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Odonata, Trichoptera, Coleoptera, and Hydrachnidia of springs in Kazimierski Landscape Park (Eastern Poland) and factors affecting the characters of these ecosystems

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Abstract – Spatial distribution and fauna composition of selected arthropod taxa were studied in 8 springs of the Kazimierski Landscape Park (SE Poland). Collected were: 12 species of water mites, 47 of water beetles, and 18 of caddisflies. Imagines of 10 dragonfly species were also observed. A great faunistic individuality of the springs was found, probably resulting from habitat diversity in the springs and from external factors, as, e.g. migrations from neighbouring biotops. Those factors are of different importance in various arthropod taxa.

Key words: Odonata, Coleoptera, Trichoptera, Hydrachnidia, spatial distribution, springs, Poland, habitat island.

1. Introduction

Springs are a particularly interesting habitat of invertebrates. Low and usually stable temperature creates optimal conditions for stenothermal cold-water organisms. Persistence and stability of habitat conditions are considered to be the reason for variety and diversity of species in the springs (Erman and Erman 1990). Groups of organisms living in the springs are very often highly specific. On the other hand, this situation is disturbed by external conditions, including natural migrations of non-specific species from other biotops. In the qualitative content of the fauna of springs the part constituted by crenobiontes is usually small in comparison with crenophiles and crenoxenes; moreover, great faunistical individualism of particular objects can be observed (Biesiadka et al. 1990, Biesiadka and Kowalik 1978, 1999, Cichocka 1999, Czachorowski 1990, 1999*a*, Czachorowski et al. 1993, Erman and Erman 1990, Khmeleva et al. 1994, Tończyk et al. 2000). Hence, the following question arises: in what degree spring biocenosis is affected by fauna migrating from neighbouring biotops and what is the role of anthropopressure. From this point of view, springs are interesting as examples in ecological investigations of heterogeneous habitats.

The aim of the research was mainly to analyse the effect of these conditions. At the same time, collected materials constitute an important contribution to the cataloguing of fauna of invertebrates in Polish springs, the knowledge concerning which is far from satisfactory.

2. Study area

The springs under scrutiny are localised in the western part of the Lublin Upland, between Wąwolnica and Kazimierz (51°15'–51°21' N, 21°51'–22°08' E). This is an area covered by a thick loess layer and dominated by arable land (over 70% of the area). The network of surface waters is poor. The whole area is situated in the Vistula drainage basin; the main river is the Bystra. The characteristic feature of the earth's sculpture is a deep cleft in the surface: loess ravines are 3 km/km^2 long, on average, maximally over 10 km/km^2, this resulting in a great number of springs (Wilgat 1992).

The research comprised 8 spring areas (Fig. 1):

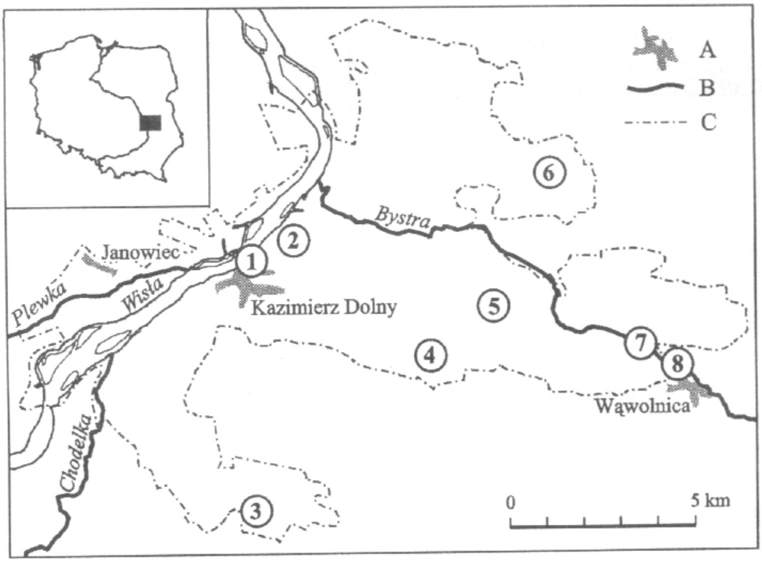

Fig. 1. Study area. A – larger villages, B – running waters, C – border of the Kazimierski Landscape Park, D – investigated springs (1 – Kazimierz Dolny; 2 – Parchatka; 3 – Rogów; 4 – Rzeczyca; 5 – Witoszyn; 6 – Stary Stok; 7 – Mareczki; 8 – Wąwolnica).

1. Kazimierz Dolny – two small helocrenes in dry-ground forest; the spring and a stream without hydrophytes, with thick detritus (leaves, parts of bark, branches); the stream with loess bottom, temporarily dry. A small reocrene at the foot of the ravine, not connected hydrologically with the first spring was also studied.

2. Parchatka – a small helocrene in dry-ground forest; the spring and a stream as in locality No 1.

3. Rogów – vast spring of the Jaworzanka River, in two ravines (eastern and western), with multiple springs of various kind situated along the stream; the stream with sandy or sandy and stony bottom, in places with thick detritus.

4. Rzeczyca – situated in a row, highly efficient reocrenes at the foot of a loess slope. They feed basins at the foot of the slopes and the outflowing streams with sandy bottoms overgrown with *Veronica beccabunga* L.

5. Witoszyn – a large helocrene (a surface of over 200 m^2) with a short outflow to the stream; spring with rich flora dominated by *V. beccabunga*, outflow without flora, clay bottom with thick detritus.

6. Stary Stok – a single reocrene, feeding constantly flowing small stream with sandy and stony bottom; spring and stream without flora.

7. Mareczki – highly efficient outflows (three reocrenes and a single reolimnocrene and reohelocrene) and at the foot of a loess slope; the springs and a stream as in locality No 4.

8. Wąwolnica – about ten highly efficient reocrenes at the foot of a loess slope; the springs and stream as in locality No 4.

The springs in Parchatka and Kazimierz Dolny and the eastern part of the spring in Rogów were situated in narrow, deep, ravines overgrown by dry land forest. Also the spring in Wąwolnica was shaded by forest growing on the slope. Helocrene in Witoszyn was situated in wet forest. The remaining of the springs were situated in the open area.

All the studied springs drained chalk rocks, this resulting in a great amount of calcium ions (Michalczyk 1993). The temperature in springs with crevice outflows was low and stable, in helocrenes changing considerably. Fluctuations of temperature in springs depended on its value in outflows and were slightly higher than in the springs. The content of dissolved oxygen was lowest in springs of high efficiency. In springs of low efficiency, with longer water retention time, the temperature in outflows reached higher values (Table I).

Table I. Some features of water in the studied springs (average values in brackets). Localities as in Fig. 1. Cap. – capacity [l s^{-1}] (after Michalczyk 1993), Temp. – temperature [°C], Cond. – conductivity [μS cm^{-1}], O_2 – dissolved oxygen [mg l^{-1}], l.d. – lack of data.

Site	Cap.	Zone	Temp.	pH	Cond.	O_2
1	<0.1	helocrene	9.7–14.6 (11.9)	7.35–7.65 (7.49)	395–676 (488)	3.56
		stream	9.7–15.6 (12.9)	7.14–7.94 (7.56)	574–702 (603)	7.05
2	<0.1	helocrene	8.1–16.8 (12.1)	6.98–7.60 (7.28)	756–1103 (904)	1.21
		stream	10.4–15.6 (13.2)	7.14–7.74 (7.44)	404–992 (701)	6.13
3a	8.7	reocrenes (W)	8.6–8.7 (8.7)	7.30–7.46 (7.41)	458–529 (491)	3.79
		stream (W)	8.7–9.1 (8.9)	7.22–7.47 (7.35)	598–536 (511)	5.13
3b	10.1	reohelocrene (E)	10.2–15.7 (13.8)	7.57–7.95 (7.72)	425–468 (441)	6.37
		reocrene (E)	9.3	7.17	440	l.d.
		reohelocrene (E)	9.6–17.3 (12.6)	7.88–8.36 (8.06)	283–730 (472)	7.83
		reolimnocrene (E)	8.9–9.4 (9.2)	7.57–7.66 (7.62)	323–395 (370)	5.54
		stream (E)	9.3–10.1 (9.6)	7.82–8.02 (7.91)	329–388 (364)	9.58
4	7.8	outflows	8.4–8.6 (8.5)	7.25–7.52 (7.41)	507–537 (522)	5.54
		reservoir	9.4–10.8 (9.9)	7.41–7.54 (7.48)	504–543 (518)	7.12
		stream	9.1–11.1 (9.9)	7.44–7.59 (7.53)	483–518 (505)	8.06
5	1.4	helocrene	8.8–11.7 (10.5)	7.35–7.65 (7.53)	554–590 (571)	7.74
		stream	9.70–10.7 (10.2)	7.45–7.67 (7.56)	553–594 (577)	7.45
6	0.2	reocrene	8.1–8.2 (8.1)	7.05–7.34 (7.18)	572–708 (599)	6.70
		stream	8.8–9.9 (9.2)	7.12–7.53 (7.32)	433–736 (633)	8.04
7	23.3	outflows – reocrenes	8.6–8.8 (8.7)	7.07–7.37 (7.29)	627–663 (642)	5.95
		outflow – reohelocrene	8.5–11.6 (9.5)	7.12–7.46 (7.34)	559–702 (649)	5.09
		outflow – reolimnocrene	8.4–8.6 (8.5)	7.19–7.39 (7.27)	625–686 (665)	l.d.
		reocrene – reservoir	8.6–8.8 (8.7)	7.16–7.37 (7.29)	621–690 (652)	5.13
		stream	8.4–9.0 (8.7)	7.15–7.42 (7.27)	383–682 (685)	5.74
8	51.2	outflows	8.6–8.8 (8.7)	7.08–7.26 (7.20)	620–684 (649)	3.54
		reservoir	8.3–8.9 (8.6)	6.96–7.28 (7.18)	645–728 (684)	3.40
		stream	8.6–8.8 (8.7)	7.14–7.49 (7.31)	577–651 (619)	4.34

3. Materials and methods

The materials were collected in 1997 (every month from April till October) and in 1998 (in April and June). Qualitative samples were collected by means of a hydrobiological scoop. Separate samples were collected in different places of eucrenal (different types of outflow, springs near outflows) and hypocrenal (streams 20–30 m below the springs). For dragonflies, observations of imagines were also conducted. Single specimens were collected by means of an entomological net.

Altogether, 196 scoop samples were collected, in which were found 1148 Trichoptera larvae and pupae, 252 Coleoptera larvae and imagines, and 1302

Hydrachnidia adults and deutonymphs. Odonata larvae did not occur in the springs; 17 imagines were collected as proof material.

In analysing faunistic similarities between the species the Biodiversity programme, qualitative formula (of Jaccard) and quantitative formula (of Bray-Curtis) were used.

Naturality of spring fauna was analysed on the basis of Trichoptera, using Fischer's formula (1996) modified by Czachorowski (Czachorowski and Buczyński 1999). The authors calculated two ratios: qualitative (Wns) and quantitative (Wni):

$$Wns = \frac{\sum Wze_i}{s}; \qquad Wni = \frac{\sum Wze_i\, n_i}{N}$$

where: Wze_i – index of environmental significance of the species i; s – number of all species; n_i – number of specimens of the species i; N – number of all specimens.

The classification of Trichoptera species specificity for springs was adopted from Czachorowski (1999*b*).

The authors systematically measured: water temperature – using a Slandi TC204 thermometer, pH – with a Slandi PH204 pH-meter and electrical conductivity – with a Slandi CM204 conductometer. Once (in April 1997) the amount of dissolved oxygen was measured – using a Hanna Instruments HI9143 dissolved oxygen meter.

4. Results

4.1. Characteristics of particular taxa

In scoop samples 77 species and 3 taxa not designated as species were found. Also found were imagines of 10 species of dragonflies (Tables II, III). The least specific for the springs were communities of Odonata (from taxa collected directly from the springs – Coleoptera) and the most – Hydrachnidia.

Coleoptera were represented by 47 species (Table II). Eighteen of them had not been found in other springs in Poland (Pakulnicka 1999). They do not belong to fauna specific for springs. Only 4 of the collected species are crenobiontes and crenophiles (*Hydroporus discretus*, *Agabus biguttatus*, *A. guttatus*, *Limnebius truncatellus*). Species of wide ecological occurrence were more numerous – they were caught in still and flowing waters (14 species), eurytops and stagnophiles that can be found in water-courses and springs (19 species), reo- and crenoxenes (8) and flowing water species (3) were fewer (Galewski and Tranda 1978, Klausnitzer 1996).

Eighteen species of *Trichoptera* were found (Table II). *Apatania muliebris*, *Beraea pullata*, *Potamophylax nigricornis*, *Micropterna sequax*, and *M. lateralis* can be classified as crenobiontes and crenophiles. *Ironoquia dubia* prefers temporarily drying flowing waters, this being a good indicator of drying springs. The rest of the species are typical of rhitral or temporary still waters (*Limnephilus auricula*, *L. griseus*).

Hydrachnidia were represented in 12 species (Table II). Half of them are taxa specific for springs, including the most numerous species: crenobiontes (*Sperchon squamosus*, *S. thienemanni*, *Lebertia stigmatifera*) and stagnophile crenophiles (*Lebertia dubia*, *L. slovenica*, *Arrenurus cylindratus*) (Biesiadka and Kowalik 1978).

Odonata larvae were not found. Imagines representing 10 species were rarely observed and occurred only accidentally (Table III). In four of them were observed

Table 2. *continued*

	Taxon	Site								N	Ns	
		1	2	3	4	5	6	7	8		Eu	Hp
38.	*L. bipunctatus* (Fabr.)			x			x	x		3	2	1
39.	*Helochares obscurus* (Müll.)					x		x		4	2	2
40.	*Enochrus affinis* (Thunb.)							x		1	1	–
41.	*E. melanocephalus* (Oliv.)								x	1	–	1
42.	*E. quadripunctatus* (Herbst)								x	1	–	1
43.	*Cimbiodyta marginella* (Fabr.)				x					1	1	–
44.	*Hydrobius fuscipes* (L.)			x	x	x		x	x	13	6	–
45.	*Hydrochara caraboides* (L.)								x	1	–	1
46.	*Coelostoma orbiculare* (Fabr.)	x							x	6	–	3
47.	*Cercyon tristis* (Ill.)						x			1	–	1
	<u>*Trichoptera*</u>											
48.	*Plectronemia conspersa* (Curt.)				x	x	x	x		29	6	7
49.	*Lype reducta* (Hag.)					x		x		3	–	3
50.	*Beraea pullata* (Curt.)	x						x		44	9	–
51.	*Apatania muliebris* McL.							x	x	218	12	5
52.	*Ironoquia dubia* (Steph.)		x							2	–	1
53.	*Anabolia furcata* Brau.				x	x				3	2	2
54.	*Limnephilus auricula* Curt.				x					2	–	1
55.	*L. extricatus* McL.				x			x	x	37	6	–
56.	*L. griseus* (L.)				x					1	2	–
57.	*L. lunatus* Curt.				x		x	x	x	33	7	13
58.	*L. fuscicornis* (Ramb.)?				x					2	1	–
59.	*Chaetopteryx villosa* (Fabr.)			x	x	x	x	x	x	702	42	25
60.	*Potamophylax cingulatus* (Steph.)	x								1	1	–
61.	*P. latipennis* (Curt.)								x	1	1	–
62.	*P. luctuosus* (Pill.)						x			1	1	–
63.	*P. nigricornis* (Pict.)			x			x	x	x	60	14	7
64.	*Micropterna lateralis* (Steph.)					x				1	–	1
65.	*M. sequax* McL.						x			2	1	1
–.	*Limnephilidae* n.det.			x		x				6	1	1
	<u>*Hydrachnidia*</u>											
66.	*Hydryphantes planus* Thon				x					1	1	–
67.	*Panisus michaeli* Koen							x		1	1	
68.	*Thyas pachystoma* Koen.							x		3	2	1
69.	*Sperchon squamosus* Kram.				x			x		30	5	2
70.	*S. thienemanni* Koen.			x						4	–	1
71.	*Lebertia dubia* Thor				x					2	–	2
72.	*L. lineata* Thor					x				1	–	1
73.	*L. slovenica* Laska				x	x		x	x	1243	19	12
74.	*L. stigmatifera* Thor				x	x				6	1	2
75.	*Hygrobates fluviatilis* (Ström)					x		x		4	1	2
76.	*Arrenurus cylindratus* Piers.				x	x				6	3	2
77.	*A. tubulator* (Müll.)					x				1	–	1
	Total number of speciments / samples:									2702	100	96

Table 2. *continued*

	Taxon	Site								N	Ns	
		1	2	3	4	5	6	7	8		Eu	Hp
38.	*L. bipunctatus* (Fabr.)			x			x	x		3	2	1
39.	*Helochares obscurus* (Müll.)					x		x		4	2	2
40.	*Enochrus affinis* (Thunb.)							x		1	1	–
41.	*E. melanocephalus* (Oliv.)								x	1	–	1
42.	*E. quadripunctatus* (Herbst)								x	1	–	1
43.	*Cimbiodyta marginella* (Fabr.)				x					1	1	–
44.	*Hydrobius fuscipes* (L.)			x	x	x		x	x	13	6	–
45.	*Hydrochara caraboides* (L.)								x	1	–	1
46.	*Coelostoma orbiculare* (Fabr.)	x							x	6	–	3
47.	*Cercyon tristis* (Ill.)						x			1	–	1
	<u>*Trichoptera*</u>											
48.	*Plectronemia conspersa* (Curt.)				x	x	x	x		29	6	7
49.	*Lype reducta* (Hag.)					x		x		3	–	3
50.	*Beraea pullata* (Curt.)	x						x		44	9	–
51.	*Apatania muliebris* McL.							x	x	218	12	5
52.	*Ironoquia dubia* (Steph.)		x							2	–	1
53.	*Anabolia furcata* Brau.				x	x				3	2	2
54.	*Limnephilus auricula* Curt.				x					2	–	1
55.	*L. extricatus* McL.				x			x	x	37	6	–
56.	*L. griseus* (L.)				x					1	2	–
57.	*L. lunatus* Curt.				x		x	x	x	33	7	13
58.	*L. fuscicornis* (Ramb.)?				x					2	1	–
59.	*Chaetopteryx villosa* (Fabr.)			x	x	x	x	x	x	702	42	25
60.	*Potamophylax cingulatus* (Steph.)	x								1	1	–
61.	*P. latipennis* (Curt.)								x	1	1	–
62.	*P. luctuosus* (Pill.)						x			1	1	–
63.	*P. nigricornis* (Pict.)			x			x	x	x	60	14	7
64.	*Micropterna lateralis* (Steph.)					x				1	–	1
65.	*M. sequax* McL.						x			2	1	1
–.	*Limnephilidae* n.det.			x		x				6	1	1
	<u>*Hydrachnidia*</u>											
66.	*Hydryphantes planus* Thon				x					1	1	–
67.	*Panisus michaeli* Koen							x		1	1	
68.	*Thyas pachystoma* Koen.							x		3	2	1
69.	*Sperchon squamosus* Kram.				x			x		30	5	2
70.	*S. thienemanni* Koen.			x						4	–	1
71.	*Lebertia dubia* Thor				x					2	–	2
72.	*L. lineata* Thor					x				1	–	1
73.	*L. slovenica* Laska				x	x		x	x	1243	19	12
74.	*L. stigmatifera* Thor				x	x				6	1	2
75.	*Hygrobates fluviatilis* (Ström)					x		x		4	1	2
76.	*Arrenurus cylindratus* Piers.				x	x				6	3	2
77.	*A. tubulator* (Müll.)					x				1	–	1
	Total number of speciments / samples:									2702	100	96

Table III. Adult Odonata observed at studied springs. Localities as in Fig. 1. * – breeding was observed.

Species	Site							
	1	2	3	4	5	6	7	8
1. *Sympecma fusca* (Vander L.)								x*
2. *Lestes sponsa* (Hansem.)								x
3. *Coenagrion puella* (L.)				x				
4. *Aeshna cyanea* (O.F. Mull.)				x*				
5. *A. mixta* Latr.				x				
6. *Libellula depressa* (L.)				x				
7. *Sympetrum danae* (Sulz.)				x*				
8. *S. flaveolum* (L.)				x*			x	
9. *S. sanguineum* (O.F. Müll.)				x*			x	
10. *S. vulgatum* (L.)	x			x*				

reproductive territoriality and/or laying eggs – over the reservoir near the springs in Rzeczyca (station 4) and the stream in Wąwolnica (station 8). In both cases in the neighbourhood could be found ponds or drainage ditches where these species were developing and created multiple populations. Species of *Sympetrum* genus were laying eggs most often, including *S. flaveolum*. Although places where eggs were laid were thoroughly penetrated, their larvae were not found.

4.2. Fauna of particular springs

Excluding dragonflies, in particular springs from 6 to 22 species were found, most at stations 4, 3, and 7, quite a number in 5 and 8, and the fewest in 2, 1 and 6 (Table II). Species found in particular taxa were different. The greatest number of beetles was found at station 1, relatively many of them at stations 8, 4 and 7, and the fewest at 6, 2, and 5. The greatest number of caddies-fly species was found at stations 7, 4, 6, 5, and 8, while the smallest at 2, 1, and 3. The greatest numbers of water-mite species were found at stations 5, 4, and 7 (they were not found at stations 6, 2, and 1 at all).

The highest ratio of naturality was characteristic of stations 1 and 8, and relatively high also of station 3. Average values were observed at stations 7 and 6, very low at 4 and 5, and the lowest at 2.

Taking into consideration naturality ratios and species variety of all groups, the springs under scrutiny can be divided into five types:

- type I: station 2 – poor in fauna, with very much changed fauna (Wze=1, Wni=1); underwent strong anthropopressure; of low efficiency,
- type II: station 1 – poor in fauna; of high fauna naturality (Wne=10, Wni=14); did not undergo anthropopressure; of low efficiency,
- type III: station 3 – species variety of beetles; average fauna naturality (Wne=9, Wni=6,29); small anthropopressure; of average efficiency,
- type IV: station 6 – species variety of caddis-flies; relatively low naturality (Wne=5, Wni=4,94); strong anthropopressure (the stream polluted and treaded over by cattle, but the spring itself untouched); of low efficiency,
- type V: stations 4, 5, 7, 8 – rich caddies-flies fauna (always in quantity, not always in quality); rich water-mite fauna; faunistic distortions were diversified, respectively: Wne=2,14 Wni=2,04 (station 4); Wne=5,33 Wni=2,77 (station 5); Wne=7,38 Wni=4,98 (station 7); Wne=4,6, Wni=12,7 (station 8).

4.3. Analysis of faunistic similarities

4.3.1. Hydrachnidia

Faunistic similarities in quality view were found in grouping according to stations (eu- and hypocrenal next to each other) and according to the spring's zone (Fig. 2). For example, taking into consideration faunistic similarities can be noted groups of: eu- and hypocrenal of station 8 and eucrenal of station 7 (over 50%); eu- and hypocrenal of station 7 (over 50%, the two groups join on a level of about 25%), a pair of eu- and hypocrenal of station 4 (over 50%) with hypocrenal of station 5 (about 25%). The hypocrenal of station 3 was the most faunistically different.

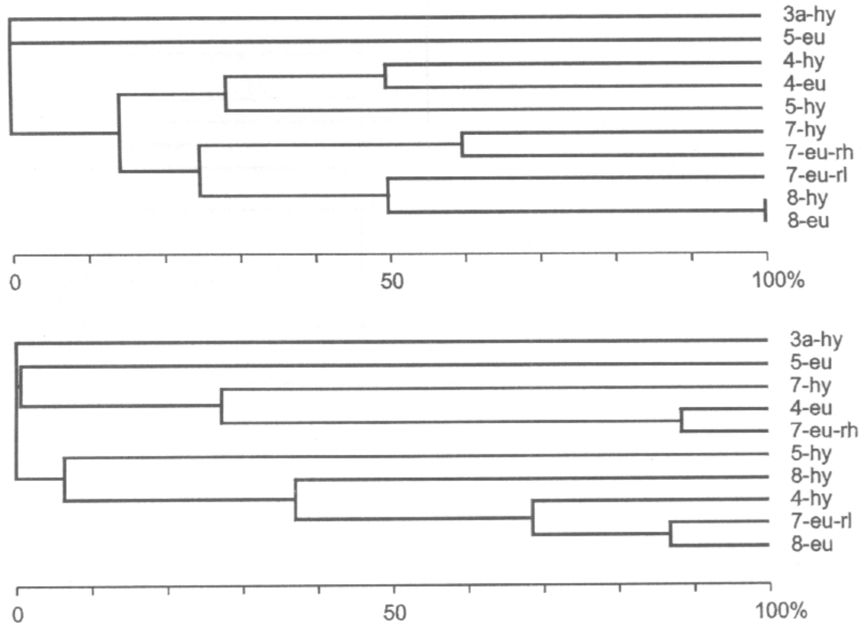

Fig. 2. Dendrogrames of qualitative similarities (upper) and quantitative similarities (lower) between studied springs, based on water mites (in % of faunistic similarity). 1–8 – springs studied (as in Fig. 1.); eu – eukrenal, hy – hypokrenal; rh – reohelocrene, rl – reolimnocrene.

Taking into consideration quantitative similarities were found weaker grouping according to station but visibly in accordance with habitat (Fig. 2). The greatest similarities (over 80%) were found between fauna of eucrenals of stations 7 and 8 and eucrenals of stations 7 and 4. The other pair is joined by hypocrenal of station 7 (about 25%), the first being joined by hypocrenal of stations 4 (about 70%) and 8 (about 40%), further by hypocrenal of station 5 (about 10%), reflecting biotop changes in oblong profile. The most faunistically different was the hypocrenal of Rogów.

In a dendrogram of qualitative similarities, eucrenal was the most conspicuous. Fewer similarities between faunas marked in quantitative formula reflect the presence of less specific species and at least partly result from migration from neighbouring biotops. Clearer distinction of the eucrenal zone in quantitative formula, strongly emphasising the presence of specific species, points to the important role of biotop conditions in creating water-mite fauna. The eucrenal type is important, as well as the differentiation of habitat of oblong profile (eucrenal, hypocrenal). Water mites indicate – best from analysed taxa – biotop changes in oblong profile, as organisms considerably less able to active dispersion (inability to fly, small size) and at the same time the most specialized.

4.3.2. Trichoptera

In a dendrogram of qualitative similarities fauna groupings were in accordance with stations, hence the distance between analysed objects was more important than their habitat characteristic (Fig. 3). The greatest similarities (100%) were characteristic of communities of eu- and hypocrenal of the eastern and western parts of the spring system in Rogów (station 3). In dendrite they are joined by the

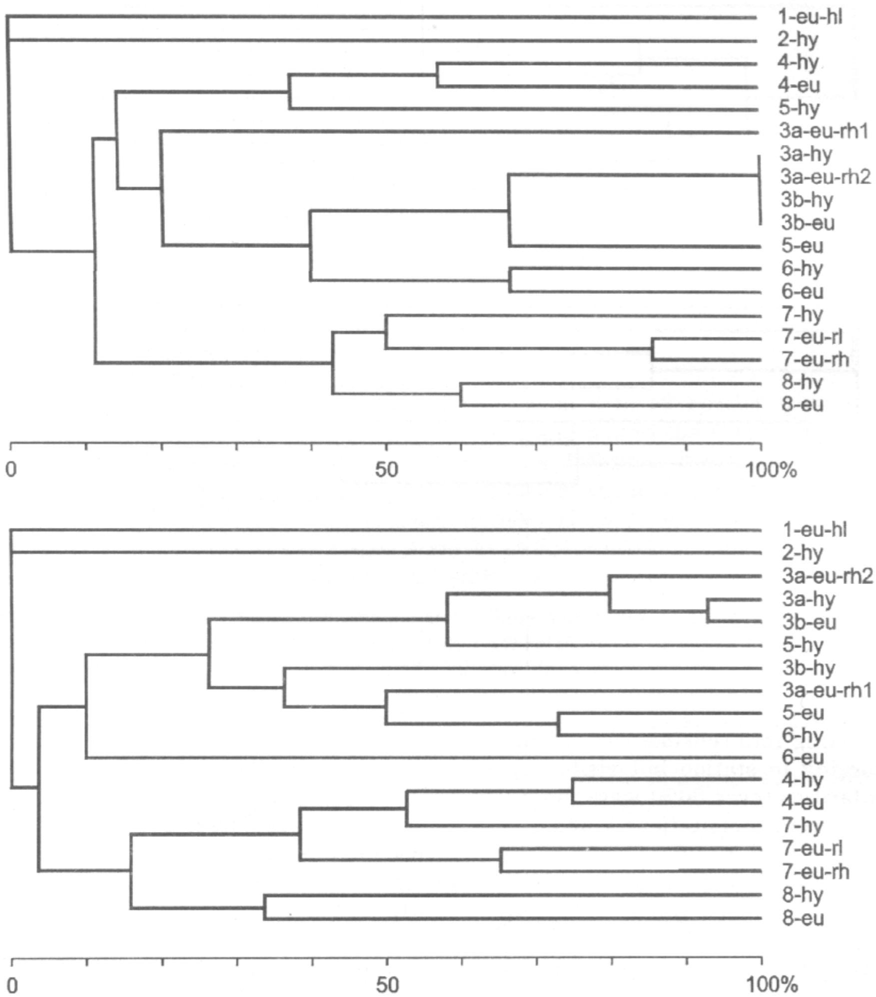

Fig. 3. Dendrogrames of qualitative similarities (upper) and quantitative similarities (lower) between studied springs, based on caddisflies (in % of faunistic similarity). 1–8 – springs studied (as in Fig. 1.); eu – eukrenal, hy – hypokrenal; hl – helocrene, r – reocrene, rh – reohelocrene (in Rogów-West: rh1 – at the beginning of the spring system, rh2 – at half of it), rl – reolimnocrene.

eucrenal of station 5 (60%). The second pair is eu- and hypocrenal at station 6 (about 60%), joining the previous pair on the level of 40%. Other pairs are eu- and hypocrenal of station 4 (above 50%) and joining them hypocrenal of station 5 (about 40%). Other conspicuous group are: eu- and hypocrenal of station 8 (above 55%), both eucrenals of station 7 (about 80%), joined by of station 7 (about 50%), those joining eucrenal of station 8 on the level of about 40%. In a dendrite of faunistic similarities can clearly be seen groups of habitat types and neighbourhood, though not so clearly as in the case of water mites: stations 7 and 8 – group 1, stations 3, 5, 6 – group 2, and stations 4, 6 – group 3. Groups 2 and 3 turned out to be more faunistically compact than group 1. The smallest similarities were seen between hypocrenal of station 2 and eucrenal of station 1.

In a dendrogram of quantitative similarities the situation appeared to be similar. The most conspicuous is part of springs of Rogów (station 3), Stary Stok (6), and Witoszyn (5), while in the other group there are springs of Rzeczyca (4), Mareczki (7), and Wąwolnica (8) (Fig. 3).

In stations' division based on caddies-flies, the eu- and hypocrenal parting was not clear. The connection between fauna and distance between eu- and hypocrenal, and particular springs, was only partially visible. It was possible to distinguish three faunistic station types. The richest fauna (taking into consideration the number of species and the presence of crenobiontes and crenophiles) was found at stations 8, 4, and 7, i.e. those of high efficiency and those which are near forested slope and open area. The caddis-fly faunas of stations 3, 5, and 6 were poorer in terms of species and less specific because their surroundings are forested with visible anthropopressure; the latter two are also of low efficiency. The poorest fauna was found at stations 1 and 2 – of very low efficiency and strong anthropopressure and temporarily drying, this being well illustrated by the presence of *Ironoquia dubia*. It points out that the richness of trichopterofauna – as different from water mites – was determined by biotop spring differentiation, resulting from immediate surroundings in the first degree. Caddies-flies are better able to disperse; many of them eat detritus so they are dependent on dead organic matter.

4.3.3. Coleoptera

In a dendrogram of qualitative similarities, we could clearly see grouping according to station type: eucrenal and hypocrenal separately (Fig. 4). Strong relationship between eu- and hypocrenal of stations 1 and 7 has been observed in one station only. In quantitative formula (Fig. 4) can clearly be seen greater faunistic similarities between zones of one spring only at station 7. There were more separate eucrenals and hypocrenals (concluding that in both cases there were several faunistic types). In one third of cases, eu- and hypocrenal of different stations were grouped. It may be concluded that in a greater degree it is the effect of accidental migrations and the presence of non-specific species rather than biotop similarities. In the case of eucrenal, could be observed partial differentiation between hydrological types of springs: reocrene and helocrene.

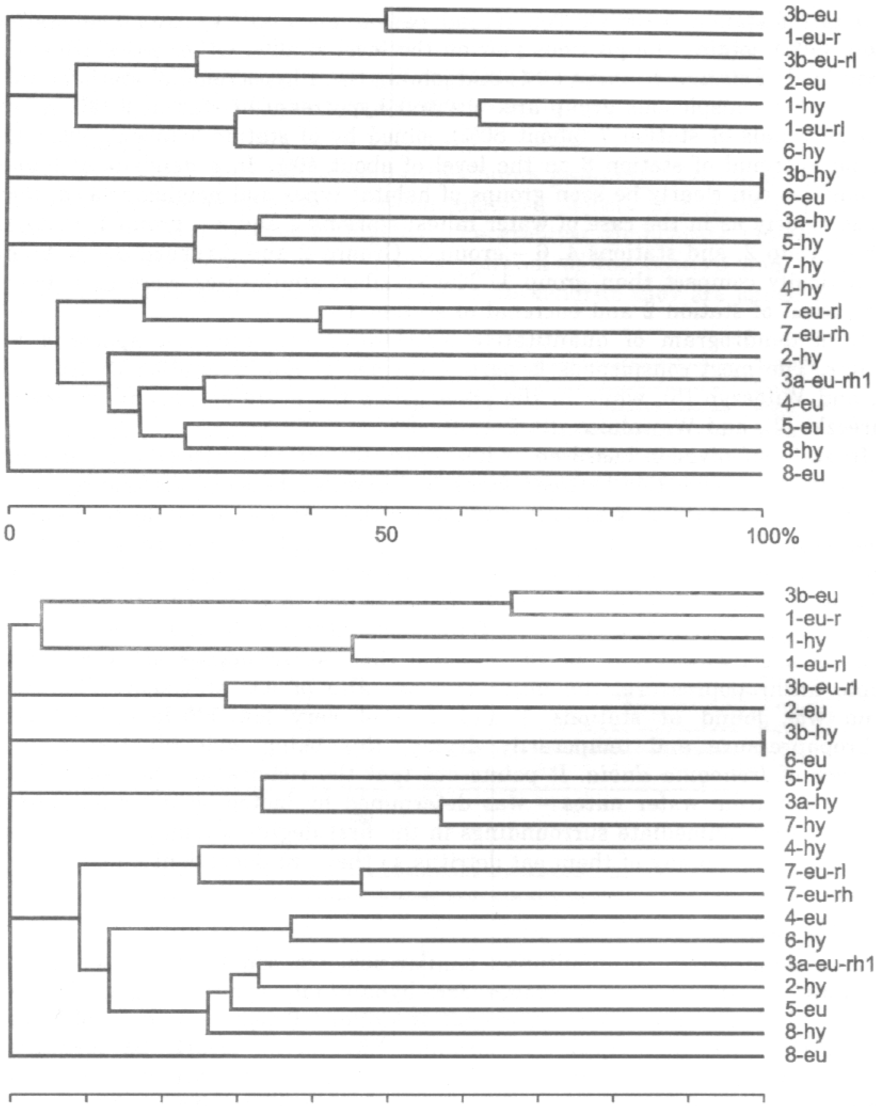

Fig. 4. Dendrogrames of qualitative similarities (upper) and quantitative similarities (lower) between studied springs, based on beetles (in % of faunistic similarity). 1–8 – springs studied (as in Fig. 1.); eu – eukrenal, hy – hypokrenal; hl – helocrene, rh – reohelocrene (in Rogów-West: rh1 – at the beginning of the spring system, rh2 – at half of it), rl – reolimnocrene.

4.3.4. All taxa together

In a dendrogram based on qualitative formula, fauna grouping according to the biotop neighbourhood was more visible (Fig. 5). In quantitative formula, stressing the importance of specific species, grouping according to biotop type (eu- and hypocrenal with different kinds) was clearer but only partially in accordance with stations (Fig. 5).

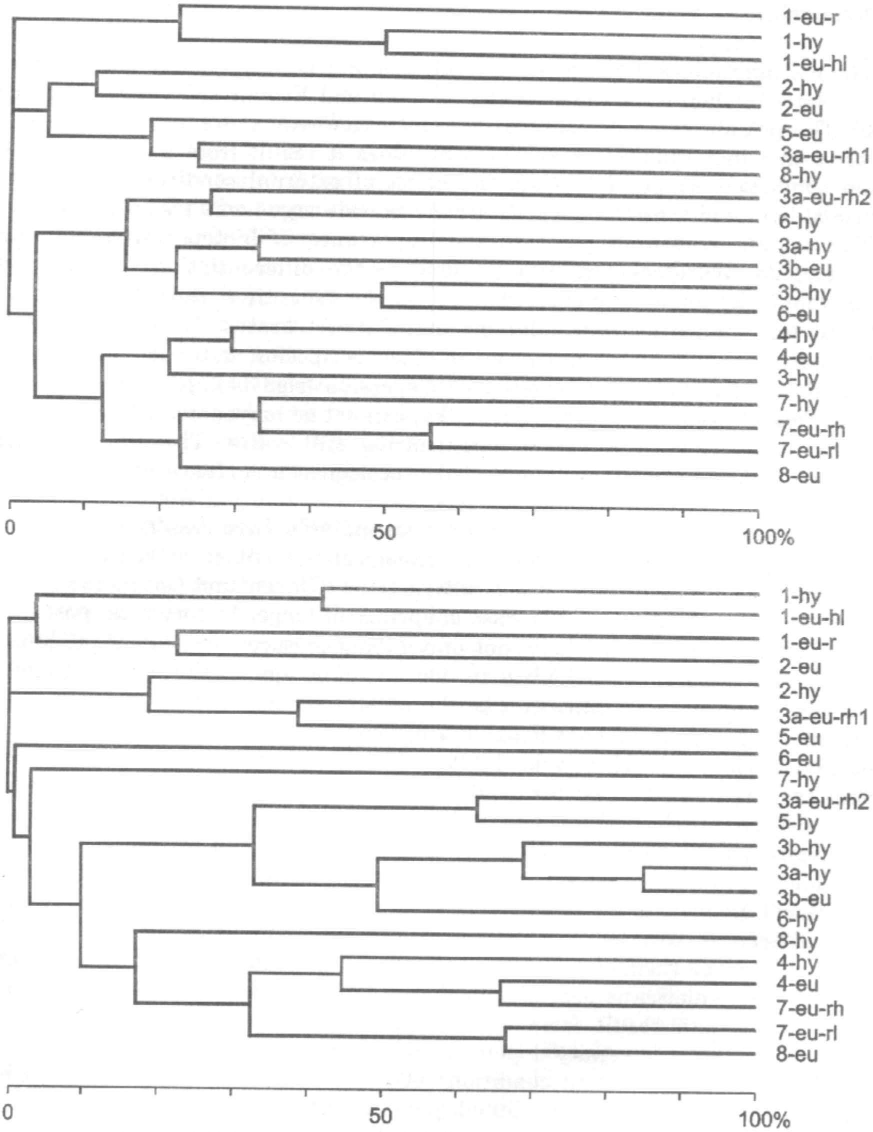

Fig. 5. Dendrogrames of qualitative similarities (upper) and quantitative similarities (lower) between studied springs, based on all taxa (in % of faunistic similarity). 1–8 – springs studied (as in Fig. 1.); eu – eukrenal, hy – hypokrenal; hl – helocrene, rh – reohelocrene (in Rogów-West: rh1 – at the beginning of the spring system, rh2 – at the half of it), rl – reolimnocrene.

Grouping of zones and stations based on the whole fauna is the resultant of different effects of particular groups. Separate analysis showed that different conditions affect every group of arthropod studied. This partially results from a different amount of crenobiontes, crenophiles, and crenoxenes in each of them. The ability to disperse and dispersion type – only by water, and also by air (insects) can also be of importance here.

5. Discussion

The considerable individualism of spring fauna has previously been discussed quite a lot (Czachorowski 1999*a*, 1999*b*, Erman and Erman 1990, Myers and Resh 1996). The present research confirms that fact. However, there arises a question as to: what this individualism results from – does it result from a great variety of biotop conditions or possibly from the effect of external conditions? The results presented here and considerable bibliography provide arguments for both possibilities.

The results presented point to the importance of biotop conditions: spring efficiency, its hydrobiological type, oblong profile differentiation (eu- and hypocrenal zone), the immediate surroundings. At the same time, these conditions have different importance for particular groups of invertebrates. It may be connected with their biology (type of nutrition: predacious species, detritus-eating species), life-history cycles and the possibility of dispersion from biotops neighbouring the spring. Part of organisms migrate from hypocrenal or maybe even from epirhitral, others may migrate by air from neighbouring still water. The ability of active dispersion seems to be important but also ecological occurrence of colonists is of significance.

Research conducted so far show that great individualism results from a variety of the biotop of particular springs and ecological occurrence of species available rather than from strong inter-species interactions (Glazier and Gooch 1987). These can have an important role in the case of springs of longer history than post-glacial (Myers and Resh 1996). In short, not only biotop features are important but also the presence of potential colonists in the surroundings of the spring. Colonists' dispersion could be more important in the case of springs more often disturbed.

In the caddies-flies fauna of Polish springs can be seen clear differences between particular regions (Czachorowski 1999*a*). The similarity of Polish and German springs was estimated to be about 40% taking into account a similar number of species (Czachorowski 1999*b*). Great differences were observed between eastern and western parts of Canada (Williams 1991, Williams and Williams 1996) or in north-south gradient in North America (Danks and Williams 1991). The geographical element is important only on a greater scale (Khmeleva et al. 1994). These differences can be interpreted as the effect of different availability of colonists. Some of them result from differences in climate. For example, spring fauna of North America is poorer than that of South America (Danks and Williams 1991) – which can result from less favourable climate, the disturbing role of glaciations, or biotop diversity dependent on climate.

So far, many environment conditions affecting the fauna of springs have been distinguished: climate, altitude, limnological spring type, strength and stability of the flow, surface features, water temperature, flora surrounding the spring, migrations from biotops neighbouring the spring, dispersion abilities of the species, present and former obstacles in migration (Bonettini and Cantonati 1996, Czachorowski 1999*a*, 1999*b*, Danks and Williams 1991, Gerecke and Sabatino 1996, Khmeleva et al. 1994, Myers and Resh 1996, Williams 1991, Williams and Williams 1996). The importance of these conditions can be different for different groups of invertebrates. For example, species variety of Trichoptera is correlated with Ca, Mg, pH, and sun exposure (Danks and Williams 1991, Erman and Erman 1990). Spring communities dominated by insects connected with low pH and sandy bottom, other groupings (including those dominated by Crustacea) are connected with other biotop conditions, e.g. mouldy bottom, algae occurrence, etc. The majority of groupings are dependent on specific physical and chemical features of the environment and on flora (Danks and Williams 1991, Glazier and Gooch 1987). Springs of high biotop variety are characterized by a greater number of species (Danks and Williams 1991, Moretti et al. 1996). Moreover, stable biotops have more species and are dominated by Crustacea. Insects, on the other hand, dominate more changeable biotops (Danks and Williams 1991). In that case, the ability to disperse – greater in insects able to fly – may decide concerning the possibility of colonizing those springs that are isolated and disturbed at different times. A similar situation was observed in other heterogeneous water habitats – in temporary pools (Czachorowski and Szczepańska 1991).

Species variety can also be determined by outflow speed and limonological spring type, which is dependent on the fact that: limnocrenes are inhabited by more species preferring lenitic biotops, reocrenes – coming from springs (Bonetti and Cantonati 1996, Danks and Williams 1991). It may be connected with ecological characteristics of potential colonists. Helocrenes are inhabited by more species connected with thin water membrane, spring reservoirs, and more fauna of benthos type inhabits outflows (Danks and Williams 1991). Running water species have better possibilities of colonizing springs, thanks to their immediate neighbourhood. Imagines and larvae can migrate (Erman 1986).

The data obtained emphasise the connection between spring fauna and biotop diversity of the springs themselves. In dendrite similarities could be distinguished several groups of eucrenal zone, which suggests the existence of springs' types, which are different in terms of biotop but similar in terms of hydrology. In the case of caddies-flies, the effect of surroundings was very clear. The presence or lack of trees affect exposure to the sun (which in turn affects the temperature and trofic base for algae), the influx of different tree detritus (deciduous, coniferous trees), and flora.

An additional factor affecting the spring fauna biodiversity can be the degree of anthropopressure. For example, water-mite fauna of Miechowska Upland – relatively strongly changed anthropogenically – was characterized by small participation of crenobiontes but was dominated by crenophiles (Biesiadka et al. 1990). In the Alpine springs, where human activity had less impact, 80% of Hydrachnidia was constituted by crenobiontes (Crema et al. 1996).

In the springs studied, it could be seen that the closer was the spring situated to the Vistula, the poorer was its fauna. It is most probably an accidental and incidental dependence. The springs situated near the Vistula were less efficient and in the forest, those further from the Vistula and more efficient with forested slope and in the open area. That means they had better sun exposure, with a great supply of detritus and were more varied structurally. In conclusion, the original factor regulating fauna species variety would be biotop characteristics. Anthropopressure had the greatest influence on its naturality, this being confirmed by comparing stations 6 and 7 in terms of hydrology. Landscape features can also play a role here: springs in the open were colonized by the greatest number of non-specific species. Owing to that fact, their fauna was less natural though important disturbing factors were lacking.

To summarise the factors affecting spring fauna, it can be stated that the spring fauna is determined by: limnological spring type, efficiency, surroundings (affecting biotop variety within the springs themselves) and zone differentiation of eucrenal-hypocrenal. Another important factor seems to be constituted by disturbances (anthropopressure, flow changeability, disturbing role of glaciers) and the possibility of spring re-colonization.

Great spring faunistical individualism was interpreted as, among other factors: migration from neighbouring biotops, including rhitral, potamal, and limnal

(Czachorowski 1999*a*). The presence of many insect imagines in springs does not settle the question of reproduction: they can only look for shelter or food here (Crema et al. 1996, Erman 1986). Not every attempt at reproduction is successful, which can be seen in the case of dragonflies. As far as crenoxene or perhaps even some crenophiles are taken into consideration – reproduction success does not guarantee population stability. In the landscape, for many species springs function as 'acceptor islands', integrated in the same metapopulation with 'donor islands' – populations in neighbouring reservoirs.

It is worth looking at group specialisation here. For crenobiontes, springs are islands on their own; here the role of distance between springs is clear (dispersion and re-colonization possibilities). For more eurytopical species, suitable biotops occur also outside springs. That is, there are more 'islands' where they can successfully live. In such cases the model of biotop islands should be studied taking into consideration all water reservoirs, not only springs.

A practical conclusion can be drawn from the above research: when undertaking spring protection, we should aim at protecting their complexes, not only single objects, however attractive or natural they are.

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