Macroinvertebrate communities of karst springs in the Julian Alps in relation to environmental factors

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Abstract. Karst springs in the Julian Alps were investigated from May to September 1999 to examine the influence of physical and chemical characteristics on macroinvertebrate community composition. The study revealed a great heterogeneity of environmental characteristics and highly variable taxonomic composition and abundance of taxa among individual springs. The results of canonical correspondence analysis (CCA) showed that spring altitude and periphyton coverage were the only environmental parameters significantly influencing the macroinvertebrate community composition.

Key words: macroinvertebrates, karst springs, Julian Alps, spring ecology

Izvleček. VPLIV OKOLJSKIH DEJAVNIKOV NA ZDRUŽBE VELIKIH VODNIH NEVRETENČARJEV V KRAŠKIH IZVIRIH V JULIJSKIH ALPAH - Preučevali smo združbe velikih vodnih nevretenčarjev v 16 kraških izvirih na območju Julijskih Alp v povezavi z fizikalnimi in kemijskimi lastnostmi izvirskih habitatov v obdobju od maja do septembra 1999. Primerjava okoljskih dejavnikov in združb med posameznimi izviri je pokazala velike razlike tako v fizikalnih in kemijskih značilnostih kot v sestavi združb med posameznimi izviri. Rezultati kanonične korelacijske analize (CCA) kažejo, da sta edino nadmorska višina in pokritost substrata s perifitonom značilno vplivala na sestavo izvirskih združb.

Ključne besede: veliki vodni nevretenčarji, kraški izviri, Julijske Alpe, ekologija izvirov

Introduction

Springs, compared to headwater streams of comparable size, have reduced annual and diurnal fluctuations in water temperature (Mc Cabe 1998). The mean water temperature is nearly equal to the mean annual temperature for the area (van der Kamp 1995). Spring communities demonstrate the majority of structural and functional properties seen in other lotic communities, yet they are significantly less complex (Williams & Williams 1998).

Discharge and substrate particle size has been found as factor controlling spring communities (Bonettini & Cantonati 1996). Other studies showed correlation between spring macroinvertebrate communities and pH (Glazier 1991), alkalinity and macrophyte cover (Glazier & Gooch 1987). Recently, Smith et al. (2003) demonstrated that the flow permanence has a dominant control over community composition. However, some studies found no correlation between single environmental parameters and the spring community structure (Lindegaard et al. 1998).

The aim of our study was to define environmental factors controlling the macroinvertebrate communities of 16 karst springs in the Julian Alps, Slovenia.

Study area

The springs examined were located within the Soča and Sava catchments at the foothills of the eastern part of the Julian Alps (NW Slovenia) (Fig. 1). The climate of the region is mountainous, with a mean annual temperature of 8°C and annual rainfall from 1600 to 3000 mm per year (Ogrin 1998). Mainly Triassic limestone underlies the area. The springs were situated along deep narrow Alpine valleys at altitudes from 410 to 955 m. Most of the springs were rheocrenes, only Kropa was limnocrene and Tresli hygropetric rheocrene. Nine springs were perennial, two were intermittent and in five of them the emergence of groundwater fluctuated up or down in the channel depending on local precipitation and groundwater levels (linear springs).

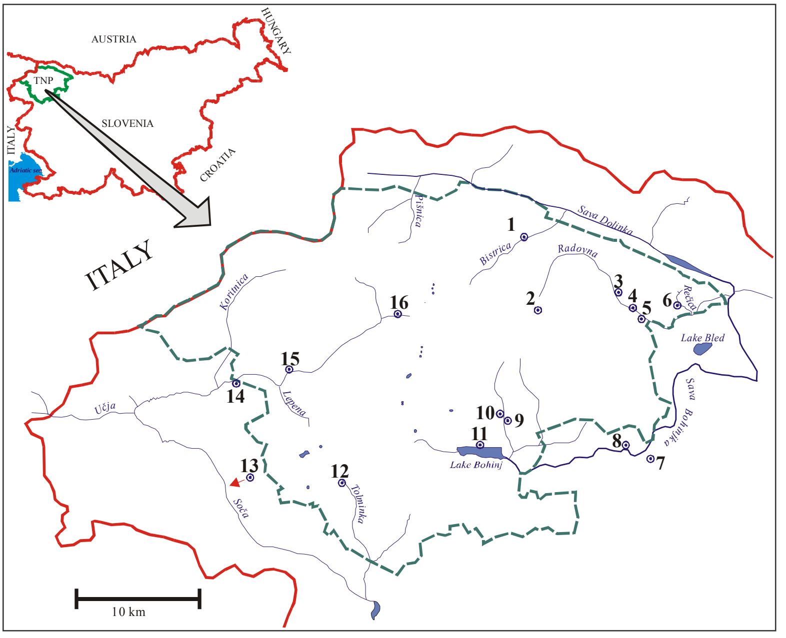

Figure 1. Map of the eastern part of the Julian Alps, indicating the location of sampling sites (1= spring in the Vrata valley, 2 = Krma, 3 = Frčkov rovt, 4 = Zatrep, 5 = Lipnik, 6 = Črna rečica, 7 = spring in Soteska, 8 = Nomenj, 9 = Kropa, 10 = Voje, 11 = spring at Lake Bohinj, 12 = Tolminka, 13 = Tresli, 14 = Kršovec, 15 = Roja, 16 = Krajcarica).
Slika 1. Zemljevid Julijskih Alp z označenimi vzorčnimi mesti (1 = izvir v dolini Vrat, 2 = Krma, 3 = Frčkov rovt, 4 = Zatrep, 5 = Lipnik, 6 = Črna rečica, 7 = izvir v Soteski, 8 = Nomenj, 9 = Kropa, 10 = Voje, 11 = izvir pri Bohinjskem jezeru, 12 = Tolminka, 13 = Tresli, 14 = Kršovec, 15 = Roja, 16 = Krajcarica).

Material and methods

The sampling of spring fauna was conducted in May, July and September 1999. Physical characteristics of the springs were noted on the spot (spring type, flow permanence, flow rate, substrate, periphyton, moss and organic matter cover) and temperature was measured. Water samples were collected at each spring-source, and analysed in the laboratory for pH, conductivity (μScm^{-1}), alkalinity (μeql^{-1}) and nitrate (mgl^{-1}) following standard methods (APHA 1998).

Aquatic macroinvertebrates were collected from each spring using a hand net (mesh size 100 µm) and standardised kicking technique (APHA 1998). Samples were preserved in 4 % formaldehyde solution. In the laboratory, organisms were identified to the lowest taxonomic level possible by means of identification keys (Bole 1969, Karaman & Pinkster 1977, Rivosecchi 1984, Graf & Waringer 1997, Studeman et al. 1992). Since many of the organisms belonged to taxonomically difficult groups and many of them were immature, taxonomic units used were mostly above the species level.

To examine differences between the macroinvertebrate communities of the springs, the Shannon-Wiener diversity index and Pielou's evenness index were calculated. Bray-Curtis index of similarity was calculated to compare degree of resemblance among springs. Canonical correspondence analysis (CCA) was used to correlate community data to environmental variables. Data on taxa abundance were transformed by natural logarithms ln(x + 1) to down weight high abundant taxa. Significance of environmental variables in CCA was tested by Monte Carlo permutation test (999 permutations) in forward selection of variables. CCA was run by CANOCO 4.5 program (ter Braak & Smilauer 2002).

Results

The mean temperatures of the 15 spring sources were between 5.6 and 8.7 ºC, but the temperature of spring not shadowed by forest vegetation (Tresli) was 15.2 ºC (Tab. 1). Mean flow rates were higher than 0.3 ms^{-1} in four springs (Zatrep, Lipnik, Črna rečica, Roja) and lower than 0.1 ms^{-1} in Krma, Frčkov rovt, Tresli and Kršovec springs. Substrate composition varied between springs, but boulders and cobbles prevailed in most of the springs studied. Mean pH varied by 0.3 (range 7.7-8.0), mean conductivity by 205 μScm^{-1} (range 200-405 μScm^{-1}), mean alkalinity by 1887 μeql^{-1} (range 1633-3520 μeql^{-1}) and mean nitrates by 4 mgl^{-1} (range 0.4-4.4 mgl^{-1}).

During the study period, a total of 72 taxa were recorded from the 16 springs (Tab. 2). *Protonemura* sp. (Plecoptera), Chironomidae (Diptera), *Gammarus* cf. *fossarum* (Amphipoda), Limnephilidae (Trichoptera) and Tricladida (Turbellaria) were the most abundant taxa. The most widespread taxa, collected from the majority of sampling sites were Chironomidae, Nematoda, Limnephilidae, Enchytraeidae (Oligochaeta), Tricladida and *Belgrandiella kuesteri* (Gastropoda).

Table 1. Environmental parameters in 16 karst springs in the Julian Alps. Spring type: R = rheocrene; L = limnocrene; HR = hygropetric rheocrene. Flow permanence: 0 = intermittent; 1 = linear; 2 = perennial. Flow rate: 1 = < 0.1 ms^{-1}; 2 = 0.1-0.3 ms^{-1}; 3 = 0.3-0.55 ms^{-1}; 4 = > 0.6 ms^{-1}. Organic matter, periphyton, moss coverage: 1= < 10 %; 2 = 10-50 %; 3 = > 50 %.

Tabela 1. Okoljski dejavniki v 16 kraških izvirih v Julijskih Alpah. Vrsta izvira: R = reokren; L = limnokren; HR = higropetrični reokren. Stalnost pretoka: 0 = občasen; 1 = spreminjajoč; 2 = stalen. Hitrost toka: 1= < 0.1 ms^{-1}; 2 = 0.1-0.3 ms^{-1}; 3 = 0.3-0.55 ms^{-1}; 4 = > 0.6 ms^{-1}. Pokritost z organskim drobirjem, perifitonom in mahovi: 1 = < 10 %; 2 = 10-50 %; 3 = > 50 %.

	Vrata	**Krma**	**Frčkov rovt**	**Zatrep**	**Lipnik**	**Črna rečica**	**Soteska**	**Nomenj**	**Kropa**	**Voje**	**at the lake**	**Tolminka**	**Tresli**	**Kršovec**	**Roja**	**Krajcarica**
altitude (m)	730	955	690	660	650	650	550	620	700	685	530	690	620	410	480	720
spring type	R	R	R	R	R	R	R	R	L	R	R	R	HR	R	R	R
mean temperature	5.8	6.4	8.7	6.4	6.9	7.7	6.6	8.4	6.9	6.8	8.2	5.7	15.2	7.9	6.3	5.6
flow permanence	2	1	1	0	2	1	1	2	2	2	2	2	2	0	2	1
mean flow rate	2	1	1	4	4	3	2	2	2	2	2	2	1	1	4	2
substrate (%)																
boulders and cobbles	0.4	0.8	0.6	0.1	0.8	0	0.7	0	0.8	0.1	0	0.4	0.2	0.9	0.6	0.1
pebbles and gravel	0.6	0	0.3	0.8	0.1	0.6	0.2	0.1	0.2	0.1	0.6	0	0.4	0.1	0.4	0.3
sand and silt	0	0.2	0.1	0.1	0.1	0.4	0.1	0.1	0	0.1	0.4	0.3	0	0	0	0.3
organic matter	3	3	3	2	1	2	2	3	3	2	2	1	1	1	1	2
mean pH	8	7.9	7.8	7.7	7.8	7.8	7.9	7.9	7.7	7.9	7.8	8	8	7.9	7.9	8
conductivity (μScm^{-1})	228	256	363	276	316	363	285	331	330	226	292	203	405	257	200	210
alkalinity (μeql^{-1})	1796	2112	2964	2314	2536	2933	2286	2816	2738	2044	2428	1633	3520	2094	1644	1667
nitrate (mgl^{-1})	1.4	2.0	3.0	1.4	1.9	1.8	4.4	2.1	1.9	1.2	1.4	2.6	0.4	2.6	2.2	1.7
periphyton	2	1	2	2	1	2	2	1	3	1	1	1	1	1	1	1
moss	2	1	2	3	1	1	1	1	1	2	1	1	1	3	1	3

Table 2. Aggregated macroinvertebrate data indicating presence or absence and abundance for the 16 springs. Key to abundance: R = rare (1-10 individuals); O = occasional (11-30 individuals); C = common (31-100 individuals); A = abundant (> 100 individuals).

Tabela 2. Podatki o prisotnosti, odsotnosti in abundanci makroinvertebratov v 16 izvirih. Razlaga: R = redek; O = občasen; C = pogost; A = množičen.

Taxa	**Vrata**	**Krma**	**Frčkov rovt**	**Zatrep**	**Lipnik**	**Črna rečica**	**Soteska**	**Nomenj**	**Kropa**	**Voje**	**at the lake**	**Tolminka**	**Tresli**	**Kršovec**	**Roja**	**Krajcarica**
TURBELLARIA																
Tricladida	C		C		C	C	R		A	O	R		O	R		C
Polycelis sp.								A			A					
NEMATODA	R	R	R	R	R	R	R	O	C	R		R		R	R	R

Taxa	**Vrata**	**Krma**	**Frčkov rovt**	**Zatrep**	**Lipnik**	**Črna rečica**	**Soteska**	**Nomenj**	**Kropa**	**Voje**	**at the lake**	**Tolminka**	**Tresli**	**Kršovec**	**Roja**	**Krajcarica**
GASTROPODA																
Ancylus fluviatilis									R							
Belgrandiella kuesteri	R				C	R	R	O	R	R	C	O		O		
Belgrandiella fontinalis								C		O	C		O			
Bythinella schmidti	R		C		O	R		R	A	R						
Iglica hauffeni							R									
Lymnaea truncatulla			R										R			
OLIGOCHAETA																
Enchytraeidae			C	A	R	R		O		O	R	R		R	O	C
Lumbriculidae	O		O			R	R		C		R	R				
Eiseniella tetraedra	R		R												R	
Naididae	R		C						R	R						
AMPHIPODA																
Gammarus cf. fossarum	C				A	C	R	A			C					
Niphargus sp.			R				0					R			R	C
Niphargus gr. *kochianus*			O		R											
Niphargus gr. *longidactylus*						R										
Niphargus gr. *stygius*			R			R			R	R				R	R	
ISOPODA																
Proasselus deminutus agg.					R			R								
ACARINA																
Hydracarina					R								R			
PLECOPTERA																
Chloroperlidae	R															
Leuctra sp.			C		C	R			C	O						
Leuctra nigra	R									R						
Nemouridae		O	O		O								R			R
Nemoura sp.		C			R	R			R		R		R			R
Nemoura cf. *marginata*		R														
Protonemura sp.	R		O		O	A	R	C	O	C	A					
Perlodidae						C			C							
Dyctiogenus sp.	R		R						O							
Dyctiogenus cf. *alpinus*															R	
Isoperla sp.					R										R	
Perlodes sp.									R							
Brachyptera sp.				O	C	O			R							
Brachyptera risi														R		
TRICHOPTERA																
Lithax niger								R								
Limnephilidae	R		O	R	R	C	A	O	A	O	R	R				C
Allogamus uncatus		R														
Drusus sp.	R								O							
Drusus chrysotus										R						
Potamophylax sp.			R					R	R				O			
Potamophylax nigricornis	R															
Polycentropodidae		R														
Plectrocnemia conspersa		R														
Psychomyiidae					R											
Tinodes sp.														R		
Tinodes dives									R				R			
Ryacophilidae										R						
Ryacophila sp.			R			R		R	R							

Taxa	**Vrata**	**Krma**	**Frčkov rovt**	**Zatrep**	**Lipnik**	**Črna rečica**	**Soteska**	**Nomenj**	**Kropa**	**Voje**	**at the lake**	**Tolminka**	**Tresli**	**Kršovec**	**Roja**	**Krajcarica**
Sericostoma sp.									R							
EPHEMEROPTERA																
Baetidae																R
Baetis sp.	R		R					R								
Baetis melanonyx			O			O										
Baetis rhodani	O				R	R										
Ecdyonurus sp.	R															
Ecdyonurus picteti					R				A							
Ecdyonurus zelleri	O															
Rhithrogena sp.	R															
DIPTERA																
Ceratopogonidae	R		R	R	R			R	R	R			R			R
Chironomidae	C	C	C	C	O	O	R	O	C	O	R	C	C	R	C	C
Culicidae													R			
Dixidae			R							R			R	R		
Empididae	R	R	R					R	R							R
Limonidae							R						R			
Psychodidae	R									R			R			
Simulidae										R						
Stratiomyidae													R			
Thaumaleidae					R			R		R		R				
Tipulidae		R		R	R		R					R				R
COLEOPTERA																
Elmidae			R		R											
Elmis sp.								R								
Dryops sp.				R					R							
Agabus sp.			R													

The number of taxa per spring was between 8 and 26, while the number of individuals per spring varied between 35 and 907 (Tab. 3). Shannon-Wiener diversity index and Pielou's evenness were between 1.51 and 3.54, and 0.43 and 0.81 respectively. The lowest taxa richness and number of specimens were observed in the spring located at the highest altitude (Krma), in two intermittent springs (Kršovec, Zatrep), and in two springs with high flow rates, poor food resources and lower water temperatures than others (Roja, Tolminka). The highest taxa richness and abundances were recorded in limnocrene spring (Kropa) and in rheocrene springs with rich food resources (Vrata, Frčkov rovt, Črna rečica, Nomenj, Voje). However, Lipnik is among the richest in taxa number, but poor in food resources and with high flow rate. The lowest Shannon-Wienner diversity and also Pielou's evenness was measured in the spring Zatrep and in the Soteska valley. The latter was a linear spring with moving water emergence and mostly with Limnephilidae present.

Table 3. Summary of taxa richness, total abundance, Shannon-Wiener diversity index, and Pielou's evenness for all 16 springs. Data represent aggregated macroinvertebrate samples for the entire study period (May 1999-September 1999).
Tabela 3. Vrstna pestrost, skupna abundanca, Shannon-Wienerjev diverzitetni indeks in Pieloujev indeks enakosti za združbe 16 izvirov. Podatki temeljijo na združenih vzorcih iz obdobja od maja do septembra 1999.

Spring	**Taxa richness**	**Total abundance**	**Shannon-Wiener diversity**	**Pielou evenness**
spring in the Vrata valley	24	258	3.34	0.73
Krma	10	122	2.03	0.61
Frčkov rovt	26	590	3.54	0.75
Zatrep	8	229	1.51	0.50
Lipnik	24	409	3.39	0.74
Črna rečica	19	873	2.50	0.59
spring in the Soteska valley	12	234	1.54	0.43
Nomenj	19	560	2.83	0.67
Kropa	26	907	3.50	0.74
spring in the Voje valley	20	194	3.28	0.76
spring at the Lake Bohinj	11	439	2.46	0.71
Tolminka	9	104	1.67	0.53
Tresli	15	144	2.72	0.70
Kršovec	9	35	2.56	0.81
Roja	8	79	1.67	0.56
Krajcarica	12	313	2.70	0.75

Each spring appeared to have a distinct macroinvertebrate community (Fig. 2). The highest coefficient of similarity was up to 67 %, but the similarity between springs was mostly up to 29 %.

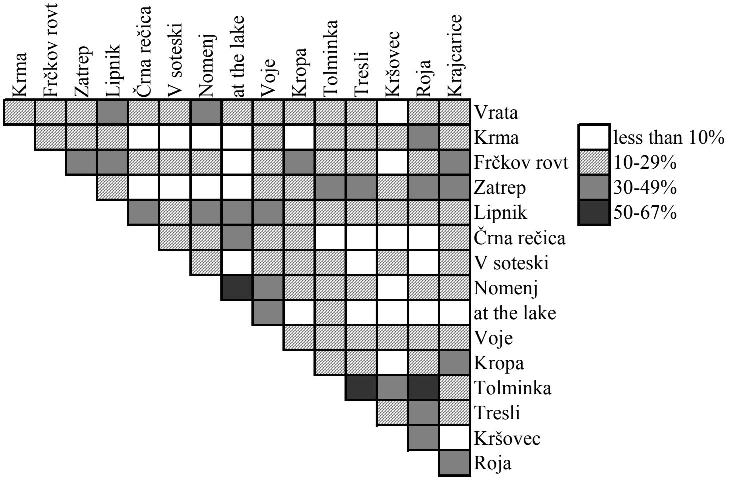

Figure 2. Similarity between 16 springs, based on the Bray-Curtis similarity index.
Slika 2. Podobnost med 16 izviri na osnovi Bray-Curtisovega indeksa podobnosti.

CCA accounted for 85.9 % of the total variance of the taxa data from the 16 springs. The eigenvalue for the first axis was 0.411 and for the second 0.333 (Fig. 4, Tab. 4). These two axes explained 30.1 % of the species-environment relation. The first CCA axis was primarily a positive gradient of altitude and negative gradient of periphyton coverage. The second axis was primarily a positive gradient of substrate and negative gradient of altitude. The only environmental variables found to be significant when examined using the Monte Carlo permutation test with the forward selection procedure were altitude and periphyton coverage. CCA clearly separated the spring Krma from others, primarily due to higher elevation and some taxa present only there. The Nomenj spring and the spring at the lake, and the springs Roja and Tolminka felt close together in the CCA ordination diagram.

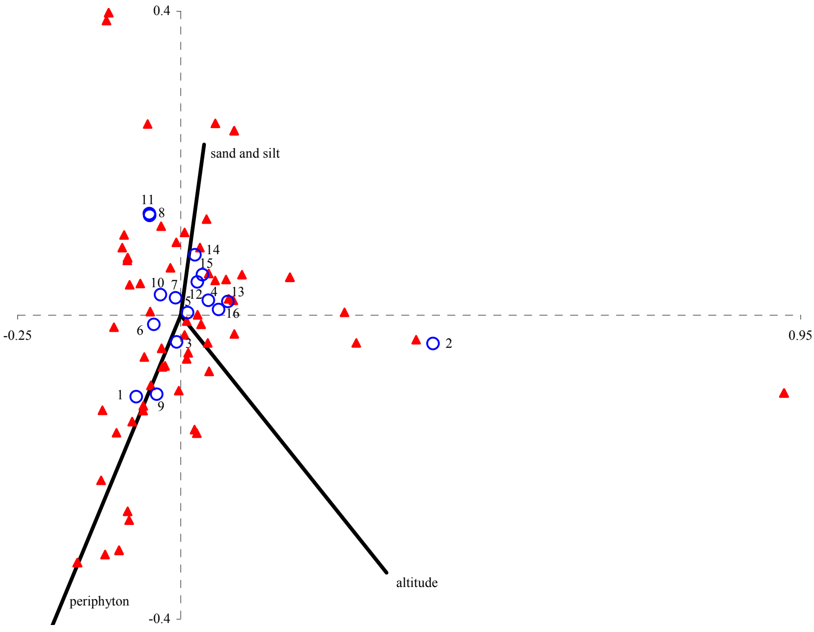

Figure 3. CCA ordination diagram based on taxa composition and abundance data of macroinvertebrates from 16 springs in relation to twelve environmental variables (only three are displayed). The eigenvalues of axis 1 (horizontally) and axis 2 (vertically) are 0.411 and 0.333 respectively. The first two axes account for 30.1 % of all variance explained by CCA. Sampling sites (circles); taxa (triangles); environmental variables (lines).
Slika 3. CCA ordinacijski diagram na osnovi makroinvertebratov, najdenih v 16 izvirih v povezavi z dvanajstimi okoljskimi dejavniki (trije so prikazani na sliki). Lastna vrednost prve osi je 0.411 in druge 0.333. Prvi dve osi pojasnjujeta 30.1 % celotne variance razložene z CCA. Vzorčna mesta (krogi); taksoni (trikotniki); okoljski dejavniki (črte).

Table 4. Summary of CCA analysis.
Tabela 4. Povzetek kanonične korespondenčne analize.

Axes	**1**	**2**	**3**	**4**	**Total inertia**
Eigenvalues	0.411	0.333	0.294	0.292	2.88
Species-environment correlations	0.991	0.994	0.998	0.995	
Cumulative percentage variance					
of species data	14.3	25.9	36	46.2	
of species-environment relation	16.6	30.1	42	53.8	
Sum of all eigenvalues					2.88
Sum of all canonical eigenvalues					2.474

Discussion

The fauna recorded in the 16 springs was composed of mainly lotic taxa, occurring in the rest of the river continuum, and to a lesser extent of hypogean taxa, belonging to the Gastropoda, Amphipoda and Isopoda groups. Chironomids and trichopterans turned out to be the most successful taxa in the spring environments, occurring frequently and in high abundances. Dipterans were recognised as the major part of the spring fauna in central Europe (Wagner et al. 1998) and chironomids as the taxonomic group richest in species in alpine springs (Gerecke et al. 1998).

Similarity between community composition was low (normally up to 29 %) due to the highly variable number of taxa and abundances among springs and due to the fact that most of the taxa found were recorded from only one or two springs. The geographical distance and isolation of those habitats, together with different combinations of environmental factors in individual spring, were probably the reasons for the great heterogeneity of macroinvertebrate communities.

The results suggested that the key environmental factors defining the macroinvertebrate spring communities were different among springs. No universal environmental factor determining all communities studied was recognised. Smith et al. (2003) showed that flow permanence, variation in water temperature and the input of leaf litter had dominant influence on the spring macroinvertebrate communities. We presume that spring morphology (type of spring), flow permanence and rate of discharge play the major role in shaping other environmental parameters. In limnocrene spring, permanent springs, springs with moderate flow rates, rich in organic matter, periphyton and moss cover, higher taxa number and density was found than in intermittent or linear springs, or in springs with high flow rates, low organic matter, periphyton and moss cover. The communities from Roja and Lipnik springs were similar in all environmental factors mentioned above, but Lipnik had a considerably higher taxa richness, abundance and diversity. We presume that discharge and consequently the spring area are the main reasons for these differences. Lipnik is a much larger spring, with estimated discharge twice as great as Roja's. The positive correlation between diversity and discharge recorded in the springs of Finland demonstrated the general rule that larger ecosystems (springs) have a greater number of species than the smaller ones (Särkkä et al. 1997). In the CCA analysis, the spring Krma (the most elevated spring) was separated from others due to *Allogamus uncatus*, *Nemoura* cf. *marginata*, Polycentropodidae and *Plectrocnemia conspersa* present only here. The CCA ordination diagram clearly showed ordination of taxa and sample points along the periphyton gradient.

Povzetek

Na območju Julijskih Alp so bile maja, julija in septembra 1999 v 16 kraških izvirih opravljene raziskave združb velikih vodnih nevretenčarjev. Namen raziskave je bil ugotoviti, kateri so okoljski dejavniki, ki vplivajo na sestavo združb velikih vodnih nevretenčarjev v izvirskih habitatih. Raziskave združb so bile opravljene z metodo vzorčevanja, imenovano "kick sampling". Poleg bioloških analiz so bile opravljene tudi meritve kemijskih in fizikalnih dejavnikov. Izbrani izviri ležijo na nadmorskih višinah od 410 m do 955 m. Vsi izviri, razen dveh, od katerih je eden limnokren, drugi pa higropetrični reokren, so reokreni. Za izvire so bila značilna različna nihanja pretokov in relativno stabilne temperature vode. Izmerjene vrednosti pH so bile v bazičnem območju. Prevodnost in alkaliteta sta bili zaradi karbonatne podlage relativno visoki. V posameznih izvirih smo izmerili od 0 do 4,82 mgl^{-1} nitratov. V izvirih smo ugotovili najmanj 72 različnih taksonov velikih vodnih nevretenčarjev. Vrbnice (Plecoptera), dvokrilci (Diptera), postranice (Amphipoda), mladoletnice (Trichoptera) in vrtinčarji (Turbellaria) so bili najpogostejši predstavniki izvirskih združb. V posameznih izvirih je bilo število taksonov od 8 do 26. Največje število taksonov, visoke abundance in diverziteto smo zabeležili v izvirih s stalnim pretokom, bogatih z organskim materialom, perifitonom in mahovi. Nizke vrednosti števila taksonov, abundanc in diverzitetnih indeksov so bile v izvirih z nestalnim pretokom ali pa v izvirih, revnih z organskim materialom, perifitonom in mahovi in višjimi hitrostmi vodnega toka. Podobnost med izvirskimi združbami na osnovi Bray-Curtisovega indeksa je bila večinoma nižja od 29 %. Preučevanje vpliva okoljskih dejavnikov na sestavo združb velikih vodnih nevretenčarjev s kanonično korespondenčno analizo je pokazalo, da na sestavo združbe v največji meri vplivata nadmorska višina in perifiton.

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