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A SUBMARINE CAVE AT THE ISLAND OF KRK (NORTH ADRIATIC SEA)

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A submarine cave near Vrbnik (the island of Krk, Croatia) is 30 m long and has the shape of an irregular triangular prism, with its bottom covered by mud and boulders. Formed in Upper Cretaceous limestone under terrestrial conditions, probably during the Würm glaciation it was submerged during the Holocene rise in the sea-level. Preliminary biocenological studies revealed 23 taxa of macroflora at the cave entrance and 115 taxa of macrofauna (22 Porifera, 7 Cnidaria, 19 Bivalvia, 6 Gastropoda, 1 Cephalopoda, 1 Echiura, 1 Sipuncula, 8 Polychaeta, 15 Crustacea, 6 Bryozoa, 5 Echinodermata, 4 Tunicata, 20 Pisces). Malacostraca comprised 13 species of Decapoda and 2 species of Mysidiacea. Among the fishes only *Gammogobius steinitzi* is considered to be an exclusive cave inhabitant. The goby *Thorogobius ephippiatus* is by far the most abundant fish. From the cave entrance and up to 3 m into the cave a precoralligenous aspect of coralligenous biocenosis was registered. The biocenosis of semi-dark caves dominated by Porifera fauna occurs up to 25 m into the cave, while the final 5 m are characterised by biocenosis of caves and ducts in complete darkness with a predominance of Polychaeta.

Keywords: karst, submarine cave, benthic biocenoses, fishes, crustaceans, Adriatic Sea, Croatia

Arko-Pijevac, M., Č. Benac, M. Kovačić & M. Kirinčić: Podmorska špilja kod Vrbnika (otok Krk, Vinodolski kanal). Nat. Croat., Vol. 10, No. 3., 163–184, 2001, Zagreb.

Podmorska špilja kod Vrbnika duga je 30 metara, i ima oblik nepravilne trostrane prizme. Oblikovana je u gornjokrednim vapnenačkim stijenama. Muljeviti i pjeskoviti sedimenti pokrivaju njeno dno. Nastala je u kopnenim uvjetima, tijekom Würma. U holocenu, izdizanjem morske razine špilja je potopljena. Tijekom biocenoloških istraživanja nađene su 23 svojte makroflore i 115 svojti makrofaune (Porifera 22, Cnidaria 7, Bivalvia 19, Gastropoda 6, Cephalopoda 1, Echiura 1, Sipuncula 1, Polychaeta 8, Crustacea 15, Bryozoa 6, Echinodermata 5, Tunicata 4, Pisces 20). Istraživanjem Malacostraca pronađeno je 13 vrsta dekapodnih rakova i 2 vrste mizida. Među zabilježenim ribama, samo se glavoč *Gammogobius steinitzi* može smatrati isključivim stanovnikom podmorskih špilja. Primjercima najbrojnija vrsta riba u špilji je glavoč *Thorogobius ephippiatus*. Od ulaza do 3 metra unutar špilje zabilježen je prekoraligenski aspekt koraligenske biocenoze. Biocenoza polutamnih špilja utvrđena je do 25 metara od ulaza, dok je u posljednjih 5 metara razvijena biocenoza potpuno tamnih špilja i prolaza s dominacijom Polychaeta.

Ključne riječi: krš, podmorska špilja, bentoske biocenoze, ribe, rakovi, Jadransko more, Hrvatska

INTRODUCTION

The cave is situated in the Vinodol Channel in the Adriatic Sea, on the northeastern coast of the island of Krk, Croatia (Fig 1), in an area that is part of the Dinaric karst as well as the Croatian mainland coast and islands in general. The Croatian coastal and channel area is mostly 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 of the Kvarner area (BOŽIČEVIĆ, 1992) and the island of Krk. The karstic caves and the cave systems of the Dinaric karst have been described in some detail (HERAK, 1972; BOŽIČEVIĆ *et al.*, 1980), and interpretations of the morphological evolution of the Adriatic Sea are also available (D'AMBROSI, 1969; VAN STRAATEN, 1970; COLANTONI *et al.*, 1979; PRELOGOVIĆ & KRANJEC, 1983; BRAMBATI, 1990; CORREGGIARI *et al.*, 1996). However, the data on the morphology and the morphological evolution of submarine caves in the Kvarner region are still insufficient.

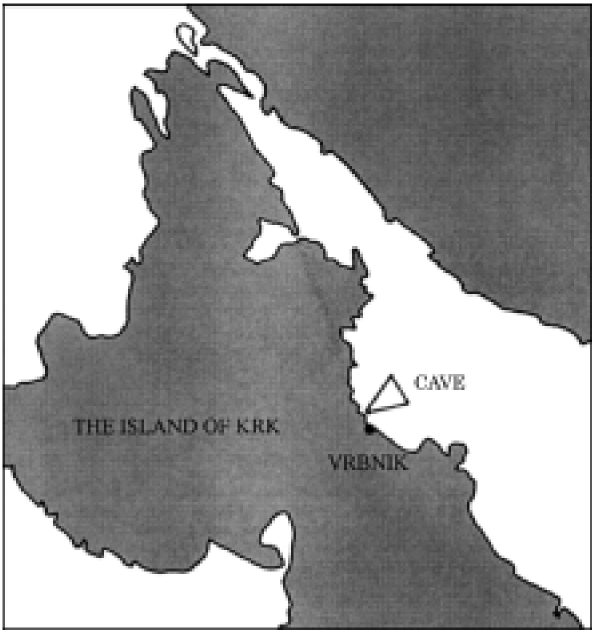

Fig. 1. Location of the sea cave investigated.

RIEDL (1966) compiled results from his research into flora and fauna in Mediterranean and Adriatic submarine caves. VACELET *et al.* (1994), VACELET (1996), HARMELIN (1997) and HERLER *et al.* (1999) provided updated data on the diversity of bryozoans, hexactinellid sponges and speleophilic fishes in the western Mediterranean Sea. One of the more recently studied caves shows close resemblance to the deep-sea environment, above all in the stable temperature conditions similar to those in the deep layers of the Mediterranean Sea (VACELET *et al.*, 1994). 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 accentuated (RIEDL, 1966, HARMELIN *et al.*, 1985, ZABALA *et al.*, 1989, BIANCHI & MORRI, 1994). With regard to hydrodynamics, nutrient level (FICHEZ, 1990; 1991a, b) and fauna composition such as sponges, anthozoans, serpulids and bryozoans (HARMELIN, 1985, HARMELIN *et al.*, 1985), dark caves show some similarities with the bathyal zone.

The present study is aimed at investigating two malacostracan groups (Decapoda and Mysidacea). There have been few data on these animal groups in the Adriatic and the Mediterranean caves (RIEDL, 1966; LEDOYER, 1968; GILI & MACPHERSON, 1987; THESSALOU-LEGAKI *et al.*, 1989; PRETUS, 1990; FRANSEN, 1991; WITTMANN, 1992).

Knowledge of Mediterranean cryptobenthic fishes has increased in recent years (AHNELT & PATZNER, 1996; HOFRICHTER & PATZNER, 1997; KOVAČIĆ, 1997; HERLER *et al.*, 1999; PATZNER, 1999a, b). However, data on fish assemblages in Mediterranean submarine caves are still rare (ABEL, 1959; RIEDL, 1966; ZANDER & JELINEK, 1976; ZANDER, 1990). The present study provides the first data on the fish assemblage in the cave near Vrbnik, except for the already published finding of *Gammogobius steinitzi* KOVAČIĆ (1999).

GEOLOGICAL CHARACTERISTICS AND GEOMORPHOLOGICAL EVOLUTION OF THE STUDY AREA

The investigated cave is situated on the north-eastern coast of the island of Krk (Fig. 1), where Cretaceous, Palaeogene, Pleistostocene and Holocene formations can be found (ŠUŠNJAR *et al.*, 1970). Cretaceous carbonate rocks (limestones, dolomites and breccias) and Palaeogene carbonate rocks (limestones and breccias) prevail in the coastal area. Palaeogene flysch (siltstone, marl and sandstone) is locally restricted. These rocks form the bedrock, which is inland partially covered by younger deposits. Terra rossa is common on carbonate rocks, but flysch is covered by weathered deposits. The sea-bottom of the Vinodol Channel is almost completely covered by Pleistocene and Holocene sediments: by gravel and sand near the coast, and by mud in deeper parts (JURAČIĆ *et al.*, 1999).

Intensive morphogenetic processes caused by tectonic movements and rapid sea level changes, as well as climatic changes, brought about the present shape of the Kvarner region. Nevertheless, traces of older morphogenetic phases during Lower and Middle Pleistocene are mostly destroyed or unrecognisable in the relief (BENAC & DURN, 1997; BENAC & JURAČIĆ, 1998).

After the Riss-Würm interglacial, in the period between 120 000–30 000 years before present (yBP), the sea level gradually decreased and oscillated between –20 m and –60 m (LOWE & WALKER, 1997). Karstifications of carbonate rocks and surface incisions caused by water flows were rather strong, most frequently reaching the depth of –50 to –60 m. As the Vinodol Channel bottoms are relatively shallow (–40 to –60m), they became the local erosional base during the fall in the sea-level.

During the relatively long Würm period, carbonate rock masses were karstified. Their morphogenesis is closely connected to tectonic movements, and therefore there are prominent differences between certain islands from the Kvarner area (BOŽIČEVIĆ, 1992).

It is considered that the majority of caves in the Kvarner area were probably formed during the Würm glacial age. Because of the sea level stagnation the fissures were enlarged at certain depths. A frequent phenomenon in the Kvarner area is the existence of the submerged caves at the depths between –20 m and –24 m (BENAC & JURAČIĆ, 1998). The cave investigated in the vicinity of Vrbnik is located at approximately this depth.

During Last Glacial Maximum some 20 000 to 25 000 yBP, the global and Adriatic sea level was lowered down to –120, or even –130 m (FAIRBANKS, 1989). In the depression of the present day the Vinodol Channel there most probably remained some freshwater lakes.

The sea began to flood the northern Adriatic area, including the Kvarner area some 18 000 years ago. A rapid rise occurred between 17 000 and 6 000 years BP (FAIRBANKS, 1989; ALLEY *et al.*, 1997). Hydrographic and sedimentary conditions similar to those of the present day appeared only after the decrease in the rise in the sea-level some 6 000 yBP (BRAMBATI, 1990; CORREGGIARI *et al.*, 1996) The sea overflowed the karst relief, and due to the fact that the input of terrigenous material was relatively small, the karstic rocky bottom remained exposed (JURAČIĆ & BENAC, 1999).

MATERIALS AND METHODS

Geological, speleological and biocenological research into the submarine cave near Vrbnik were carried out from October 1998 to August 1999 using scuba equipment. *In situ* observations and notes were complemented by photo documentation.

The cave was measured in width, height and length to the nearest 10 cm. The sediment types were classified and described by standard sedimentologic *in situ* tables (ANON, 1979).

Temperature was measured by an ordinary thermometer (°C) at 5 m depth intervals. Light was measured by a light meter inside the cave at 2.5 m distances and expressed as percentages of light measured just below the sea surface. Average abundances of flora and fauna were estimated visually according to the following degrees: r=rare and single individuals, +=common species, c=abundant species, cc=dense population, numerically prevailing species. On the basis of field notes and laboratory identification benthic communities were classified according to

PÉRÈS & PICARD (1964), as applied previously by BELLAN-SANTINI *et al.* (1994) in the Mediterranean, and by GAMULIN-BRIDA (1967) and PÉRÈS & GAMULIN-BRIDA (1973) in the Adriatic Sea.

Crustaceans were collected by hand using special baited traps and other collecting tools and relative abundance was noted during ten dives. 5% formol in 50 ml injections was used to drive the crabs out of their holes. Identification of decapods was carried out in accordance with ZARIQUIEY ALVAREZ (1968), INGLE (1993) and FALCIAI & MINERVINI (1992), while mysids were identified by Karl Wittmann (Vienna University).

Fishes were investigated during several collecting dives and six visual census dives. Visual census dives covered the entire length of the cave, and lasted for about 60 minutes each. All fish specimens were counted. However, since the checked area was difficult to estimate, the data were expressed as relative abundance and not per surface or volume of the cave.

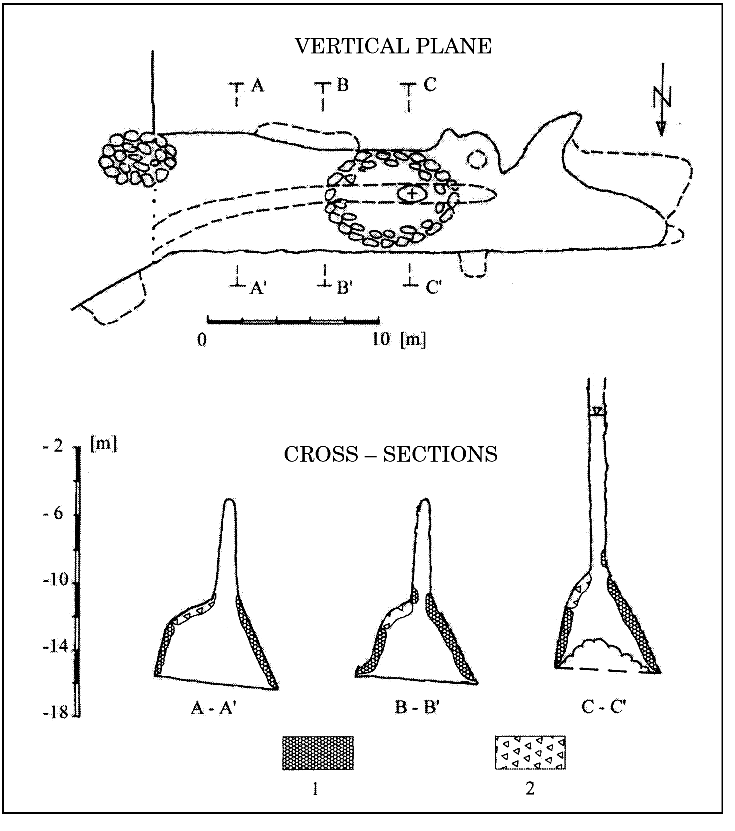

Fig. 2. Cave projection and cross-sections. Distribution of benthic communities in the cave: 1 – biocenosis of semi-dark caves with a predominant sponge fauna, 2 – biocenosis of semi-dark caves (facies *Leptopsammia pruvoti).*

RESULTS

Cave geology and morphology

The investigated cave near Vrbnik was formed in joined limestone rocks from t he Upper Cretaceous. Its position was predestined by faults, the directions of which are 70–250° and 30–210°. The cave has the shape of an irregular triangular prism, with a base of 3 to 7 m wide (Fig. 2). The cave is approximately 30 m long and 6 to 11 m high (Fig. 3). The cave entrance is about 6 m high at the depth of 11 to 17 m. Along the cave, above its ceiling, a narrow vertical crevice is noted, and a part of it (an ancient sinkhole) reaches up to the ground surface at 9 m above the sea level. Some hollows (small caves with height < length) are positioned laterally to the main cave. Allochthonous sediments completely cover the cave bottom. Coarse sand and rough organic detritus cover the bottom up to 5 m from the entrance. Muddy sand covers the front part, and quick mud covers the back part of the cave bottom. Rocky blocks (pebbles and boulders) are found near the cave entrance and below the submerged sinkhole. Stalactites and stalagmites are not evident. Other possible speleothems on the walls and the roof are completely covered by sessile organisms.

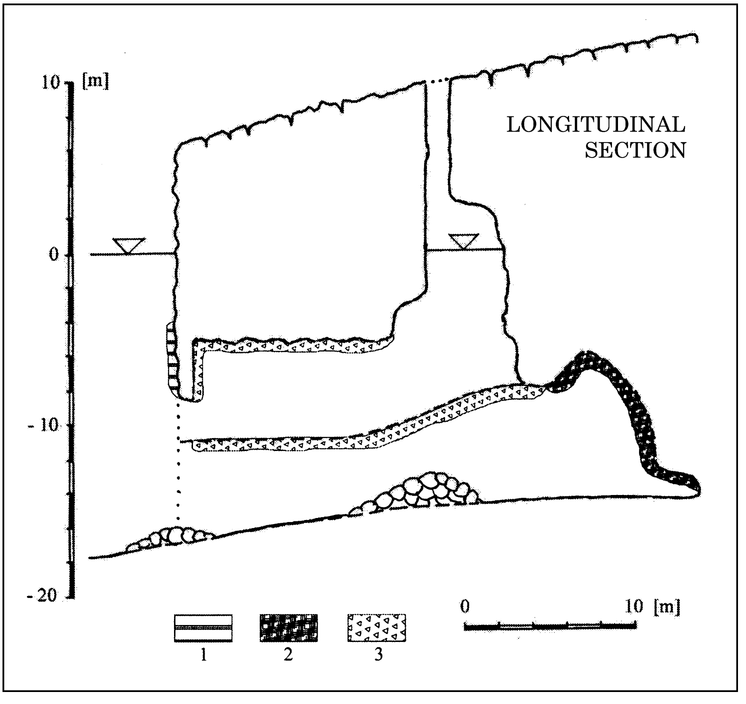

Fig. 3. Cave longitudinal section. Distribution of benthic communities in the cave: 1 – praecoralligenous aspect of coralligenous biocoenosis (facies *Parazoanthus axinellae*), 2 – biocenosis of caves and ducts in complete darkness, 3 – biocenosis of semi-dark caves (facies *Leptopsammia pruvoti).*

Light, temperature and water movement

Light intensity rapidly decreased from the cave entrance to the innermost part of the cave (>0.5% to <0.002%), but the sinkhole also contributed to the light intensity within the cave (Fig. 4). Inside the cave temperature data did not differ temperatures from the outside. Currents within the cave have not been measured but water inside the cave was brackish and more turbid after strong rains.

Biocenosis

The identified taxa are listed in Tab. 1: 23 taxa of macroflora and 115 taxa of macrofauna (22 Porifera, 7 Cnidaria, 19 Bivalvia, 6 Gastropoda, 1 Cephalopoda, 1 Echiura, 1 Sipuncula, 8 Polychaeta, 15 Crustacea, 6 Bryozoa, 5 Echinodermata, 4 Tunicata, 20 Pisces). The vegetation of macroalgae at the cave entrance is characteristic of the vertical rocks in the North Adriatic zone. From 0 to 5 metres the association of calcareous alga *Amphiroa rigida* is present. At 5–18 metres deep the red alga of the *Peyssonnelia* genus is dominant and it is the only species present at a distance of 3 metres from the cave entrance. The green alga *Cladophora prolifera* is frequent along the vertical profile at the depth of 3–18 metres. A praecoralligenous aspect of a coralligenous biocenosis extends to about 3 m inside the cave entrance (*Para-*

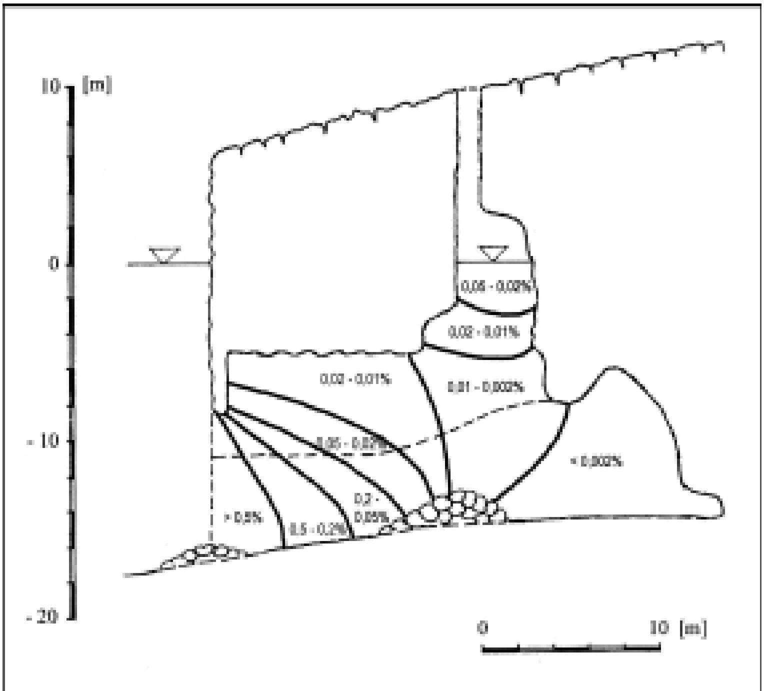

Fig. 4. Light intensity.

Tab. 1. List of recorded taxa.

Species list	Distribution and abundance				
	out		in		
	0 m	0–5 m	5–15	15–20	20–30
RHODOPHYTA					
Corallina officinalis Linnaeus		+			
Peyssonnelia squamaria (Gmel.)Dec.	cc	+			
Gelidium latifolium Born. ex Hauck	+				
Amphiroa rigida Lamour	c				
Laurentia obtusa (Huds.) Lamour	+				
Jania rubens (L.) Lam.	+				
Lithophylum sp.	r				
Hypnea musciformis (Wulf.) Lamour	r				
Sphaerococcus coronopifolius Stack.	+				
Polysiphonia sp.	+				
PHAEOPHYTA					
Padina pavonica (L.) Thivy	+				
Halopteris scoparia (L.) Sauv.	+				
Cutleria multifida (Smith) Grew	+				
Cystoseira sp.	+				
Colpomenia sinuosa (Mert.ex Roth) Derb.et Sol.	+				
Dictyota dichotoma (Huds.) Lamour	+				
Dictyota linearis (C.Ag.) Grev.	+				
CHLOROPHYTA					
Cladophora prolifera (Roth) Kutz.	c				
Codium bursa (L.) C.Ag.	+				
Codium adhaerens C.Ag.	+				
Codium tomentosum Stack	r				
Valonia utricularis (Roth) C.Ag.	+				
Udotea petiolata (Turra) Börg.	+				
PORIFERA					
Sycon raphanus O.Schmidt, 1862	r				
Oscarella lobularis (O.Schmidt, 1862)	+	r			
Chondrilla nucula O.Schmidt, 1862	+				
Spirastrela cunctatrix O.Schmidt, 1868	+	+	+	+	
Cliona celata Grant, 1826	+	+	+	+	
Cliona viridis (O.Schmidt, 1862)	+	+			
Axinella damicornis (Esper, 1794)	+	+			
Axinela verrucosa (Esper, 1794)	+	+			
Acanthella acuta O.Schmidt, 1862	+	+			
Agelas oroides (O.Schmidt, 1864)	+	r			
Hemimycale columella (Bowerbank, 1874)	+				
Crambe crambe (O.Schmidt, 1862)	r	+	+	+	
Anchinoe tenacior Topsent, 1925	+				
Haliclona rosea (Bowerbank, 1874)	+				
Haliclona cratera O.Schmidt, 1862	+	+			

Species list	Distribution and abundance				
	out		in		
	0 m	0–5 m	5–15	15–20	20–30
Petrosia ficiformis (Poiret, 1789)	+	+	+	r	
Spongia officinalis Linnaeus, 1759	+				
Ircinia variabilis (O.Schmidt, 1862)	+	+			
Ircinia sp.	+	+			
Aplysina aerophoba (O.Schmidt, 1862)	+				
Aplysina cavernicola Vacelet,1959	+	cc	c	r	
Porifera indet.				+	+
CNIDARIA					
Serturalella sp.	+				
Cerianthus membranaceus (Spallanzani, 1784)				r	
Parazoanthus axinellae O.Schmidt, 1862	cc	+			
Aiptasia mutabilis (Gravenhorst, 1831)	r				
Caryophyllia inornata (Duncan, 1878)			+	+	+
Balanophyllia europaea (Risso, 1826)	+				
Leptopsammia pruvoti Lacaze-Duthiers, 1897	+	cc	cc	cc	c
BIVALVIA					
Arca tetragona Poli,1795		+	+		
Barbatia barbata (Linnaeus,1758)	+	+	+	+	
Mytilus galloprovincialis Lamarck,1819			+		
Lithophaga lithophaga (Linnaeus, 1758)	+	+	+	+	+
Chlamys varia (Linnaeus, 1758)	+	+			
Chlamys distorta (da Costa, 1778)	+	+			
Chlamys pesfelis Linnaeus, 1758			r		
Spondylus gaederopus Linnaeus, 1758				r	
Anomia ephippium Linnaeus, 1758			+	+	
Pododesmus squamula (Linnaeus, 1758)			r		
Lima lima (Linnaeus, 1758)		r	r		
Neopycnodonte cochlear (Poli,1795)			r		
Chama gryphoides Linnaeus, 1758		+	+	+	+
Pseudochama gryphina (Lamarck, 1819)			r	+	
Donax sp. juv.		r			
Venus verrucosa Linnaeus, 1758	+	+	+		
Gastrochaena dubia (Pennant, 1777)	c	c	c	+	+
Hiatella arctica (Linnaeus, 1767)		+	+		
Hiatella rugosa (Linnaeus, 1767)		+	+		
GASTROPODA					
Patella rustica Linnaeus, 1758	+				
Homalopoma sanguineum (Linne, 1758)			+	+	
Bittium reticulatum (Da Costa, 1778)	+				
Muricopsis cristata (Brocchi, 1814)		r			
Bolma rugosa (Linnaeus, 1767)	r				
Discodoris atromaculata (Bergh, 1880)	+	+	+	+	
CEPHALOPODA					
Octopus vulgaris Cuvier, 1798	r				

Species list	Distribution and abundance out 0 m	 in 0–5 m	 5–15	 15–20	 20–30
ECHIURA					
Bonellia viridis Rolanda, 1868		r			
SIPUNCULA					
Phascolosoma granulatum Leuckart, 1828		r			
POLYCHAETA					
Amphiglena mediterranea (Leydig,1851)	+				
Bispira viola (Grube, 1863)		r			
Sabella pavonina (Savigny, 1820)	+	r			
Sabella spallanzanii (Gmelin, 1791)		r			
Pomatoceros triqueter (Linnaeus, 1797)	+	+	+	+	c
Protula tubularia (Montagu, 1803)	+	+	+	+	c
Serpula vermicularis Linnaeus, 1797	+	+	+	+	c
Spirorbidae indet.	+	+	+	+	c
CRUSTACEA in Table 2					
BRYOZOA					
Securiflustra papyracea	+	+			
Scrupocellaria reptans Linnaeus, 1758	+				
Beania hirtissima (Heller, 1867)		+	+	+	
Smittina cervicornis (Pallas, 1766)	+				
Frondipora verrucosa (Lamouruoux, 1821)	+	+			
Lichenophora radiata (Audouin, 1826)			r		
Bryozoa indet.		+	+	+	+
ECHINODERMATA					
Holothuria polii Delle Chiaje, 1823			r		
Marthasterias glacialis (Linnaeus, 1758)			r		
Ophioderma longicaudum (Retzius, 1805)			+		
Sphaerechinus granularis (Lamarck, 1816)	+				
Paracentrotus lividus (Lamarck, 1816)	+				
TUNICATA					
Ascidia conchilega (O.F. Müller, 1776)		+	+	+	
Ascidia virginea O.F. Müller, 1776			r		
Halocynthia papillosa (Linnaeus, 1767)	+	+	+		
Microcosmus vulgaris Heller, 1877	+	+			
PISCES in Tab. 4					

zoanthus axinellae facies, Fig. 2, 3 and 5). The biocenosis of semi-dark submarine caves is represented by several facies: facies of *Parazoanthus axinellae*, facies of *Aplysina cavernicola*, and facies of *Leptopsammia pruvoti*. The facies of biocenosis of semi-dark caves with a predominant sponge fauna (Fig. 2, 3 and 6) occurs along the walls. *Aplysina cavernicola* is the dominant sponge in the front part of the cave, while deeper into the cave the most common sponges are *Spirastrella cuntatrix*, *Haliclona cratera*, *Haliclona* sp., *Agella oroides*, *Crambe crambe*. The *Leptopsammia pruvoti* facies of the biocenosis of semi-dark caves spreads along the entire cave ceiling (Fig. 2, 3 and 7). In the innermost part, 25–30 m from the entrance, the biocenosis of caves and ducts in full darkness is represented. This community is dominated by the serpulid polychaetes (the larger species being *Protula tubularia* and *Pomatoceros triqueter* and other small unidentified species) (Fig. 2, 3 and 8). The fauna of the cave floor comprise *Ascidia virginea* and *Cerianthus membranaceus*. In the cave chimney, the gastropoda *Homalopoma sanguineum* dominate in the rock crevices below 2 m in depth. The mussel population (*Mytilus galloprovincialis)* was present close to the sea surface in rock crevices inside the »chimney«. Endolithic bivalvian fauna (*Lithophaga lithophaga* and *Gastrochaena dubia*) and epilithic species of the genus *Chama* were widespread along the entire cave.

Crustacea

Fifteen species of *Malacostraca* were identified; thirteen decapods and two mysids (Tab. 2). The spatial distribution of each species within the cave, abundance (Tab. 2) and characteristics of their habitats (Fig. 9) were assessed. All main decapod taxa were found (2 Natantia, 1 Macrura, 5 Anomura and 5 Brachyura). None of the decapods observed are strictly cave–dwelling species but several, like *Lysmata seticaudata, Galathea strigosa, Scyllarus arctus, Dromia personata, Herbstia condyliata,* are sciaphilic species often seen in marine caves (LEDOYER, 1968). The collected material contains three species (*Galathea dispersa*, *Xantho pilipes* and *Herbstia condyliata*) that

Tab. 2. Species list, abundance and distribution of crustaceans in the cave.

Species list	Abundance	Distribution out in 0 m 10 m 20 m 30 m	Habitat
Decapoda			
Lysmata seticaudata (Risso, 1816)	**cc**		**B, C, F**
Palaemon sp.	**r**		**D**
Scyllarus arctus (Linnaeus, 1758)	**+**		**D**
Pagurus anachoretus Risso, 1827	**c**		**F**
Pagurus prideaux Leach, 1815	**r**		**F**
Pagurus chevreuxi (Bouvier, 1896)	**c**		**F**
Galathea dispersa Bate, 1859	**+**		**G**
Galathea strigosa (Linnaeus, 1861)	**cc**		**A, B, C**
Dromia personata (Linnaeus, 1759)	**r**		**D**
Xantho pilipes A. Milne-Edwards, 1867	**r**		**E**
Pilumnus spinifer H. Milne Edwards, 1834	**+**		**G**
Herbstia condyliata (Fabricius, 1787)	**+**		**C**
Maja crispata Risso, 1827	**r**		**E**
Mysidacea			
Hemimysis speluncola Ledoyer, 1963	**cc**		**C, F, H**
Siriella gracilipes (Nouvel, 1942)	**cc**		**C, F, H**

Fig 5. Precoralligenous aspect of coralligenous biocoenosis (facies *Parazoanthus axinellae*).

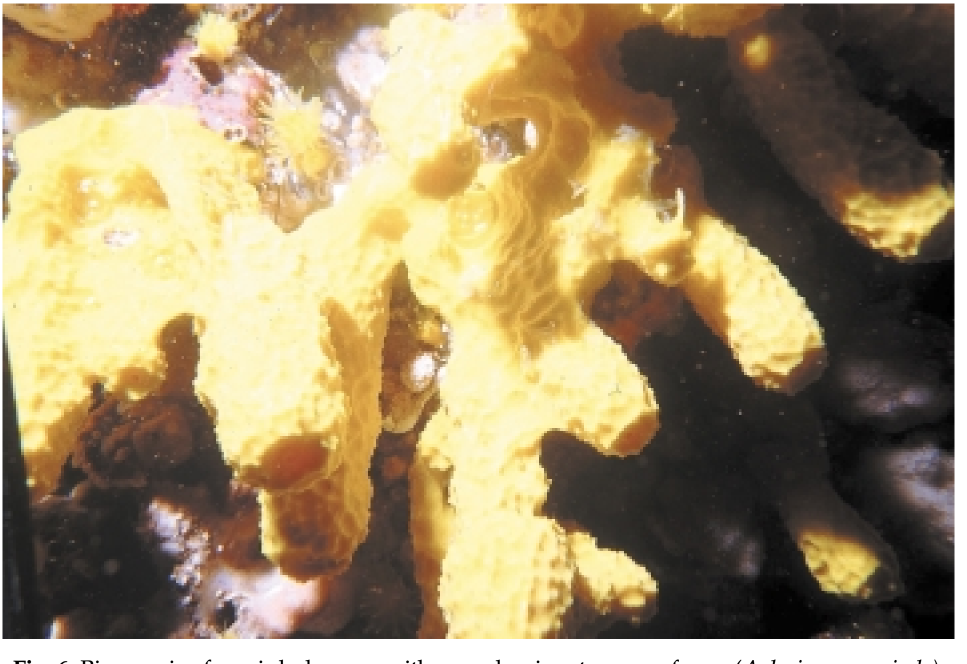

Fig. 6. Biocenosis of semi-dark caves with a predominant sponge fauna (*Aplysina cavernicola).*

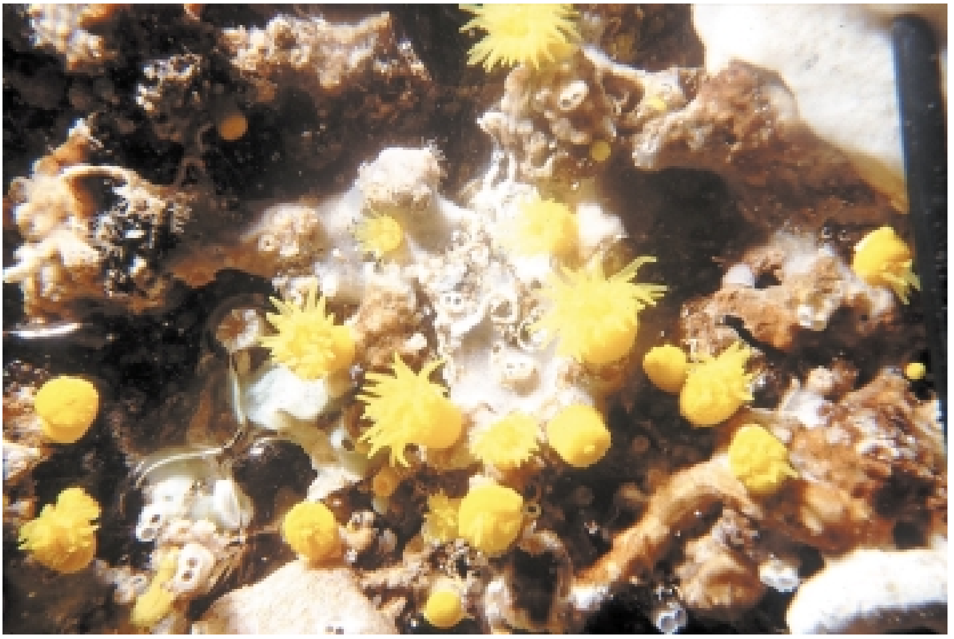

Fig. 7. Biocenosis of semi-dark caves, facies *Leptopsammia pruvoti*.

Fig. 8. Biocenosis of caves and ducts in full darkness.

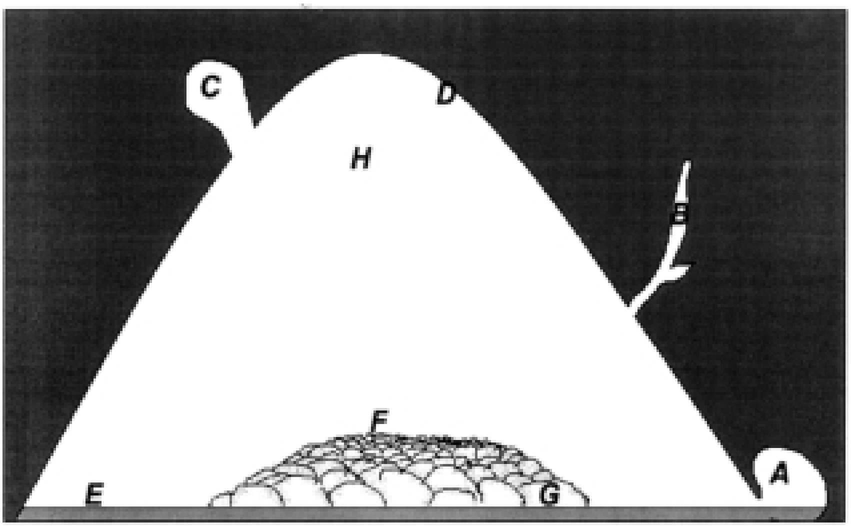

Fig. 9. Crustacean microhabitats in the sea cave. Key to symbols: A – cavities at the edge of the muddy floor, B – crevices in the walls, C – concavities in the walls, D – plain surface of the walls, E – muddy floor, F – rocky floor (scree), G – spaces between stones, H – free water.

can be considered relatively rare for the Adriatic Sea (ŠTEVČIĆ, 1990). The record of the hermit crab *Pagurus chevreuxi* is the first for the Adriatic Sea. *P. chevreuxi* has previously been recorded in various circalittoral habitats (corraligenous biocenosis, biocenosis of semi-dark caves and biocenosis of caves and ducts in full darkness in the Mediterranean) (LEDOYER, 1968). The size of the presently collected *Herbstia condyliata* specimens (60 mm) exceeded the maximum size noted previously (FALCIAI & MINERVINI, 1992). All recorded mysid species are widely distributed in the Mediterranean (WITTMANN, personal communication) and noted like ordinary species for cave-dwelling fauna (LEDOYER, 1968).

Pisces

Seven out of the 20 fish species were observed regularly (Tab. 3). Cryptic gobies (*Thorogobius ephippiatus*, *Corcyrogobius liechtensteini*, and *Gammogobius steinitzi*) are common inhabitants of the investigated cave, and the most abundant species. *G. steinitzi* occurred only inside the cave, while *T. ephippiatus* and *C. liechtensteini* were also found in cryptic habitats outside the cave (Tab. 4), *T. ephippiatus* in front of the cave at the depth of 17–20 m, in cavities with a sandy bottom and *C. liechtensteini* above the cave entrance, in small holes bored in the rock wall. Within the cave, these gobies have different microhabitat preferences. *C. liechtensteini* is abundant on walls and ceilings of the entrance area, rich in sessile invertebrates. *G. steinitzi* resides on poorly covered ceilings and walls in the innermost cave area. *T. ephippiatus* is mostly abundant on the fine sediment bottom of the back part and lateral cavities,

Tab. 3. Frequency of occurrence and relative abundance of fish species observed in the cave.

Species observed during every dive in the cave (6/6)
Counted more than 20 specimens during a 60′ dive
Thorogobius ephippiatus
Counted between 5 and 19 specimens during a 60′ dive
Corcyrogobius liechtensteini
Gammogobius steinitzi
Counted 4 or less specimens during a 60′ dive
Labrus bimaculatus
Serranus hepatus
Serranus scriba
Thorogobius macrolepis
Species observed in 3/6–5/6 dives in the cave
Chromis chromis
Coris julis
Diplodus annularis
Gobius cruentatus
Lipophrys nigriceps
Parablennius rouxi
Phrynorhombus regius
Scorpaena notata
Species observed only once or twice within the cave (1/6–2/6)
Conger conger
Gobius geniporus
Oblada melanura
Scorpaena porcus
Scorpaena scrofa

but it also shares poorly covered ceilings and walls with *G. steinitzi*. *T. ephippiatus* is the only fish species present in the shallower part of the sinkhole at 2 to 6 m depth.

Thorogobius macrolepis lives on the sediment bottom near the rocky shelters in the front part of the cave where the conditions are in accordance with the usual open bottom habitat of this species (AHNELT & KOVAČIĆ, 1997). Compared to the closely related *T. ephippiatus*, it resides in a microhabitat more exposed to light. Around the boulder scree below the sinkhole, *T. macrolepis* is present at the front, and *T. ephippiatus* at the back of the agglomeration. *T. macrolepis* is not a real cave inhabitant, like various less often registered epibenthic and cryptobenthic fishes found along the walls and the ceiling of the entrance area (Blenniidae, Scorpaenidae) or at the bottom (Gobiidae) (Tab. 3 and 4). *Phyrnorhombus regius* is the first flatfish (Pleuronectiformes) noticed as common in cave habitats. Specimens of different size were observed on the bottom, but also on low slope cave walls.

Among hyperbenthic fishes, three species were observed during each dive: *Labrus bimaculatus*, *Serranus hepatus*, *Serranus scriba*, which reveals their strong preference for this habitat (Tab. 3). They were also found in the innermost part of the cave, as

Tab. 4. Distribution of fishes within the cave (▬). Species present only at the ceilings and walls (═), species present only at the bottom (▪ ▪ ▪): O – outside the cave opening, I – front part of cave, II – middle part, III – back part, IV – »chimney«.

	O	I	II	III	IV
Blenniidae					
Lipophrys nigriceps (Vinciguerra,1883)	═	═			
Parablennius rouxi (Cocco,1833)	═	═			
Congridae					
Conger conger (Linnaeus, 1758)			▬		
Gobiidae					
Corcyrogobius liechtensteini (Kolombatović, 1891)	═	═	═		
Gammogobius steinitzi Bath, 1971		═	═	═	
Gobius cruentatus Gmelin, 1789	▪ ▪ ▪	▪ ▪ ▪			
Gobius geniporus Valenciennes, 1837	▪ ▪ ▪	▪ ▪ ▪			
Thorogobius ephippiatus (Lowe, 1839)	▬	▬	▬	▬	▬
Thorogobius macrolepis (Kolombatović, 1891)	▪ ▪ ▪	▪ ▪ ▪	▪ ▪ ▪		
Labridae					
Coris julis (Linnaeus, 1758)	▬	▬			
Labrus bimaculatus Linnaeus, 1758		▬	▬	▬	
Pomacentridae					
Chromis chromis (Linnaeus, 1758)	▬	▬			
Scophtalmidae					
Phrynorhombus regius (Bonnaterre, 1788)	▬		▬		
Scorpaenidae					
Scorpaena scrofa Linnaeus, 1758		▬			
Scorpaena notata Rafinesque, 1810	═	═	═		
Scorpaena porcus Linnaeus, 1758	▬	▬			
Serranidae					
Serranus hepatus (Linnaeus, 1758)	▬	▬	▬	▬	
Serranus scriba (Linnaeus, 1758)	▬		▬	▬	
Sparidae					
Diplodus annularis (Linnaeus, 1758)	▬	▬			
Oblada melanura (Linnaeus, 1758)	▬			▬	

was the rarely noticed *Oblada melanura* (Tab. 4). Other rarely seen hyperbenthic fishes (*Chromis chromis, Coris julis, Diplodus annularis*) were present only in the front part of the cave.

The three common gobiid species of the investigated cave are associated with different biocenosis and facies. C. *liechtensteini* occurs in the precoralligenous facies of the corallinous biocenosis and in the biocenosis of semi-dark caves, in the facies of *P. axinellae* and the facies of *L. pruvoti*. *T. ephippiatus* and *G. steinitzi* occur in the biocenosis of caves and ducts in full darkness, and in the biocenosis of semi-dark caves, in the facies with predominant sponge fauna and in facies of *L. pruvoti*. *T. ephippiatus* is also common on the fine sediment bottoms of the innermost part and in the sinkhole whose fauna could not be characterized synecologically. Regular hyperbenthic visitors (*L. bimaculatus, S. hepatus, S. scriba*) were noticed in all types of communities, the shallow part of the sinkhole excepted.

DISCUSSION

The investigated cave near Vrbnik was formed under terrestrial conditions in Upper Cretaceous limestone rocks, probably during Würm glacial age, when the sea level fell and oscillated between –20 m and –60 m (LOWE & WALKER, 1997). The position of the cave was determined by faults with directions of 70–250° and 30–210°. The water flow enlarged the fissures and washed away material in the crush belt. The rocky blocks on the bottom of the cave fell down from the ceiling. The ancient sinkhole is the opening leading towards the surface. During the last Holocene rise in the sea level (CORREGGIARI *et al.*, 1996), waves enlarged the existing cave and destroyed the speleothems. Therefore, no speleothem cave formations were found. This evidence could indicate tectonic activity, sea-level variations and climatic changes. Caves of similar morphology were discovered on the Istrian peninsula (BOŽIČEVIĆ, 1983).

Fine-grained particles in the cave bottom could originate from flysch around the Vrbničko polje, because during rainy periods the seawater in the cave is very muddy. Coarse-grained particles could be formed by processes of marine erosion and bioerosion of limestone rocks.

The submarine cave near Vrbnik shows similarities to the cave communities with biocenosis distributed in the circalittoral zone. This is especially evident with regard to sponge fauna (*Aplysina cavernicola, Agelas oroides, Spirastrela cuntatrix, Reniera sarai, Petrosia ficiformis, Axinella verrucosa, Axinella damicomis, Acanthella acuta*). No typically cave anthozoans have been found, but some recorded species are widely distributed in the circalittoral zone and in infralittoral semicaves (*Parazoanthus axinellae, Leptopsammia pruvoti, Caryophyllia inornata*). Occasionally *Ascidia virginea* specimens (Tunicata) can be noticed on the muddy bottom, at just 5–15 m depth although this species was previously noted in the circalittoral depth zone. The gastropod *Homalopoma sanguineum* was also reported to occur in deeper sea and it is considered a rare species (PARENZAN, 1974; RIEDL, 1983). The ostreid *Neopycnodonta cohlear* is supposed to be characteristic at depths of 30–1000 m (PARENZAN, 1976) but we have found it inside the cave at a depth of only 10 m. A part of the recorded bryozoan fauna is otherwise common in circalittoral zone. The decrease and even absence of light caused the presence of circalittoral species in this cave located in the upper infralittoral zone. Among the Mediterranean caves studied by RIEDL (1966), three (Vinca, Prvić and Žrnovnica) are in the Kvarner area close to the presently studied cave. However, the RIEDL (1966) studies and more recently published research on the fauna and ecological factors of caves (VACELET *et al.*, 1994; VACELET, 1996; HARMELIN, 1997 and HERLER *et al.*, 1999) did not include biocenological descriptions of caves. The finding of the nudibranch *Discodoris atromaculata* on the sponges *Petrosia ficiformis, Spirastrella cuntractis* and *Haliclona* sp. along the entire cave shows that this species does not live and feed only on *Petrosia ficiformis* (CATTANEO-VIETTI *et al.*, 1990).

The decapods are, along with the fish, one of the main mobile parts of the biocenoses and facies of the semi-dark caves. They are also present in the praecoralligenous aspect of the biocenosis of coralligenous bottom at the cave entrance. Along the cave they are distributed in a similar way as in microhabitats described in other communities. This group was not encountered in the biocenosis of caves and ducts in full darkness of the innermost part of the cave. Here, the mysids occur in large numbers. Along with some polychaets, they are the main community members. Most of the decapods studied live solitarily, hidden in holes, crevices or under rocks (Fig. 9). Mysids on the contrary live in swarms slowly floating through the rear space of the cave.

The fish assemblage in the investigated cave near Vrbnik is different from those from previous cave studies data (ABEL, 1959; RIEDL, 1966; ZANDER & JELINEK, 1976; ZANDER, 1990). The most common and abundant species of the Vrbnik cave (*T. ephippiatus*, *C. liechtensteini*, and *G. steinitzi*) were not mentioned as components of the described fish assemblages in caves in previous papers. *T. ephippiatus* was reported at Banjole (ZANDER & JELINEK, 1976) and Prvić islands (RIEDL, 1966), but outside caves at about 30 m depth. The difference between the present and previous studies of submarine cave fishes is in the type and size of the investigated caves. RIEDL´s (1966) topographic, and especially functional definitions of sea caves cover a large scale of hidden habitats. Almost all known data on Mediterranean fish assemblages in caves include caves of limited size (<10 m long), and even other, smaller cryptic spaces within the bedrock. A distinction and definition of caves, cavities, hollows and crevices were recently given by HERLER *et al.* (1999) and PATZNER (1999a). Many species mentioned in previous papers (ABEL, 1959; RIEDL, 1966; ZANDER & JELINEK, 1976; ZANDER, 1990) as cave dwellers were actually cryptobenthic fishes of other hidden habitats. Fish assemblage was described for only one Mediterranean cave (Banjole, about 30 m long) of the size similar to the Vrbnik cave (ZANDER & JELINEK, 1976). Furthermore, the size of the Banjole cave is of limited importance since the two most important cave abiotic factors, decreasing light and decreasing water movement are retarded by the cave position in shallow depths (most of the cave ceilings are above the sea surface). This probably enabled the species elsewhere noted as acrophilic: *Speleogobius trigloides* (FESSER, 1980; KOVAČIĆ, 1997) and *Pomatoschistus pictus adriaticus* (MILLER, 1986) to enter deeply into the Banjole cave (ZANDER & JELINEK, 1976). Many epibenthic and cryptobenthic fish species, especially those whose distribution is restricted to shallow depths (Blenniidae, Tripterygiidae, some Gobiidae) were enlisted as the part of cave fauna in previous papers. Only a part of them (*Lipophrys nigriceps, Parablennius rouxi*), as well as some hyperbenthic fishes mentioned by ABEL (1959) and RIEDL (1966) were found in the entrance area of the presently investigated cave. Some cryptic fishes deeply penetrating the Banjole grotto: *Parablennius gattorugine, Parablennius zvonimiri, Tripterygion melanurus* (ZANDER & JELINEK, 1976) have a limited depth distribution. They were observed only at rocky walls and overhangs in shallow water above the cave at Vrbnik. Fishes observed within the cave near Vrbnik are, according to the classification of ABEL (1959), speleophilic or speleoxenic species, depending on how often and how deep they were found in the cave (Tab. 3 and 4). Only *G. steinitzi* occurred exclusively in the cave (BATH, 1971; AHNELT *et al.*, 1998; KOVAČIĆ, 1999; PATZNER, 1999a).

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REFERENCES

ANON, 1979: Classification of rock and soils for engineering geological mapping., Part 1-Rock and soil materials. Report of the Commission of Engineering Geological Mapping. Bulletin of the International Association of Engineering Geology **19**, 364–371.

ABEL, E. F., 1959: Zur Kenntnis der Beziehungen der Fische zu Höhlen im Mittelmeer. Pubbl. Staz. Zool. Napoli **30** (Suppl.), 519–528.

AHNELT, H. & R. A. PATZNER, 1996: Kryptobentische Meergrundeln von den Balearen (Westliches Mittelmeer) mit Anmerkungen zum Unterartstatus von *Chromogobius zebratus levanticus* Miller, 1971. Ann. Naturhis. Mus. Wien **98B**, 529–544.

AHNELT, H. & M. KOVAČIĆ, 1997: A northern Adriatic population of *Thorogobius macrolepis* (Gobiidae). Cybium **21** (2), 149–162.

AHNELT, H., J. HERLER, S. SCEPKA & R. A. PATZNER, 1998: First record of two rare Mediterranean Gobiidae in the northern Tyrrhenian Sea. Cybium **22** (2), 183–186.

ALLEY, R. B., P. A. MAYEWSKI, T. SOWERS, M. STUIVER, K. C. TAYLOR & P. U. CLARK, 1997: Holocene climatic instability: A prominent, widespread event 8200 yr ago. Geology **25/6**, 483–486.

BATH, H., 1971: *Gammogobius steinitzi* n. gen. n. sp. aus dem westlichen Mittelmeer. Senckerbergiana biol. **52**, 201–210.

BELLAN-SANTINI, D., J.-C. LACAZE & C. POIZAT, 1994: Les biocénoses marines et littorales de Méditerranée: synthèse, menaces et perspectives. Muséum National d' Histoire Naturelle, Paris, 246 pp.

BENAC, Č. & G. DURN, 1997: Terra rossa in the Kvarner area – geomorphological conditions of formation. Acta Geographica Croatica **32**, 7–19.

BENAC, Č. & M. JURAČIĆ, 1998: Geomorphological indicators of the sea level changes during Upper Pleistocene (Würm) and Holocene in the Kvarner region. Acta Geographica Croatica **33**, 27–45.

BIANCHI, C. N. & C. MORRI, 1994: Studio bionomico comparativo di alcune grotte marine sommerse: definizione di una scala di confinamento. Mem. Ist. Ital. Speleo. Ser II **6**, 107–123.

BOŽIČEVIĆ, S., 1981: Morfološke i hidrološke karakteristike krškog podzemlja Istre. Liburnijske teme **4**, Prirodna podloga Istre, Opatija.

BOŽIČEVIĆ, S., 1992: High frequency of subterranean karst phenomena as an indicator of karstification process on the Adriatic islands. Proceeding of the International symposium: Geomorphology and Sea, Mali Lošinj, September 1992, Zagreb, 111–114.

BOŽIČEVIĆ, S., GARAŠIĆ, M. & B. JALŽIĆ, 1980: Pregled najvećih speleoloških objekata u Hrvatskoj. 7.jugoslavenski speleološki kongres, Titograd 1980, 77–86.

BRAMBATI, A., 1990: Origin and evolution of the Adriatic Sea. In: COLOMBO, G. (ed.): The Adriatic Sea: 25th European Marine Biology Symposium, University of Ferrara, 5–24.

CATTANEO-VIETTI, R., R. CHEMELLO & R. GIANNUZZI-SAVELLI, 1990: Atlas of Mediterranean nudibranchs. La Conchiglia, Roma, 264 pp.

CHAPELL, J. & N. J. SHACKLETON, 1986: Oxygen isotopes and sea level. Nature, **324**, 137–140.

COLANTONI, P., P. GALIGNAN, & R. LENAZ, 1979: Late Pleistocene and Holocene Evolution of the North Adriatic Continental Shelf (Italy). Marine Geology, **33**, 41–45.

CORREGGIARI, A., ROVERI, M., & F. TRINCARDI, 1996: Late Pleistocene and Holocene evolution of the north Adriatic Sea. – Il Quaternario. Italian Journal of Quaternary scienc. **9** (2), 697–704.

FALCIAI, L. & R. MINERVINI, 1992: Guida dei Crostacei Decapodi d' Europa. Franco Muzzio editore, Padova. 282.

FESSER, R., 1980: Zusätzliche Beschreibung von *Speleogobius trigloides* Zander & Jelinek (1976) (Gobiidae, Perciformes), sowie neue Fundorte und Freilandbeobachtungen. Verhandlungen der Zoologisch-Botanischen Gesellschaft in Wien **118/119**, 123–126.

FICHEZ, R., 1990: Decrease in allochthonous organic inputs in dark submarine caves, connection with lowering in benthic community richness. Hydrobiologia **207**, 61–69.

FICHEZ, R., 1991a: Benthic oxygen uptake and carbon cycling under aphotic and resource-limiting conditions in a submarine cave. Mar. Biol. **110**, 137–143.

FICHEZ, R., 1991b: Suspended particulate organic matter in a Mediterranean submarine cave. Mar. Biol. *108*, 167–174.

FRANSEN, C. H. J. M., 1991: *Salmoneus sketi*, a new species of alpheid shrimp (Crustacea: Decapoda: Caridea) from submarine cave in the Adriatic. Zool. Med. Leiden **65** (11), 171–179.

GAMULIN-BRIDA, H., 1967: The benthic fauna of the Adriatic Sea. Oceanogr. Mar. biol. Ann. Rev. **5**, 537–568.

GILI, J. M. & E. MACPHERSON, 1987: Crustáceos Decápodos capturados en cuevas submarinas del litoral Balear. Inv. Pesg. **51** (1), 285–291.

D'AMBROSI, C., 1969: L'Adriatico nel Quaternario. Atti del Museo Civico di Storia Naturale **26** (5), 129–175.

HARMELIN, J. G., 1985: Bryozoan dominated assemblages in Mediterranean cryptic environments. In: NIELSEN C., LARWOOD G. P. (eds.) Bryozoan: Ordovician to recent. Olsen & Olsen, Fredensborg,135–143.

HARMELIN, J. G., J. VACELET & P. VASSEUR, 1985: Les grottes sousmarines obscures: un milieu extrême et un remarquable biotope refuge. Téthys **11**, 214–229.

HARMELIN, J.-G., 1997: Diversity of bryozoans in a Mediterranean sublittoral cave with bathyal-like conditions: role of dispersal processes and local factors. Mar. Ecol. Prog. Ser. **153**, 139–152.

HERAK, M., 1972: Karst of Yugoslavia. – In: HERAK, M. & V. T. STRINGFIELD: Karst, Important Karst Region of the Northern Hemisphere. Amsterdam-London-New York, Elsevier, 25–83.

HERLER J., R. A. PATZNER, A. AHNELT & H. HILGERS, 1999: Habitat selection and ecology of two speleophilic gobiid fishes (Pisces: Gobiidae) from the western Mediterranean Sea. Marine Ecology **20** (1), 49–62.

HOFRICHTER & R. A. PATZNER, 1997: A new species of *Apletodon* from the Mediterranean Sea and the eastern Atlantic with notes on the differentiation between *Apletodon* and *Diplecogaster* species (Pisces: Teleostei: Gobiesociformes: Gobiesocidae). Senckenbergiana biologica **77**, 15–22.

INGLE, R., 1993: Hermit crabs of the northeastern Atlantic ocean and the Mediterranean Sea. Chapman & Hall, London, 495.

JURAČIĆ, M., Č. BENAC, & R. CRMARIĆ, 1999: Seabed and surface sediments map of the Kvarner Bay, Adriatic Sea, Croatia. Geologica Croatica **52** (2), 131–140.

KOVAČIĆ, M., 1997: Cryptobenthic gobies (Pisces, Perciformes, Gobiidae) and clingfishes (Pisces, Perciformes, Gobiesocidae) in the Kvarner area, Adriatic Sea. Natura Croatica **6** (4), 423–435.

KOVAČIĆ, M., 1999: *Gammogobius steinitzi* Bath, 1971, a fish new to the Adriatic Sea. Natura Croatica *8* (1), 1–7.

LEDOYER, M., 1968: Ecologie de la fauna vagile des biotopes Mediterraneens accessibles en scaphandre autonome (Region de Marseille principalement) IV. – Synthese de l'etude ecologique. Rec. Trav. St. Mar. Endoume Bull. **44** fasc. 60, 125–295.

MILLER, P. J., 1986: Gobiidae. – In: WHITEHEAD, P. J. P., M.-L. BAUCHOT, J.-C. HUREAU, J. NIELSEN & E. TORTONESE (eds): Fishes of the North-eastern Atlantic and the Mediterranean, 3. 1019–1085. UNESCO. Paris.

PARENZAN, P. 1974: Carta d'identità delle conchiglie del Mediterraneo. Vol. II Bivalvi. Ed. Bios Taras – Taranto, 1, 5–277.

PARENZAN, P. 1976: Carta d'identità delle conchiglie del Mediterraneo. Vol. II Bivalvi. Ed. Bios Taras – Taranto, 2, 283–546.

PATZNER, R. A., 1999a: Habitat utilization and depth distribution of small cryptobenthic fishes (Blenniidae, Gobiesocidae, Gobiidae, Tripterygiidae) in Ibiza (western Mediterranean Sea). Envir. Biol. Fish **55**, 207–215.

PATZNER, R. A., 1999b: Sea urchins as a hiding-place for juvenile benthic teleosts (Gobiidae, Gobiesocidae) in the Mediterranean Sea. Cybium **23** (1), 93–97.

PÉRÈS, J. M., & H. GAMULIN-BRIDA, 1973: Biološka oceanografija. Bentos. Bentoska bionomija Jadranskog mora. Školska knjiga Zagreb, 493 pp.

PÉRÈS, J. M., J. PICARD, 1964: Nouveau manuel de bionomie bentique de la Mer Méditerranée. Recl Trav. Stn. mar. Endoume **47**, 5–137.

PRELOGOVIĆ, E. & V. KRANJEC, V., 1983: Geološki razvitak područja Jadranskog mora. Pomorski zbornik **21**, 387–405.

PRETUS J. LI., 1990: Description of *Odontozona addaia* spec. nov. (Crustacea. Decapoda: Stenopodidae) from a marine cave in the island of Minorca, western Mediterranean. Zoologische Mededelingen **26**, 343–357.

RIEDL, R., 1966: Biologie der Meereshöhlen. – Paul Parey, Hamburg, Berlin, 636.

RIEDL, R., 1983: Fauna und Flora des Mittelmeeres. Verlag Paul Parey, Hamburg und Berlin, 835.

ŠTEVČIĆ, Z., 1990: Check list of the Adriatic decapod Crustacea. Acta Adriat. **31**, 183–274.

ŠUŠNJAR, M., BUKOVAC, J., NIKLER, L., CRNOLATAC, I., MILAN, A., ŠIKIĆ, D., GRIMANI, I., VULIĆ, Ž. & BLAŠKOVIĆ, I., 1970: Osnovna geološka karta, 1:100.000, list Crikvenica. Institut za geološka istraživanja, Zagreb, Savezni geološki zavod, Beograd.

THESSALOU-LEGAKI, M., FRANTZIS, A., NASSIOKAS, K., HATZINIKOLAU, S., 1989: Depth zonation in a *Parapandalus narval* (Crustacea, Decapoda, Pandalidae) Population from Rhodos Island, Greece. Estuarine, Coastal and Shelf Sience **29**, 273–284.

TOOLEY, M. J., 1993: Long Term Changes in Eustatic Sea Level. In: WARRICK, R. A., E. M. BAROROW & T. M. WIGLEY: Climate and sea level change: observations, projections and implications. Cambridge, Cambridge University Press, 81–110.

VACELET, J., N. BOURY-ESNAULT, & J. G. HARMELIN, 1994: Hexactinellid cave, a unique deep-sea habitat in the scuba zone. Deep Sea Res. Part I Oceanogr. Res. Pap. **41**, 965–973.

VACELET, J., 1996: Deep sea sponges in a Mediterranean cave. Deep-sea and extreme shallow-water habitats: affinities and adaptations. Biosys. Ecol. Ser. **11**, 299–312.

VAN STRAATEN, L. M. J. U., 1970: Holocene and Late Pleistocene sedimentation in the Adriatic Sea. Geologische Rundschau **60**, 106–131.

WITTMANN, K., 1992: Cyclomorphosis in the temperate zone Mysidacea: Evidence and possible adaptive taxonomical significance. Taxonomy, Biology and Ecology of Mysids 1992, 25–32.

ZABALA, M., T. RIERA, J. M. GILI, M. BARANGE, A. LOBO & J. PENUELAS, 1989: Water flow, trophic depletion, and benthic macrofauna impoverishment in a submarine cave from Western Mediterranean. PSZNI: Mar. Ecol. **10**, 271–287.

ZANDER, C. D., 1990: Benthic fishes of sea caves as components of mesolithion in the Mediterranean Sea. Mémories de Biospéléologie **17**, 57–64.

ZANDER, C. D. & H. JELINEK, 1976: Zur demersen Fischfauna im Bereich der Grotte von Banjole (Rovinj, YU) mit Beschreibung von *Speleogobius trigloides* n. gen. n. sp. (Gobiidae, Perciformes). Mitt. Hamburg. Zool. Mus. Inst. **73**, 265–280.

ZARIQUEY ALVAREZ, R., 1968: Crustáceos Decápodos Ibéricos. Inv. Pesq., Barcelona, 510 p.

SAŽETAK

Podmorska špilja kod Vrbnika (otok Krk, Vinodolski kanal)

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Podmorska špilja kod Vrbnika istraživana je autonomnom ronilačkom opremom od listopada 1998. do srpnja 1999. godine. Ulaz špilje nalazi se na dubini –11 do –17 m. Špilja ima oblik nepravilne trostrane prizme širine baze 3 do 7 m. Duga je otprilike 30 metara, sa visinom 6 do 11 m. U stropu uzduž špilje vidljiv je rascjep nastao proširenjem paraklaze rasjeda, čiji jedan dio poput dimnjaka izbija na površinu zemlje. Pijesak, mulj i obrušeni kameni blokovi pokrivaju njeno dno. Špilja je oblikovana u gornjokrednim vapnencima, u kopnenim uvjetima dok je morska razina bila znatno niža od današnje, vjerojatno tijekom Würma. Dizanjem morske razine u holocenu špilja je najprije proširena a zatim potopljena. Na taj način su uništeni stalaktiti i stalagmiti. Tijekom kišnih razdoblja u špilju prodire zamuljena slatka voda iz obližnjeg Vrbničkog polja.

Biocenološkim istraživanjima utvrđene su 23 svojte makroflore i 115 svojti makrofaune (Porifera 22, Cnidaria 7, Bivalvia 19, Gastropoda 6, Cephalopoda 1, Echiura 1, Sipuncula 1, Polychaeta 8, Crustacea 15, Bryozoa 6, Echinodermata 5, Tunicata 4, Pisces 20). Istraživanjem Malacostraca pronađeno je 13 vrsta Decapoda i 2 vrste Mysidacea. Dok su dekapodni rakovi predstavljali, uz ribe, glavnu mobilnu faunu biocenoza polutamnih špilja, mizidi su bili, uz polihete dominantna fauna u biocenozi potpuno tamnih špilja i prolaza. Od 20 zabilježenih vrsta riba, 7 vrsta su bile redovito prisutne u špilji. Od njih, tri glavoča su tipični stanovnici podmorskih špilja (*Thorogobius ephippiatus, Corcyrogobius liechtensteini,* and *Gammogobius steinitzi*). Samo se *G. steinitzi* može smatrati isključivim stanovnikom špilja, dok se *T. ephippiatus* i *C. liechtensteini* mogu pronaći i u drugim skrivenim staništima. Primjercima najbrojnija vrsta riba u špiljama je *T. ephippiatus*. Od ulaza do 3 metra unutar špilje zabilježen je prekoraligenski aspekt koraligenske biocenoze. Biocenoza polutamnih špilja zabilježena je do 25 metara od ulaza, na zidovima sa dominacijom spužvi (posebno vrstom *Verongia cavernicola*), a na stropu s razvijenim facijesom vrste *Leptosammia pruvoti.* Na završetku špilje, u posljednjih 5 metara nađena je biocenoza potpuno tamnih špilja i prolaza s dominacijom Polychaeta i mizida. U pukotinama i dimnjaku špilje do 2 m od površine najčešća je vrsta puž *Homalopoma sanguineum*.