastern Ontario in relation to their chemical and physical environments – Can. J. Zool. 75: 1404–1414.

Wojtas F. (ed.) 1972 – Hydrobiologia. Fauna Niebieskich źródeł. [Hydrobiology. Fauna of the Niebieskie Źródła springs] – Zesz. Nauk. Uniw. Łódz., Nauki Mat-Przyr. Ser.II, 46: 1–115. (in Polish).

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