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BENTHIC MACROFAUNA OF A SUBMARINE CAVE ON THE ISTRIAN PENINSULA (CROATIA)

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ABSTRACT

Karst phenomena are common under the sea level in the submarine zone of Istrian Peninsula: a typical phenomenon of karst hydrography is the presence of submarine fresh water springs locally known as "vrulije". Submarine caves are considered ideal habitats, where selection of species is remarkable due to the reduced light, slow water circulation and low nutrient level. From the entrance to the inward end of the cave there is a progressive reduction in the number of taxa and total biomass. This study examines the macrofauna inhabiting the soft bottom, including a thanatocoenosis analysis, and the sessile fauna living on the hard substrate of the wall and the ceiling in a small submarine cave in the Adriatic Sea. The cave presents, on hard substrata, the circalittoral community of the semi-dark cave and there is a horizontal zonation of the communities inhabiting the wall. The macrofauna inhabiting the soft bottom did not show any clear zonation in terms of species richness or abundance.

Key words: macrobenthos, submarine cave, Northern Adriatic, Croatia

LA MACROFAUNA BENTONICA DI UNA GROTTA SOTTOMARINA NELLA PENISOLA ISTRIANA (CROAZIA)

SINTESI

Lungo la costa Istriana sono frequenti i fenomeni dell'idrografia carsica che danno origine a grotte ed a risorgive subacquee localmente conosciute con il nome di "vrulije". Nelle grotte subacquee parametri come la riduzione dell'intensità luminosa, la diminuzione dei nutrienti e della circolazione delle masse d'acqua provocano una progressiva riduzione del numero di taxa e della biomassa totale procedendo dall'ingresso verso il fondo della grotta. Il presente lavoro esamina le comunità macrobentoniche del substrato molle, l'analisi delle tanatocenosi e la fauna sessile insediata sul substrato roccioso delle pareti e del soffitto di una piccola grotta subacquea del Mare Adriatico. La grotta presenta, sul substrato roccioso, comunità circalitorali caratteristiche delle grotte semioscure ed indica una zonazione orizzontale delle comunità insediate lungo le pareti. La macrofauna presente nel substrato molle non indica una chiara zonazione in termini ricchezza e di abbondanza.

Parole chiave: macrobenthos, grotta sottomarina, Alto Adriatico, Croazia

INTRODUCTION

The Croatian coastal and channel area is mostly a submerged karst relief. Various karst phenomena (sinkholes and caves) are common under the sea level in the submarine zone of the Adriatic Sea, including the islands in the Kvarner region (Božičević, 1992; Arko-Pijevac *et al.*, 2001). A typical phenomenon of karst hydrography is the presence of submarine freshwater springs (locally known as "vrulje") connected to the Adriatic Sea by coastal underground water circulation systems, which flow mostly through marine caves (Alfirević, 1966). Their number in the Adriatic Sea is relatively large along the eastern shore. They are present from the west coast of Istria to the Albanian waters, and in the Adriatic archipelago (Alfirević, 1969).

Submarine caves are considered ideal habitats to study the influence of many environmental parameters on the settled benthic communities (Riedl, 1978) due to the presence of strong environmental gradients on spatial scales of a few meters (Ott & Svoboda, 1976; Cinelli *et al.*, 1977). In the interior of a cave, changes in the intensity of light and in the hydrodynamic regime are easily perceived (Benedetti-Cecchi *et al.*, 1996).

Due to the reduced light, slow water circulation and low nutrient level, submarine caves are considered to be a habitat where selection of species is remarkable (Riedl, 1966; Harmelin *et al.*, 1985; Zabala *et al.*, 1989; Bianchi & Morri, 1994). Dark caves show some similarities with the bathyal zone (Arko-Pijevac *et al.*, 2001) with regard to hydrodynamics, nutrient level (Fichez, 1990, 1991a, b) and fauna composition including sponges, anthozoans, serpulids and bryozoans (Harmelin, 1985; Harmelin *et al.*, 1985).

All studies on Mediterranean caves have revealed a remarkable horizontal zonation of the animal communities inhabiting the walls (Laborel & Vacelet, 1958; Laborel, 1960; Pérès & Picard, 1964; Gili *et al.*, 1982; Bibiloni *et al.*, 1984). The number of taxa from the entrance to the inward end of the caves is progressively reduced; sponges, scleractinians and polychaetes become dominant at the expense of other taxa, and total biomass decreases (True, 1970; Gili *et al.*, 1986).

This study examines the macrofauna inhabiting the soft bottom, including a thanatocoenosis analysis, and the sessile fauna living on the hard substrate of the wall and the ceiling in a small submarine cave in the Adriatic Sea (Columbera cave) characterized inside by the presence of freshwater springs.

MATERIAL AND METHODS

Columbera cave (45°10'18"N, 14°14'07"E) is located near Brseč, on the eastern coast of the Istrian Peninsula (Fig. 1). The cave entrance is about 3 m high at a depth of 6 to 9 m at the bottom of a cliff. The cave has a linear shape and is approximately 11 m long. The length-width ratio is about 3:1 and this ratio is characteristic of a "Sackhöhle" cave, as described by Riedl (1966) (Fig. 2). Muddy-sand and rough organic detritus, mostly shells fragments, cover the cave floor. Two freshwater springs are located in the cave at 10.6 and 2 m from the entrance: the former in muddy sediment, the latter in detritic sand.

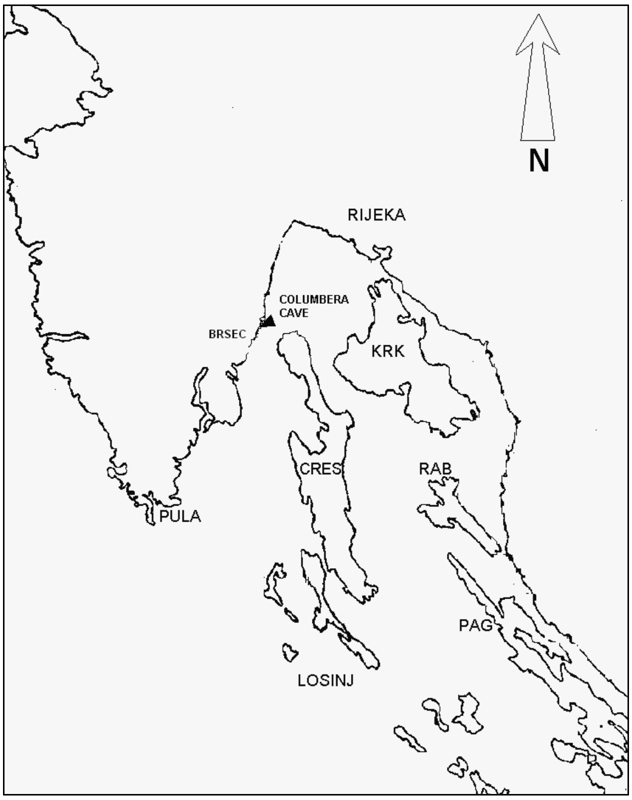

Fig. 1: Location of Columbera cave.
Sl. 1: Lokacija jame Columbere.

Direct sampling was performed in April 2001 using scuba dive. The sessile macrofauna on the wall and ceiling of the cave was analyzed by visual-census in each meter from the entrance to the bottom of the cave (1 to 9 meters) and organisms were photographed with a Nikon F90 in an underwater housing; species of uncertain determination were collected for identification in the laboratory. Hierarchical classification and MDS based on the Bray-Curtis similarity coefficient was calculated, using complete linking (PRIMER software package developed at the Plymouth Marine Laboratory).

Three sites were chosen to study soft bottom communities: site A located in the inner area of the cave, site B situated among the springs, site C close to the outer spring. A set of four squares (0.1 m^2 × 0.20 m) were positioned, next to each other, on site A and B to collect the sediment using a small shovel (Di Geronimo &

Robba, 1976). In site C it was impossible to place the square into the sediment and thus only 9 l of sediment were collected directly using a shovel. Samples were sieved on 1 mm mesh and preserved in 4% formalin. In the laboratory, living organisms were sorted and determined at the lowest possible taxonomic level. The thanatocoenoses were analyzed by sorting intact shells and skeletal structures; each empty bivalve shell was counted as a separate individual (Peharda *et al.*, 2002).

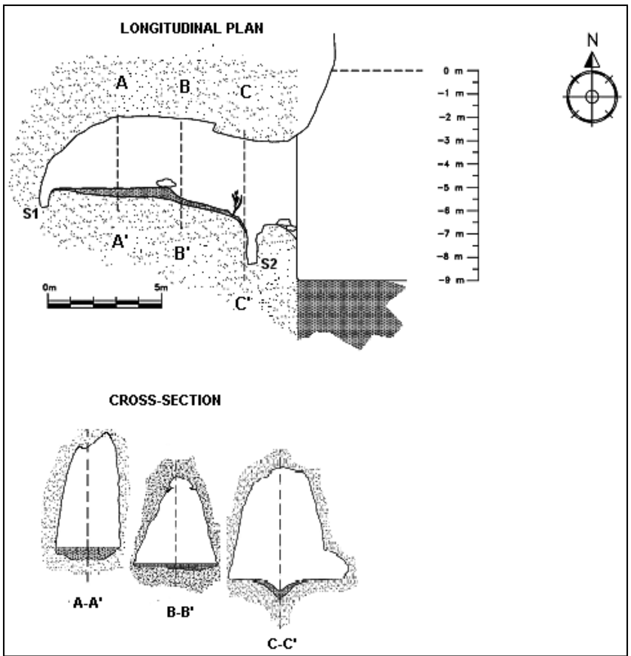

Fig. 2: Cave longitudinal plane and cross section.
Sl. 2: Podolžna ploskev in prerez jame.

RESULTS

A total of 21 sessile species living on the hard substrate were recognized. The more representative taxa were Porifera (15 species), Cnidaria (2 species), Briozoa (2 species) and Tunicata (2 species).

Hierarchical classification and MDS performed on sessile species yielded three groups: group I included 18 species from the entrance to 3 meters (1–3), group II with 18 species represented the middle portion to 6 meters (4–6) and group III with 9 species comprised the inner area to 9 meters (7–9) (Fig. 3). Table 1 shows the species present in the cluster groups: seven species were found in each group I–II–III, from the entrance to the bottom of the cave: nine species were found only in groups I and II, to 6 meters, and 1 species in the groups II and III. Two species were found only in group I, one species in group II, and one species in group III.

A total of 197 living organisms belonging to 26 taxa were collected in the soft bottom. The richest site in terms of abundance and taxa was site A (23 taxa and 136 specimens), whereas site C was the poorest (8 taxa and 14 specimens), probably due to the small amount of sediment collected. The main taxonomic groups were (Tab. 2): molluscs (8%), polychaetes (37%), sipunculids (31%), crustaceans (2%) and echinoderms (22%). The most representative groups in terms of taxa and abundance were polychaetes and molluscs, respectively, whereas the most abundant species were the sipunculid *Aspidosiphon muelleri* and the echinoderm *Amphiura chiajei*. These two species were present at all sampling sites.

Tab. 1: Hard bottom community (sessile fauna).
Tab. 1: Združba trdega dna (prirasli organizmi).

	Species	group I 0–3 m	group II 3–6 m	group III 6–9 m
Tunicata	*Diplosoma listerianum*	*		
Tunicata	*Halocynthia papillosa*	*		
Porifera	*Anchinoe tenacior*	*	*	
Porifera	*Aplysina aerophoba*	*	*	
Porifera	*Cacospongia scalaris*	*	*	
Porifera	*Chondrosia reniformis*	*	*	
Porifera	*Clathrina clathrus*	*	*	
Porifera	*Dysidea avara*	*	*	
Porifera	*Hemymicale columella*	*	*	
Porifera	*Ircinia variabilis*	*	*	
Bryozoa	*Myriapora truncata*	*	*	
Bryozoa	*Hornera frondiculata*		*	
Porifera	*Agelas oroides*	*	*	*
Porifera	*Axinella verrucosa*	*	*	*
Porifera	*Crambe crambe*	*	*	*
Porifera	*Oscarella lobularis*	*	*	*
Cnidaria	*Parazoanthus axinellae*	*	*	*
Porifera	*Petrosia ficiformis*	*	*	*
Porifera	*Spirastrella cunctatrix*	*	*	*
Porifera	*Aplysina cavernicola*		*	*
Cnidaria	*Leptopsammia pruvoti*			*

Regarding the thanatocoenosis, a total of 6555 specimens belonging to 83 species were collected in the detritus. The richest station in term of abundance and taxa was site B, whereas site C was the poorest. The main taxonomic groups were: molluscs (90%), echinoderms (9%) and brachiopods (1%); of the molluscs, 56% were gastropods, 43.7% bivalves and 0.3% scaphopods (Tab. 3). Of the 83 species, only 5 species were detected as living organisms, accounting for 28% of the total specimens collected as the thanatocoenosis. Twelve species were found at all sampling stations and represented 36% of total abundance (Tab. 3).

DISCUSSION AND CONCLUSIONS

Submarine caves are mostly found around the islands and islets in the area of the open Adriatic and along the eastern rocky shore; they are fairly scarce in the other parts of the Adriatic Sea. The hard substrate community inside caves is characterized by the presence of the circalittoral biocoenosis of semi-dark caves (Gamulin-Brida, 1967) or GSO (Grottes Semi-Obscures) (Pérès & Picard, 1964). This biocoenosis comprises only animals, and sponges represent the dominant fauna (Pérès & Picard, 1964). In the Columbera cave, more than 70% of sessile fauna were sponges. The following species characterized the GSO biocoenosis: *Aplysina cavernicola*, *Petrosia ficiformis* (Fig. 4), *Oscarella lobularis*, *Agelas oroides* (Porifera); and *Parazoanthus axinellae* (Fig. 5) and *Leptposammia pruvoti* (Pérès & Picard, 1964) (Cnidaria). The sponge *Aplysina aerophoba*, characteristic of the infralittoral biocenosis of photophilic algae, was found nearby the entrance and in the middle zone of the cave. Some species common in the sciaphilic niche of this biocenosis or present in the circalittoral biocenosis of rocks in the open sea are also present in the GSO biocoenosis: *Axinella verrucosa* (Fig. 5) (Porifera), *Echinaster sepositus* (Echinodermata), *Bonellia viridis* (Echiurida), *Diplosoma listerianum* and *Halocynthia papillosa* (Tunicata), *Hornera frondiculata* (Bryozoa), as well as *Myriapora truncata* (Bryozoa), a species characteristic in the circalittoral biocenosis of coralligenous (Pérès & Picard, 1964; Gamulin-Brida, 1967, 1974).

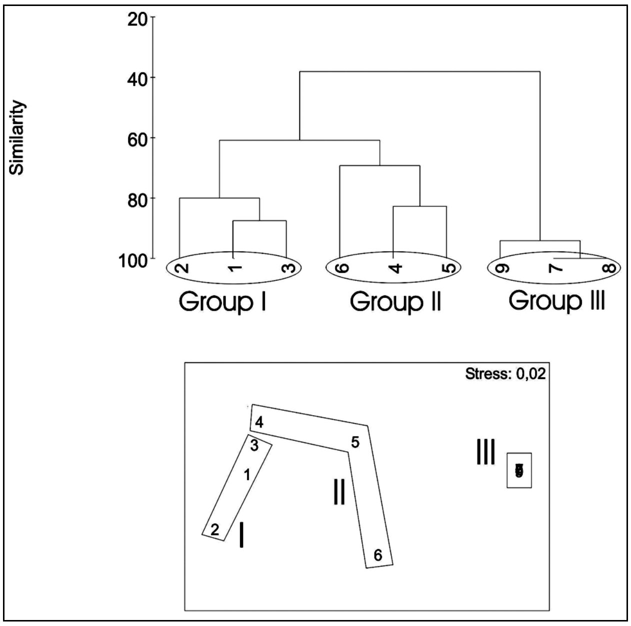

Fig. 3: (Top) Hierarchical classification and (bottom) multidimensional scaling (MDS) of the hard bottom community.
Sl. 3: (Zgoraj) Hierarhična klasifikacija in (spodaj) večdimenzionalno skaliranje (MDS) združbe, živeče na trdem dnu.

Cluster analysis and MDS clearly showed a separation among the inner area of the cave and the entrance up to the middle portion. Group III showed a reduction in the number of species (True, 1970; Gili *et al.*, 1986), and the populations constituted of species capable of living in the inner area of semi-dark caves (Bianchi & Morri, 1994, 1999): in particular, *L. pruvoti* was present only at this site, and small serpulids, characteristics of dark caves, (Bianchi & Morri, 1994) were noted.

At the entrance, all species present at the other stations inside the cave were found, with the exception of *H. frondiculata*, *A. cavernicola* and *L. pruvoti*. *D. listerianum* and *H. papillosa* disappeared in the middle portion, where *H. frondiculata* was recorded and *A. cavernicola* appeared. Among the motile fauna we observed, at the entrance, the opistobranch *Flabellina affinis* and *Cratena peregrina*, the echiurid *B. viridis* and the echinoderm *E. sepositus*, whereas an individual of the cnidarian *Cerianthus membranaceus* was found in the soft bottom of the middle area. Finally, many individuals of the opisthobranch *Discodoris atromaculata* feeding on the sponge *P. ficiformis* (Cattaneo-Vietti *et al.*, 1990; Jaklin, 1998; Turk, 2000) were found between the entrance and the bottom.

Tab. 2: Soft bottom community.
Tab. 2: Združba mehkega dna.

Station	A	B	C
Mollusca			
Cerithium vulgatum			1
Bittium latreillii	3		2
Polinices nitida			1
Marshallora adversa	1		
Muricopsis cristata	2		1
Nassarius incrassatus	1	1	
Myrtea spinifera	1		
Plagiocardium papillosum	1		1
Polychaeta			
Paraonidae non ident.	1	1	
Pseudoleiocapitella fauveli	5	7	
Capitellidae non ident.	8		
Glycera rouxii	1		
Glycera unicornis	2	1	
Nereidae non ident.			1
Nephtys hombergi	1	1	
Sthenelais sp.	1		
Aponuphis bilineata	11	15	
Eunice vittata	2		
Marphysa bellii	1	1	
Sabellidae non ident.	11	2	
Sipunculida			
Aspidosiphon mulleri+	54	2	6
Crustacea			
Athanas nitescens	1		
Anisopoda	1		
Amphipoda	1		
Echinodermata			
Amphiura chiajei+	25	16	1
Schizaster canaliferus	1		
Total abundance	**136**	**47**	**14**
Total No. of species	**23**	**10**	**8**

+ Species present in each sampling station.

In the inner area of the cave, 9–11 m, no organisms were found and the visibility was limited owing to the inflowing spring freshwater. The ceiling of this area and of another portion of the cave, directly influenced by two freshwater springs, was completely defaunated with evident erosion phenomena.

The macrofauna inhabiting the soft bottom did not show any clear zonation, either in terms of species richness or abundance, from the entrance to the bottom of the cave, as opposed to the case for solid substrata. *Amphiura chiajei* (Echinodermata) and *Aspidosiphon mulleri* (Sipunculida) were the most abundant species, the former being common in coastal detritic bottoms more or less mixed with mud (Gamulin-Brida, 1967), the latter inhabiting *Turritella communis* shells, the latter being characteristic for the circalittoral biocenosis of the coastal terrigenous muds (Gamulin-Brida, 1967) or VTC (Vases Terrigènes Cotieres) (Pérès & Picard, 1964; Gamulin-Brida, 1974). Most of polychaetes found are common in the soft bottoms of the northern Adriatic Sea (Aleffi *et al.*, 2003) and the species recorded are not specific to particular biocoenoses or sediment texture. The same considerations are valid for other taxa, except for *Plagiocardium papillosum* and *Schizaster canaliferus*, which are considered to prefer the circalittoral biocenosis of sand-detritus more or less mixed with mud (DC-E) (Gamulin-Brida, 1974). Gastropods shells constituted about 50% of shell detritus and most of them are common on the solid substrata in the infralittoral and mediolittoral zones (Vio & De Min, 1999), such as *Bittium reticulata* and *Diodora* sp. Some species are restricted to or prefer the infralittoral biocenosis of photophilic algae, such as: *Columbella rustica*, *Patella caerulea*, *Cerithium vulgatum* and *Rissoa variabilis* (Gamulin-Brida, 1967, 1974). Many of bivalve shells present are commonly found in detritic bottoms and some species are considered characteristics or preferential of the circalittoral biocenosis of coastal detritic bottoms like: *Pitar rudis*, *Venus casina*, *Tellina balaustina*, *P. papillosum*, *Lima hians*, *Chlamys varia* and *C. flexuosa* (Gamulin-Brida, 1967, 1974). Among endolitic bivalve burrowers, *Lithophaga lithophaga* lives also abundantly in the boring holes on the rock round Rijeka Bay from the lower mediolittoral zone down to 13 m depth (Hrs-Brenko *et al.,* 1998).

The faunal composition and zonation on solid substrata in Columbera cave were similar to those described in a submarine cave near Vrbnik on the Island of Krk (Arko-Pijevac *et al.*, 2001): but the number of taxa in Columbera cave (Porifera 15, Cnidaria 3 and Echinodermata 2) was always lower than in the latter cave (Porifera 22, Cnidaria 7 and Echinodermata 5).

Although the length of the cave and its entrance location are not as deep as at Vrbnik cave, this study revealed a marked horizontal zonation within the animal communities inhabiting the walls (Laborel & Vacelet, 1958; Laborel, 1960; Pérès & Picard, 1964; Gili *et al.*, 1982; Bibiloni *et al.*, 1984), even if not considering the abundance and the cover of sessile fauna. Species that are characteristic or common in the biocenosis of rocks in the open sea were found. This biocenosis occurs at the boundary between the circalittoral and bathyal zone, near the break in the slope of the continental plateau (Gamulin-Brida, 1967). Reduced light penetration and slow water circulation are probably the main environmental parameters to permit the settlement of these species in few meters depth, thus showing some similarities with the bathyal zone (Arko-Pijevac *et al.*, 2001). Below

Fig. 4: *Discodoris atromaculata* ***(Foto: B. Furlan).***
Sl. 4: *Discodoris atromaculata* ***(Foto: B. Furlan).***

1% of superficial light intensity, benthic populations are markedly sciaphylic (Bianchi & Morri, 1999), and sciaphylic organisms, mostly sponges and cnidarians, were observed just several meters under the sea surface in the crevices of breakwater dams in the Gulf of Trieste (Bettoso *et al*., 1999). In this area, Orel & Specchi (1967) already pointed out the role of light conditions and substratum morphology as the main features determining the zonation of benthic organisms in a cavity of the tidal zone. Water circulation determines the structure of benthic populations in caves (Bianchi & Morri, 1999). Gili *et al*. (1986) found no gradient for temperature, salinity, oxygen, chlorophyll *a* or suspended particles, suggesting a constant circulation within the caves which guarantees water-exchange. In Columbera cave, the

Tab. 3: Thanatocoenosis.
Tab. 3: Tanatocenoza.

Station	A	B	C
Gastropoda			
Alvania aspera	8	6	
Alvania cancellata	49	45	
Alvania cimex	313	258	
Alvania geryonia	38	27	
Bittium reticulata	243	157	
Bolma rugosa	1	2	
Calliostoma laugieri	9	13	
Cerithiopsis minima	5	7	
Cerithiopsis tubercolaris	9	6	
Clanculus corallinus	9	24	
Clanculus cruciatus	3	2	
Diodora graeca		10	
Diodora italica+	45	61	1
Emarginula octaviana	41	75	
Emarginula sicula	3	19	
Epitonium aculeatum	12	7	
Epitonium commune	48	22	
Eulimia bilineata	1	2	
Fusinus rostratus	31	41	
Haliotis lamellosa+	12	70	1
Homalopoma sanguineum	1		
Jujubinus exasperatus	22	35	
Leiostraca glabra	3	1	
Mangelia multilineolata	5	3	
Mangelia stossiciana	50	52	
Mangelia unifasciata	39	16	
*Marshallora adversa**	152	171	
Mitra nigra	2	4	
*Muricopsis cristata**	273	192	
*Nassarius incrassatus**	172	105	
Patella caerulea		6	
Patella ulyssiponensis+	8	2	12
Philiberthia bofilliana	4		
*Polinices nitida**	30	16	
Raphitoma linearis	18	24	
Rissoa guerrinii	10	18	
Rissoa splendida	16	7	
Rissoa variabilis	17	13	
Rissoina bruguieri	13	8	
Tricolia pullus	2		
Turritella communis	33	11	
Vexillum tricolor	3	3	
Bivalvia			
Nucula nitidosa	9	16	
Abra tenuis	15	1	
Acanthocardia echineata	22	11	
Anodonthia fragilis	11	52	
Anomia ephippium	6	4	
Arca noae+	2	11	1
Arca tetragona	7	19	
Azorinus chamasolen	4	5	
Barbatia barbata+	110	158	23
Chlamys flexuosa		1	
Chlamys multistriata	28	41	
Chlamys varia+	312	364	73
Coralliophaga litophagella	2	6	
Corbula gibba	2	2	
Ctena decussata		1	
Cuspidaria cuspidata		1	
Gouldia minima	14	4	
Hiatella arctica	75	101	
Irus irus	5	2	
Lima hians+	4	36	4
Lithophaga lithophaga+	6	8	4
Mytilaster minimus+	1	1	12
Nuculana pella	1	1	
Palliolum incomparabile		2	
Parvicardium exiguum	51	21	
Pitar rudis	11	3	
*Plagiocardium papillosum**+	240	279	28
Pseudochama gryphina+	19	48	17
Scrobicularia cottardi	27	29	
Spondylus gaederopus	1		1
Tellina balaustina	87	49	
Thyasira flexuosa		1	
Timoclea ovata	6	6	
Venus casina+	9	39	4
Venus verrucosa	7	2	
Scaphopoda			
Dentalium vulgare	1		
Dentalium inaequicostatum	10	9	
Fustiaria rubescens		1	
Brachiopoda			
Argyroteca cordata		1	
Argyroteca cuneata	25	12	
Echinodermata			
Echinocyamus pusillus	151	451	
Total abundance	3034	3340	181
Total No. of species	74	78	13

+ Species present in each sampling station.
* Species detected as living organisms.

output of freshwater flowing along the ceiling draws the external sea water inside the cave. This fact might promote the water-exchange, although defaunation was observed at sites directly influenced by spring activity. The lack of zonation of the soft bottom community could be related to spring activity, which disturbs sedimentary patterns and consequently community structure. Thus no indicative soft bottom benthic community was present in the cave. The cave probably constitutes a deposit zone for shell detritus coming from outer area because the entrance is open to southern and northern winds (mainly the wind known as "bora").

BENTOŠKA MAKROFAVNA PODMORSKE JAME V ISTRI (HRVAŠKA)

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POVZETEK

Podmorske jame najdemo predvsem ob otokih v odprtem delu Jadranskega morja in vzdolž njegove vzhodne skalnate obale. V istrski jami, imenovani Columbera, obstajata dva izvira sladke vode, kar je značilen pojav kraške hidrografije. Podmorske jame so habitati posebne vrste: parametri, kot so svetloba, vsebnost hranil in kroženje vode, se občutno zmanjšajo že po nekaj metrih in tako vplivajo na izjemen izbor vrst. Trda podlaga v jami je dom cirkalitoralne združbe slabo presvetljenih vodnih okolij, medtem ko med združbami, živečimi na steni jame, obstaja očitna horizontalna conacija. V makrofavni, ki poseljuje mehko dno, ni bilo zaslediti jasne conacije, kar zadeva gostoto in številčnost vrst. Vrste, živeče na mehkem dnu, so značilne za obalno detritično dno, bolj ali manj pomešano z glenom. Dejstvo, da tu ni conacije, bi lahko pripisali sladkovodnima izviroma, ki moteče delujeta na sedimentne vzorce in zatorej tudi na strukturo tam živeče združbe.

Ključne besede: makrobentos, podmorska jama, severni Jadran, Hrvaška

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