

Habitats in Submerged Karst of Eastern Adriatic Coast – Croatian Natural Heritage

Due to specific geomorphologic characteristics of the Dalmatian coast type, formed primarily from karst limestone, Eastern Adriatic coast shows great diversity of habitats. This diversity is also influenced by the position of the Adriatic Basin, stretching from northwest to southeast, climatic differences along its length, and the direction of sea currents.

Habitats in the submerged karst characteristic for the Croatian side of the Adriatic Sea are anchihaline caves, sea caves, cold sea caves and pits with bathyal elements, *vruljas*, karst estuaries, submerged river canyons, submerged tuffa barriers, marine lakes, and bare karst in the sea. Though sea caves, *vruljas*, coralligen, marine lakes, and *Posidonia* beds are today threatened by direct and indirect anthropogenic influences (pollution, eutrophication, tourism, nautical tourism, coastal development, aquaculture), only a few of these habitats have been declared as areas of special interest for conservation or as threatened habitats under the relevant international conventions. There are still too few targeted studies that could contribute to better understanding of these habitats and their levels of threat. Therefore, some of these specific and valuable habitats are in danger to be destroyed before they can be investigated (1).

Sea caves, *vruljas*, and coralligen are quite inaccessible and, therefore, there is insufficient in-

formation on the organisms living there. The mechanisms how deep-sea organisms settle into cold-water sea caves and how they survive and reproduce in these caves are insufficiently investigated. All the ecological factors which result in such a large diversity of sponges in the semi-dark cave communities are also unknown. Preliminary research of anchihaline caves shows that it might be possible that karstification processes occur just beneath the sea surface (2). Marine lakes, ecologically separate from the surrounding sea due to limited contact, are very rare at the eastern Adriatic coast and, therefore, very threatened. The benthos of these lakes includes a small number of organisms that have very large populations, which is contrary to what we find in the surrounding sea. All the preliminary research has proven these habitats to be very interesting.

Anchihaline caves

Anchihaline caves stretch from a few meters to a few kilometres from the coast toward the inland, forming a transition zone between freshwater underground and the sea. In the surface parts there is an inflow of freshwater, while marine water remains in the bottom. The inflow of karstic underground freshwater brings along a number of endemic aquatic species. The caves present a special challenge for scientists (3), since

often the only access to them is through caves on the surface near the coast, usually requiring speleological equipment and skills.

Marine caves and cold sea caves and pits with bathyal elements

Marine caves and pits were formed in subaerial conditions and later became submerged (sea level rise after the last glaciations). Preserved speleothems deep below present sea level (as deep as 65 m in the Adriatic), covered with marine organisms, play an important role in the research of dynamics of sea level rise. Semi-dark parts of marine caves are mostly inhabited by sponges (4,5), and little is known about other life forms living in deeper parts.

Ecological conditions inside marine pits are similar to the deep sea, since they trap cold winter sea-water throughout the year. They are dark, cold, and contain small amount of food. Since one of the characteristics of the Mediterranean Sea is deep homothermy – the Mediterranean is the only sea with the whole water column mixing during the cold part of the year – the settlement and survival of deep-sea organisms in shallow and dark cold water pits is enabled. Shallow depths and near-shore location allow scientist divers to research these organisms *in situ* and take undamaged samples. A particularly interesting discovery was a deep-sea cladorhizid sponge of the genus *Asbestopluma*, devoid of an aquiferous system and choanocytes, at the depth of 17 m in the littoral cave in France (6). Research showed that this sponge was macrophagous and “carnivorous” (7). It passively captures prey such as small crustaceans (up to 8 mm long) on its filaments provided with raised, hook-shaped spicules. Capture is followed by intense sponge cell migration, extracellular digestion, phagocytosis, and intracellular digestion by archaeocytes and bacteriocytes – the whole process taking up to 10 days (8). The strange sponge was de-

scribed as a new species, *Asbestopluma hypogea* (9). *Asbestopluma hypogea* and hexactinellid sponge *Oopsacas minuta* were also found in shallow depths in descending littoral pits in the Adriatic Sea (10), which points toward its exceptional scientific potential. We have already found seven littoral caves with bathyal sponges in the Adriatic and we have merely begun our research.

Vruljas

Vruljas are submerged pits or springs. They were formed as a result of pressurised freshwater flow in the karstified coast. In sieve-type *vruljas*, freshwater is flowing from the sea bottom through numerous tiny openings in the sand, which makes them hardly accessible for research. On the other hand, pit-types *vruljas* are much bigger and more easily accessible for scientist divers. There are many pit-type *vruljas* at the Eastern coast of Adriatic. Their geomorphologic characteristics have been researched but little is known about their biology and biodiversity. Few species live in *vruljas*, which are subjected to temporary salinity shocks during the moment of freshwater flow (11,12).

Stratified estuaries

There are two stratified microtidal estuaries at the Croatian coast – estuary of the Krka river, together with Prokljan Lake, and estuary of the Zrmanja river with Novigrad Sea. In Zrmanja estuary, denser sea water enters the estuary up to 14 km upstream – to the waterfall Jankovića Buk, while in Krka estuary it enters up to 40 km upstream – to the waterfall Skradinski Buk. Between upper, freshwater layer and lower, sea-water layer, there is a special interface, a few hundreds of molecules thick. This interface is a site where very peculiar biogeochemical processes take place (13). Although these two estuaries are located between

oligotrophic open sea and oligotrophic karstic river, they both act as natural bioreactors. Since estuaries are rich in fish and bivalves, which are used for food, it is in human interest to keep this sensitive system in balance.

Submerged river canyons

Submerged river canyons were formed by elevation of the sea level after the last glacial period. Two of such canyons are Zrmanja and Krka canyons, with steep canyon walls on more or less flat channel bottom. Marine communities on these steep rocks, mostly coralligenous, have still not been investigated.

Submerged tuffa barriers

Tuffa barriers are former waterfalls in submerged river canyons. On the Krka or Zrmanja river, there are some which are more than 10 m high. In Novsko Ždrilo, there is a 20 m-high tuffa barrier with a crown at the depth of 26 m. In Krka estuary, between Skradin and Prokljan there are at least three such barriers, the highest of which is 6 m high, with a crown at the depth of 3 m. Marine organisms inhabit all of them but these communities have not been investigated yet.

Marine lakes

Marine lakes represent a peculiarity of our karstic coast, and there are only 4 of them in Croatia. Their general characteristics are: weak exchange of water with the surrounding sea, lowered tidal amplitude, temperature extremes, almost permanent water column stratification, and temporal hypoxia/anoxia in the bottom layers. In the marine lakes, there is a small number of species but the population density is high. Also, species composition is different than in the nearby sea (14). Marine lakes on the island of Mljet constitute a ma-

ior part of the Mljet National Park. Significant scientific research has already been done there, but it is still far from finished. They are home to very dense populations of jellyfish, among the densest on the Mediterranean, as well as the biggest specimens of jellyfish. Due to the process of natural eutrophication, marine lakes represent small natural bioreactors. This is especially true for small marine lake near Rogoznica – Zmajev Otok. As a consequence of eutrophication, the bottom layer of the lake is almost permanently anoxic. Lake Mir on the island of Dugi Otok is the shallowest among the Croatian marine lakes. During summer, its temperature often exceed 30°C. In fall, natural eutrophication is so strong that during strong southeast wind, the surface of the lake gets covered by thick foam of plankton surfactants.

Conclusion

To prove the scientific value of these habitats, as well as to assess the level of threat and propose the appropriate measures for their protection and use, we launched a scientific project called “Research of Threatened Marine Habitats in the Coastal Submerged Karst of Croatia.” Through the cooperation within the scientific program “Systems & Technologies in Sub-Sea, Coastal Zone Protection and Maritime Security” of the Faculty of Electrical Engineering and Computing at the University of Zagreb (coordinator Professor Zoran Vukić), we want to ensure new technology and automation for investigating sea habitats, especially the use of unmanned underwater vehicles (remotely operated vehicle and autonomous underwater vehicle), which have not been used for such purpose in Croatia so far. In this way, it will be possible to research a greater number of under-water locations (sea bed surfaces), including those inaccessible to divers. This research will gather information on threatened sea habitats and habitats in need of conserva-

tion in Croatia, their representation, and actual level of threat. This will later enable European and global assessment of the importance of these areas as a basis for funding various development and/or protection projects. The results will also contribute to making specific Croatian sea habitats recognizable at the level of the European Union, as well as for improving Croatian legislation in the fields of environmental protection and conservation. All this will ultimately contribute to the proper management of our valuable natural heritage.

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