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THE ADRIATIC COAST AS THE CRADLE OF ANCHIHALINE (ANCHIALINE) ECOLOGY

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A short investigation history of anchihaline (anchialine) habitats is given. In the 1950s to 1960s the Adriatic coast was particularly intensely studied in this respect. The first systematic research into anchihaline ecology was done in this area in the 1960s (published in 1986). Stability of salinity--density stratification was noted, resulting in occurrence of dysoxic-sulfidic layers. The fauna is distributed mainly within the paralittoral merodinaric zone; two paradoxical phenomena were named the 'Kvarner inversion' and the '*Hadzia* inversion'.

Key words: anchialine-anchihaline, ecology, biogeography, review

1 SHORT HISTORY OF OLD (INITIAL) ANCHIHALINE CAVE INVESTIGATIONS WORLDWIDE

1.1 Before World War II

Research into anchihaline caves started very early in the history of speleobiology. Highly troglomorphic species of fish and shrimps were found on Cuba in the 19th Century (e.g. *Stygicola dentatus* Poey 1856; *Barbouria cubensis* Martens 1872), and later in a lava tube in Islas Canarias (description of *Munidopsis polymorpha* Koelbel 1892). Early also are discoveries of anchihaline fauna in Zanzibar and Kenya (ALLUAUD & JEANNEL, 1914), while soon after, a giant anchihaline shrimp was found in Libya (*Typhlocaris lethaea*, Parisi 1921) and a similar one in the southern Adriatic (*T. salentina*, Caroli 1923). PEARSE *et al*. (1936) edited a comprehensive study of the cenotes in the Mexican Yucatan, which appeared to be mainly anchihaline habitats.

But, particularly important was the early finding of a cirolanid isopod in the anchihaline Coves del Drac in Mallorca (RACOVITZA, 1904), which 'forced' the ingenious Romanian zoologist E. Racoviţa to redirect his professional career to speleobiology; he became one of the most meritorious of all speleobiologists.

1.2 After World War II – till 1960s

After WW II, till the 1960s, research was mainly done in the Adriatic. KARAMAN (1953a, b) provided the first data for the cave Šipun in Cavtat, Dalmacija. RUFFO (1957) published a comprehensive study of the cave fauna of Puglia, south Italy, which included anchihaline caves and where he also solved the problem of the poorly defined 'troglophiles' dividing them reasonably into eutroglophiles and subtroglophiles. RIEDL (1966) wrote an important book about marine caves, based to a high degree on the Adriatic. RIEDL (1966) and RIEDL & OZRETIĆ (1969) also defined

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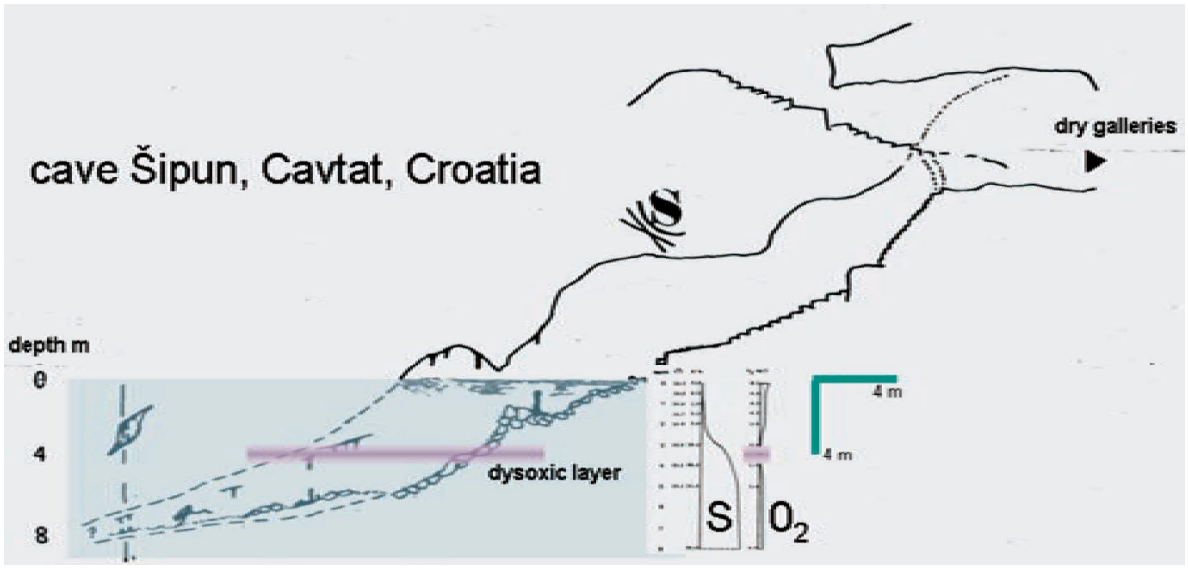

Fig. 1. Profile of the anchihaline cave Šipun in Cavtat, Croatia. Stratification of the salinity (S) and of water oxygenation (O_2) is shown.

and particularly studied 'marginal caves'. HOLTHUIS (1973) studied impressive 'red shrimps' and defined the 'anchialine habitat'. Thanks mainly to Holthuis, POR (1985) (mainly for pools!) and STOCK *et al*. (1986) this term (also amended to 'anchi**h**aline') successfully replaced the similarly, although not identically, conceived 'marginal caves' (SKET, 1996). Ecological data at this stage were mainly restricted to salinity and hydrology data of open pools.

2 RECENT INVESTIGATIONS

The speleobiology team from Ljubljana started to investigate Adriatic anchihaline habitats in late 1950s, at first only faunistically (SKET, 1969) but later also ecologically (SKET, 1981, 1986). They sampled approximately 30 cavities with anchihaline water along the whole NE Adriatic coast and found approximately 30 troglobiotic, mainly mixohaline species (beside some trogloxenes). In recent decades Croatian colleagues increased the number of known coastal caves to more than 60 (BILANDŽIJA *et al*., 2009; JALŽIĆ *et al*., 2009).

2.1 Ecological data

In most coastal caves and natural wells (SKET, 1986) a stratification of salinity has been noted. The surface is often limnic, most probably depending on seasonal precipitations. The halocline is variably thick. As water density relates to salinity, the increasing salinity with depth prevents vertical mixing and restoration of oxygenation. The final consequence is the establishment of dysoxic or even anoxic layers enriched with H_2S. In most anchialine systems researched at that time, the water body is exposed to the outside, therefore illuminated and rich with organic debris. The presence of daylight may result in the growth of unicellular algae while no pools with a very massive algal growth were investigated, although they do exist.

Following these studies, similar conditions were found all around the world, and studied mainly in the tropical belt.

Due to the stability of the water column, temperatures in the deeper layers are stable, at the yearly mean temperature of the area. The temperature may vary seasonally only in the surface layers. Temperatures in the deeper positioned sea caves are in the Mediterranean (and Adriatic) comparatively high, well above 10 °C.

2.2 Faunistics; peculiarities of the Adriatic anchihaline fauna

Although moderately rich, the NE Adriatic anchihaline fauna (SKET, 1986, 1988, 1994) contains no shrimps and no cirolanids, so characteristic of tropical anchihaline caves. The continental *Troglocaris* sp. occurs only exceptionally and at very low salinity. In coastal caves, the most evident are some limnic elements, mainly *Niphargus* spp. (Amphipoda) and different Cyclopidae (Copepoda). The amphipods *Hadzia fragilis* and *Pseudoniphargus adriaticus* belong to primarily marine genera, but the Adriatic species might also be secondarily mixohaline (see below). More explicitly marine by provenience might be *Monodella halophila* (Thermosbaenacea). More reliably of a marine provenience seem to be only inhabitants of euhaline caves, like alpheid decapods (FRANSEN, 1991) misophrioids and some calanoids (KRŠINIĆ, 2005, 2008) as well as the non-troglobiotic deep sea sponges (BAKRAN-PETRICIOLI *et al*., 2007).

In deeper water bodies the fauna may be stratified (SKET, 1986). The presence of some troglobionts appears to be little influenced by the presence of light as well as of the oxygenation of water. At least *Niphargus hebereri* and *Monodella halophila* may occur deep within the sulphurous layer. Salinities much below the euhaline and slightly above the limnic values do not appear to define the distribution of different species. It seems that some vulnerable species (like *Monodella*) are limited to less favorable layers by their stronger competitors and predators.

2.3 Biogeography

One of the distribution patterns of the subterranean biota in the Dinaric (and Adriatic) regions is the **paralittoral mero-dinaric** distribution pattern (SKET, 1994). It includes most of the NE Adriatic coastal belt, but the coast of the Kvarner (Quarnero) Gulf is outside it. Both are inhabited by the anchihaline fauna, which testifies to the historical nature of the former distribution pattern. Two paradoxical phenomena (SKET, 1988) are notable. (1) The 'Kvarner inversion': while the paralittoral belt is inhabited by more accentuated marine elements (*Hadzia* being the most important), anchihaline habitats within the Kvarner are inhabited by the continental *Niphargus arbiter*. (2) The '*Hadzia* inversion': while *Hadzia fragilis* occurs along the paralittoral belt in anchihaline i.e. mixohaline habitats, it occurs in Kvarner (and in some other points) only in inland freshwater. However, the taxonomic identity of both ecological types has not yet been proven by DNA analysis. Also paradoxical is the limitation of the big *Trogloaega virei* (Isopoda: Cirolanidae) to freshwater, inland along the whole paralittoral belt (SKET, 1964).

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