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Distribution Patterns of Copepods (Crustacea: Copepoda) in Percolation Water of the Postojnska Jama Cave System (Slovenia)

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Tanja Pipan and Anton Brancelj (2004) Distribution patterns of copepods (crustacea: copepoda) in percolation water of the postojnska jama cave system (Slovenia). *Zoological Studies* **43**(2): 206-210. In the last decade, the biodiversity of groundwaters, including karstic systems, has become intensively studied in Slovenia. We have especially focused on stygobitic copepods which inhabit small fissures and cracks in the so-called vadose (or unsaturated) zone, i.e. the space between fossil cave galleries and the surface. The upper layer of this zone is called the epikarstic zone. Epikarstic species can be collected in trickles of percolating water as well as in the pools filled with it. Faunal samples, along with water for physical and chemical analyses, were collected once per week over a period of 1 yr. Twenty-three taxa of copepods were recorded from the trickles and pools in 3 caves of the Postojnska Jama Cave System. Four taxa of Cyclopoida and 19 taxa of Harpacticoida were recognized. Eight harpacticoid species are probably new to science and belong to 7 genera. We collected 13 species in Postojnska jama, 14 species in Pivka jama, and 11 species in Črna jama. The survey of both trickle and pool habitats in the 3 caves showed qualitative and quantitative differences between them. In Postojnska jama, large differences in the number of copepod species as well as in their abundance were recorded between the 2 habitats. In the other 2 caves, species compositions were similar, but there was a difference in the frequency of specimens. http://www.sinica.edu.tw/zool/zoolstud/43.2/206.pdf

Key words: Copepoda, Percolation water, Caves, Karst, Slovenia.

By the end of 2001, 36 species and subspecies of copepods living in percolation water had been reported from the Postojnska Jama Cave System. Six of them are endemic to Slovenia, and often their distribution is limited to a single cave. The most important specialists who contributed to our initial knowledge of cave-dwelling copepods in the Postojnska Jama Cave System were Chappuis (1924 1928 1936), Kiefer (1930 1933), and Stammer (1932). Additional contributions were published by Petkovski (1983) and Brancelj (1986 1987).

The goals of this research were: a) to determine the total number of taxa in trickles of water in the unsaturated karst zone, b) to detect differences between trickles and pools where percolation water collects, c) to detect differences in faunas among caves in the same cave system and in caves in the same geographical area, and d) to follow seasonal dynamics of copepods assemblages in a particular water body. Results of the copepod fauna research are supplemented with data on the thickness of the cave ceilings, the exterior vegetation cover, and the physical and chemical characteristics of the percolated water.

The Postojnska Jama Cave System is the longest cave system in Slovenia with about 20 km of galleries [covering an area on the surface of about 1.5 x 6 km]. It is in Upper Cretaceous carbonate rocks (Šebela 1995). The system includes caves (cave = jama) Postojnska jama, Pivka jama, Črna jama, Otoška jama, and Magdalena

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jama (Fig.1). Postojnska jama, Pivka jama, and Črna jama were the part of the region investigated. In Pivka jama, the thickness of the cave ceiling above the sampling points is between 45 and 70 m. A tourist camp is built above the cave. The area above Črna jama is mostly covered with fir and spruce forest. The thickness of the ceiling above the sampling points in Črna jama varies between 30 and 60 m. The entire area above Postojnska jama is also mainly fir forest, and the cave ceiling thickness above the sampling points ranges from 30 up to 90 m.

Permanent or temporary sources of percolation water drip from the ceiling in several locations. They are fed by rain. The amount and duration of percolation depend on rainfall. During the sampling period, 1827 mm of rain fell in the area. In wintertime, there was also snow, but the amounts of melted snow were not measured. On the floor of the caves, percolating water collects in pools. The bottoms of these pools are covered by clay, sand, or calcite. Some pools contain the remains of rotting wood. The pH, temperature, and conductivity at the individual sampling points inside the caves showed little change during the 1-yr sampling period. The minimum and maximum values for pH, measured in the 3 caves were between 7.4 and 8.8, and 322 and 464 µS cm^{-1} for conductivity. The main differences occurred in the measured discharge, which is influenced by the dry or rainy season. The highest measured discharge was 291 ml min^{-1}, while the lowest was less than 1 ml min^{-1}. The minimum and maximum values for temperature differed by season, and were between 3.0 and 10.4°C.

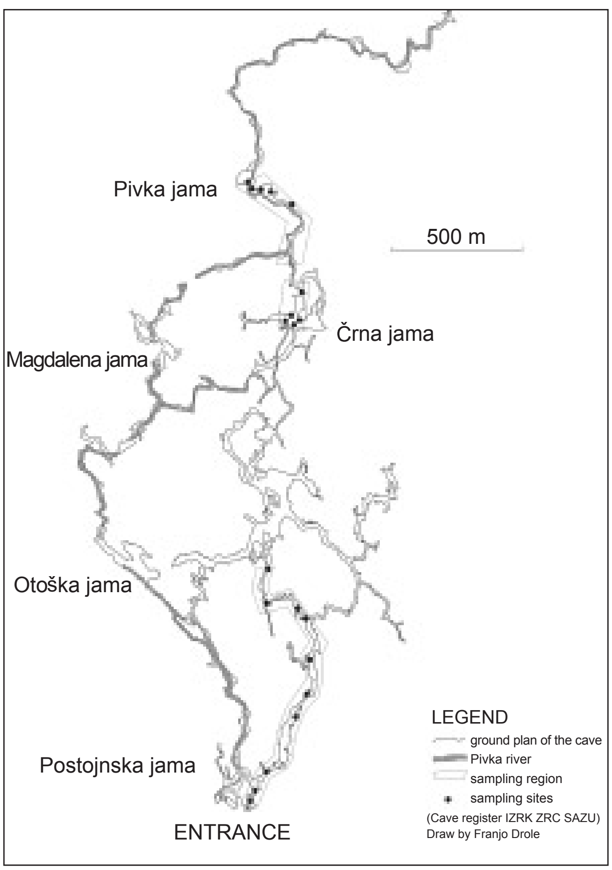

Fig. 1. Postojnska Jama Cave System (Slovenia, Europe) consists of five interconnected caves (Postojnska jama, Pivka jama, Črna jama, Otoška jama, and Magdalena jama; jama = cave). Sampling points for percolating water, filtered during year 2002 are indicated.

MATERIALS AND METHODS

In the caves Postojnska jama, Pivka jama, and Črna jama, we sampled water trickles once per week for 1 yr. Samples of fauna as well as samples for water quality analysis were collected each week from a container. In Postojnska jama, 10 trickles (i.e., 10 sampling points) were selected. In the other 2 caves, we selected 5 trickles in each. During the period of 1 wk, the water from trickles was directed through a funnel into 0.25 L plastic containers. On 2 sides, the container had holes covered with a net (with a mesh size of 60 µm) to retain animals in the container. The content of the plastic containers was fixed with a 4% final solution of formaldehyde at the sampling spot and stored for further processing. In the laboratory, we separated the organisms by means of a stereomicroscope at 40x magnification and stored them in 70% ethanol. Further processing and identification of the organisms were performed under a compound microscope.

Samples from the pools were collected separately into plastic containers by means of an adjusted suction pump. We pumped various quantities of pool water at different sampling points and filtered it through a 60-µm net. Samples were then processed in the same way as those from the trickles.

RESULTS

Nineteen different taxa of harpacticoids and 4 of cyclopoids were recognized in the samples collected from percolation water in the 3 caves (Table 1).

Among 23 species of copepods from trickles and pools, we found only 5 species which were present in all 3 caves. In addition, in the drips of percolation water and in small pools fed by them, there were probably 8 species new to science, belonging to 7 genera. In caves, which belong to the same cave system and are 3 km apart, we did not found a correlation between the distances the caves were apart and the similarity of the fauna using Pearson correlation coefficients. The similarity was expressed as a ratio of the species in common between 2 locations and the sum of the taxa at both locations (Jaccard's similarity coefficient)

In samples collected from trickles, the highest number of species was recorded in Pivka jama, whereas from pools the highest number of species of copepods occurred in Postojnska jama. In the caves Postojnska jama and Črna jama, there were only 4 species common to trickles and puddles, and in Pivka jama there were 7 species (out of 14 species). In Postojnska jama, there were 13 and in Črna jama 11 total species.

Three taxa of cyclopoids were recorded only from pools and not from trickles. They were found only in Postojnska jama. The most abundant and frequent were specimens of *Diacyclops* of the *languidoides*-group, whereas the other 2 species, *Acanthocyclops kieferi* and *Paracyclops fimbriatus*, were much less abundant or frequent. *Speocyclops infernus* was the only species which was found in pools and drips in all 3 caves.

Among harpacticoids, there were a few specimens of *Elaphoidella* sp., *Moraria* sp., *Nitocrella* sp., *Parastenocaris* sp. 1, and *Stygepactophanes* sp. which were found only in trickles of percolation water. Four species of harpacticoids were record-

Table 1. List of species of copepods (Crustacea: Copepoda), their occurrence, and percentage (%) based on the total number of taxa, recorded from percolation water and from pools filled with it in 3 karst caves in Slovenia. Species presumed to be new to science are marked with an asterisk (*)

Species/cave	stygobitic species	Postojn. j.		Pivka j. percentage (%)		Črna j.	
		drips	pools	drips	pools	drips	pools
CYCLOPOIDA							
1. *Acanthocyclops kieferi* (Chappuis, 1925)	+		4.3				
2. *Diacyclops languidoides* -group (Lilljeborg, 1901)	+		18.4				
3. *Paracyclops fimbriatus* (Fischer, 1853)			1.5				
4. *Speocyclops infernus* (Kiefer, 1930)	+	54.5	17.2	26.0	1.6	10.8	22.3
HARPACTICOIDA							
5. *Bryocamptus* (*B.*) *balcanicus* (Kiefer 1933)	+	9.1	17.4	0.3		39.6	18.1
6. *Bryocamptus* (*L.*) *dacicus* (Chappuis 1923)			0.5	22.7	15.5		0.5
7. *Bryocamptus* (*R.*) *pyrenaicus* (Chappuis, 1923)	+				0.2		
8. *Bryocamptus* (*B.*) typhlops (Mrazek, 1893)	+		0.3		0.5		
9. *Bryocamptus* sp.*	+			0.3	0.4		
10. *Elaphoidella cvetkae* Petkovski, 1983	+			5.0	0.3	39.2	1.6
11. *Elaphoidella* sp.*	+			1.0			
12. *Epactophanes richardi* Mrazek, 1893					4.4		
13. *Maraenobiotus* cf. *brucei**	+			32.0	6.9		
14. *Moraria poppei* (Mrazek, 1893)		9.1	2.5	1.0	69.8		13.5
15. *Moraria varica* (E. Graeter, 1911)			0.3	3.3	0.4		
16. *Moraria* sp.*	+					1.6	
17. *Morariopsis scotenophila* (Kiefer 1930)	+		36.4				43.5
18. *Nitocrella* sp.*	+	18.2					
19. *Parastenocaris nolli alpina* (Kiefer, 1938)	+			2.0		1.5	0.5
20. *Parastenocaris* sp. 1*	+					1.1	
21. *Parastenocaris* sp. 2*	+	9.1	0.5	6.4		4.6	
22. *Phyllognathopus viguieri* (Maupas, 1892)			0.7				
23. *Stygepactophanes* sp.*	+					1.6	
		5	12	11	10	8	7
Sum of taxa		13		14		11	

ed from pools: *Bryocamptus pyrenaicus*, *Epactophanes richardi*, *Morariopsis scotenophila* and *Phyllognathopus viguieri*. There were no harpacticoids present in drips or pools in any of the 3 caves.

In Postojnska jama, 55% of all the copepods belonged to *Speocyclops infernus*, and about 20% of the copepods were specimens of a new species of *Nitocrella*. The remaining 3 species found in trickles did not exceed 10% of the total specimens present. Among the 601 copepods in percolation water samples from Pivka jama, there were numerous specimens of *Maraenobiotus* cf. *brucei* (32%), *S. infernus* (26%), and *Bryocamptus dacicus* (23%). Nauplii comprised 45% of all copepods. In percolation water in Črna jama, *B. balcanicus* and *Elaphoidella cvetkae* were the most abundant (40% out of 291 copepods). Specimens of *S. infernus* represented 11% of all copepods. The other species were poorly represented in the samples and did not exceed 5%.

In samples collected from pools, there were much fewer nauplii, with the exception of Postojnska jama, where nauplii were found just in pools. The assemblages in the pools were more abundant compared to those in trickles of percolation water. In Postojnska jama, we obtained 504 copepods, of which 36% were specimens of *M. scotenophila*. Specimens of *Diacyclops* of the *languidoides*-group, *S. infernus*, and *B. balcanicus* (18% each taxa) were also abundant. Eight other taxa of copepods from pools in Postojnska jama did not reach 5% each. Of the 1013 specimens filtered from pools in Pivka jama, 70% were *Moraria poppei* and 16% were *Bryocamptus dacicus*. The majority of other species from pools in Pivka jama did not reach 5% or even 1% each of the total number of specimens. One percent of copepods were nauplii. In pools in Črna jama, we found specimens of *M. scotenophila* to be the most abundant (44% of 207 specimens). Of all the copepods, 22% were specimens of *S. infernus* and 18% of *B. balcanicus*. Other taxa were much less frequent. We recorded 6% nauplii of the 207 copepods present.

DISCUSSION

The intensive sampling of 2 different habitats in the Postojnska Jama Cave System indicated that the system is especially rich in fauna of harpacticoids (including nauplii). During our systematic collection of the fauna of cyclopoids and harpacticoids in these 3 horizontal caves, we identified 23 taxa of copepods, with at least 7 species among them new to science. These species are particularly restricted in distribution to 1 or a few trickles of water percolating from the ceiling. We still do not know what the important ecological differences are causing the presence of those species in individual trickles. Six taxa could be designated as stygophiles (*P. fimbriatus*, *B. dacicus*, *E. richardi*, *M. poppei*, *M. varica*, and *P. viguieri*) and are frequently found in subterranean environments but have apparently been transported from their epigean habitats. The rest of the taxa, i.e., 17 species, are stygobitic (Table 1), among which 9 are endemic to Slovenia. Males of *M. scotenophila* were found for the 1st time. The stygobitic diversity is supported by mutual spatial and ecological partitioning of the subterranean environment by immigrants. The former is a consequence of endemism and distribution barriers, while the latter is caused by a more-detailed specialization of stygobionts (Sket, 1999).

In drips and pools, we found specimens of the same stygobitic species, at least an abundance of them, which differed only in the frequency of their occurrence. The similar species compositions in both the trickle and pool habitats in a single cave indicate that the primary habitat of stygobitic species of copepods is an interface between the topsoil and the underlying limestone in karst areas. The subcutaneous zone can be the primary habitat for a variety of crustaceans, including amphipods such as *Niphargus* and *Stygobromus* (Fong and Culver 1994).

The stygobitic species of cyclopoids are *A. kieferi*, *Diacyclops* of the *languidoides*-group, and *S. infernus*, which inhabit crevices filled with percolation water and also drift to the pools (Pospisil and Stoch 1999). *Paracyclops fimbriatus* is a species that also lives in other surface habitats and can persist for a long time in a subterranean environment (Kiefer, 1933, Galassi 2001).

In drips of percolation water, we found some very interesting harpacticoids. The most interesting species are *E. cvetkae*, *M. varica*, *M. scotenophila*, and *Parastenocaris nolli alpina*. The drips and pools are inhabited also by stygobitic and stygophilic species of harpacticoids such as *B. balcanicus*, *B. dacicus*, *B. pyrenaicus*, *B. typhlops*, *E. richardi*, *M. poppei*, and *P. viguieri*. Some of these are cosmopolitan.

The similarity in composition of copepod fauna between the 3 caves of the same cave system is not unexpected due to the same geographical and geological situation and the same influence of external environmental factors. The vadose zone is formed by the upper layer of limestone rocks, and its specific properties are due to the processes of weathering which directly affect this layer. Development of the epikarstic zone is controlled by both lithology (textural and structural properties of the rock) and climate (Klimchouk 1995). Ward and Palmer (1994) in their work categorized abiotic variables, among which geomorphic and hydrogeologic processes influenced the distribution of subterranean organisms. Furthermore, Culver and Fong (1994) stressed that interspecific interactions and migration among units have distributional impacts on subterranean Crustacea only at the smallest scale. Geological and climatological events, the ecology of cave habitats, and the physiology of organisms have impacts on distributions at larger scales.

Results of the correlation analysis (using the Spearman correlation coefficient) indicate that there is a statistically significant correlation ($r_S \geq 0.8$, $p < 0.05$) between the discharge and the number of specimens. The precipitation shows a highly positive co-variation with the number of specimens on the one hand and with discharge on the other. The correlation between the thickness of the cave ceiling and the discharge on the one hand and the number of specimens on the other was not significant. For more precise conclusions about the correlation between the quantity of filtered water and the number of specimens, a large number of samples should be analyzed.

The fauna of copepods in percolation water of the vadose zone is unusually rich. It is characterized by a low number of specimens, resulting in a low frequency of appearance. The high total number of taxa found in the caves and the high number of taxa per cave (11~14 taxa) with a dominance of stygobitic taxa indicate that biodiversity in subterranean environments is high. New distribution data and new species can be obtained from further investigations in trickles of percolation water.

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