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THE MEIOFAUNA OF TWO PROTECTED WETLANDS ON THE SLOVENE COAST: THE ŠKOCJAN INLET AND THE STRUNJAN LAGOON

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ABSTRACT

The paper presents ecological and meiofaunal comparisons between two extremely shallow intracoastal formations along the Slovene part of the Adriatic Sea, i.e. the Škocjan Inlet in the Bay of Koper and the somewhat smaller Stjuža Lagoon near the salt-pans of Strunjan. The inlet is a highly degraded, isolated and stagnant neritic environment, affected with temporary summer anoxias, caused by algal decompositions of huge Ulva *aggregations. The Lagoon is an undisturbed sea grass community. Lower meiofaunal diversity and abundances were observed in the Škocjan Inlet, though less as expected, with some mixed "thiobios" symptoms in its highly sulforeducted surroundings.*

Key words: meiofauna, Škocjan Inlet, Strunjan Lagoon, protected wetlands

MEIOFAUNA DI DUE ZONE UNIDE PROTETTE DELLA COSTA SLOVENA: VAL STAGNON E LA LAGUNA DI STRUGNANO

SINTESI

L'articolo presenta un confronto ecologico e meiofaunistico tra due formazioni intracostali poco profonde: la Baia di San Canziano (Val Stagnon) nella baia di Capodistria e la più piccola laguna Stjuža vicino alle saline di Strugnano. La prima rappresenta un esempio di ambiente altamente degradato, isolato e stagnante neritico, affetto da temporanee anossie estive causate dalla decomposizione di ingenti aggregati dell'alga Ulva. *La laguna di Strugnano è invece una comunità indisturbata di fanerogame marine. Diversità e abbondanza meiofaunistiche sone risultate basse nella Baia di San Canziano, persino più basse del previsto, con alcuni sintomi misti "thiobios" nelle vicinanze altamente solforidotte.*

Parole chiave: meiofauna, Baia di San Canziano, laguna di Strugnano, zone umide protette

INTRODUCTION

The research carried out so far into the meiofauna of the Slovene sea has been focused mostly on the open waters of the Gulf of Trieste and much less on its shallow margins, the only exception being the extensive exploration of meiobenthos in the Strunjan Lagoon at the end of the 1970s (Vrišer, 1979, 1982). The shallow lagoonar part of Koper Bay, however, has till recently been totally unresearched. It was only the sampling carried out a couple of years ago in the Škocjan Inlet (Čermelj *et al.*, 2000) that enabled the origin of this paper, in which a comparison between the two very unique lagoonar environments, surrounded by land and officially protected, is presented. The contribution is not an integral, synchronously implemented study, but a comparative outline of this specific maritime environment at the level of meiobenthos. Here we were able to lean merely on the disposable, although for our particular purpose not always optimal ecological data. The Škocjan Inlet, which presently enjoys the status of a protected environment, will be in the future, after the planned deepening of its aquatory, certainly a subject of numerous investigations.

The study of lagoonar benthic associations and their appurtenant meiofauna, as an important part of these systems, presently deals with, judging from the literature, particularly the following four topical segments.

In the foreground are largely investigations of bioproductional characteristics, faunistic structure (taxonomy) and diversity ecology of their associations. Since the complexity of the three stated spheres inseparably interact between each other, the mentioned research aspects can be usually found in joint, more complex publications, such as Coull (1969, 1970); den Hartog (1971); Sikora & Sikora (1982); Witte & Zijlstra (1984); Fleeger *et al.* (1984); Armonies (1988); Bin Sun *et al.* (1993); *etc.* The fourth and very special sphere of lagoonar studies constitute the research on specific putrescent and to the high concentrations of sulphuretted hydrogen adapted meiobenthic associations of the extreme maritime environments, the so-called thiobioses (Reise & Ax, 1979, 1980; Powell *et al.*, 1980, 1983; Meyers et *al.*, 1988; Wetzel *et al.*, 1995).

The samplings in the Škocjan Inlet and its stagnant tributaries, which are heavily marked with decaying substrate, were carried out also in order to ascertain the possible "thiobiosity" of this environment.

ECOLOGICAL CONDITIONS

Due to the exceptional specificity of the study area, some more space is dedicated to its ecological outline than actually deserved by this preliminary meiobenthic delineation in view of the extent of the achieved results.

Position, depth configuration and hydrological regime of the Inlet and the Lagoon

The two systems, the one at Škocjan as well as the one at Strunjan, are not entirely natural formations but the result of various human activities carried out in the last few centuries in this shallow marine environment, enabled by the estuaries of the Rižana river in Koper Bay and of the Strunjan stream and its discharge area in Strunjan Bay.

The Škocjan Inlet originated with the linking of the former island of Koper with land through the complex of salt fields, and was finally cut off from the sea by the new Port of Koper, due to which it now communicates with the sea only through the narrow man-made canal. The extensive filling up of the Inlet in the last thirty years has made this once entirely marine environment extremely shallow (the depth of its central part does not exceed 30 cm), virtually cut it in half as far as its surface area is concerned and thus made life in it unbearable. Its only freshwater tributaries, the canals of the Rižana river and the Badaševica stream (Fig. 1), are scarce with water, while the smaller and presently more or less freshwater mere (with its own small spring) is only a part of the Inlet, cut off from the main body by the railway embankment. With its spillway past the Inlet, the Badaševica stream has been diverted directly into Koper Bay.

The Strunjan Lagoon (Fig. 2) is for some half a century abandoned fish farm of the Venetian type. It is an artificial formation, with no direct freshwater inflow, originating from the time when the Strunjan salt-pan complex was formed. It is made up of the smaller discharge lagoon and of the larger main Stjuža Lagoon of the silted former fish-farming pond. The latter is up to half a meter deep and through the mouth of the discharge lagoon (and a series of smaller spillways between the two lagoons) hydrologically (intertidally) fairly effectively and much more directly linked with the sea than the Škocjan Inlet.

Temperature, salinity, and oxygen

Thermal conditions in both lagoons are, owing to their shallowness, very severe and seasonally change from one extreme to the other: in the winter between 5° and 10°C (they periodically freeze over), and between 24° and 27°C during the summer, while in other seasons they adapt to the atmospheric temperatures.

Salinity and oxygen content of the Škocjan Inlet's water body oscillate a great deal both temporally and spatially: from periodically almost freshwater conditions in the rainy seasons, via brackish level of salinity to quite high salinities in warmer periods (hypo – hypersaline environment). The salinity and oxygen measurements in the Inlet also showed some extreme spatial

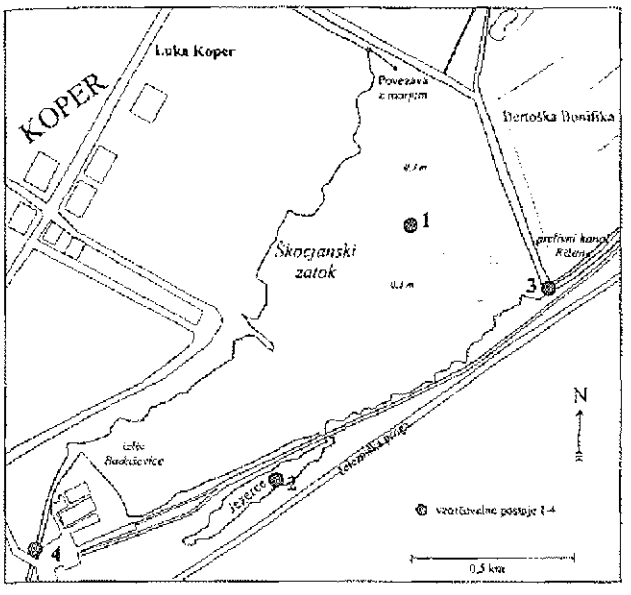

Fig. 1: Study area with sampling stations in Škocjan Inlet.
Sl. 1: Raziskovano območje z razporeditvijo vzorčevalnih postaj v Škocjanskem zatoku.

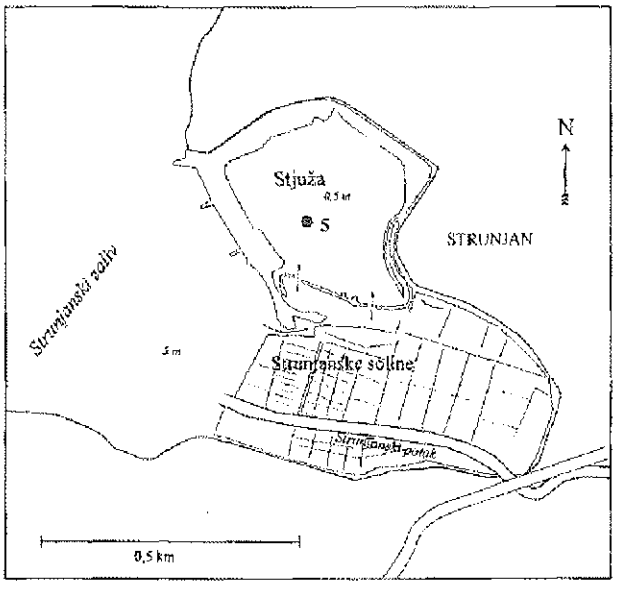

Fig. 2: Study area with sampling station in the Strunjan Lagoon.
Sl. 2: Raziskovano območje z vzorčevalno postajo v Strunjanski laguni.

changes due to the mixing of strong tidal flows: utterly comparable with the outer condition (in the Bay) along the inner mouth of the tidal canal, and severe along the mouth of the spillway canal of the Rižana river and the Badaševica stream (high salinities, around 40 psu, and consequently critically low, with hypoxic oxygen values – below 30 ppm).

Similar hypoxic and occasionally even anoxic conditions of the water oxygen often occur in late summer in the Inlet itself, although exclusively due to the massive decaying of the huge agglomerations of sea lettuce accumulated at the time of low water levels, saturated nitrites and high temperatures. For the time being, however, we have no detailed accompanying ecological data on the physical-chemical changes in this process, which may at times bring the system into the state of biotic collapse. The only permanent freshwater locality of the Inlet can be found in the already mentioned mere, where seawater can be detected only at its bottom.

Salinity, oxygen content and thermal conditions in the Strunjan Lagoon are owing to the more direct as well as ample water exchange generally completely comparable with those of Strunjan Bay, in spite of ever present intertidally turbid oscillations in the Lagoon.

Plankton

Phytoplankton density in the Inlet and in the Lagoon is high, in fact higher than in open waters, while its species diversity is much lower. Phytoplankton biomass in terms of chlorophyll *a* concentration in the Škocjan Inlet generally surpasses the averages of the Gulf of Trieste (around 1.0 µg/l). Chlorophyll *a* concentrations oscillate a great deal both temporally and spatially, from the low 1.8 µg/l in winter to the high 220 µg/l in spring (Čermelj *et al.*, 2000). The measurements made in the Strunjan Lagoon have shown comparable, although slightly lower values. In the species-poor phytoplankton association, microflagellates are predominant (70 – 90%) (Čermelj *et al.*, 2000).

The zooplankton fauna, too, is poorer in view of its species than in open waters, with predominant naupli larvae and harpacticoid copepods of the benthic-semipelagic type. No great differences can be detected between the Inlet and the Lagoon.

Substrate

Substrate of the major part of the Inlet and the Lagoon is grey-coloured compact-fine argillaceous silt with a slight admixture of sand, with a thin (0.5 – 1 cm) yellowish brown layer of flocculent organic detritus. This is the main natural habitat of the researched, predominantly burrowing meiofauna, which with a branched out capillary system of oxygenated burrows also inhabits up to 5 cm deeper layers of otherwise anaerobic although unreduced unputrescent substrate.

The sediment in the mouth of the Badaševica stream and in the discharge canal of the Rižana river, however, is completely without aerobic surface layer, highly putrescent and thus badly degraded, of black coloured, with high decomposing organic detritus content. Sulfide

hydrogen remains permanently dissolved in pore water of this substrate in high measured concentrations (0.5-2.5 mmol/l).

Macrophytobenthos

Macrophytobenthos of the Škocjan Inlet is, owing to its exceptional shallowness, almost entirely limited to the free floating benthopleustophytous and acropleustophytous species, such as *Ulva rigida* (sea lettuce) and, to a smaller extent, *Gigartina acicularis* and *Halopitys incurvus*. As a result of the increased evaporation, low water level and greater amount of nitrites during the summer, water lettuce spreads in the Inlet to such extent that it fills up the entire water volume and due to it and especially owing to its decaying disables the existence of the *Cymodocea* sea meadow, which once commanded at that time much deeper Inlet.

The Strunjan Lagoon is overgrown with a normally developed sea meadow consisting predominantly of the species *Cymodocea nodosa*, and *Zostera noltii* on its margins. Species diversity is usual for this phytoassociation, for apart from the two above mentioned species, at least another 7 species are present there.

Macrofauna

Macrofauna of the Strunjan Lagoon consists of a very diverse association of characteristic species closely associated with the environment of seagrasses: numerous mollusc (bivalves, gastropods), benthic crustaceans (mysids, amphipods, decapods, isopods), echinoderms (brittlestars, starfishes), and at least 20 species of polychaets.

In the ecologically degraded Škocjan Inlet, no comparable macrofauna association was noted, with the exception of few polychaets and bivalves.

MATERIAL AND METHODS

The first sampling was carried out on October 26th 1999 at four localities of the Škocjan Inlet, *i.e.* in its centre (Station 1) and on its margins (Stations 2 – the mere on the other side of the railway embankment, 3 – the Rižana river channel, 4 – the bed of the Badaševica stream) (Fig. 1), and at a single locality in the Strunjan Lagoon (Station 5) (Fig. 2). The second sampling was carried out on March 8th 2000 in the central parts of the Inlet and the Lagoon only.

We took the substrate samples manually with corer and extracted the meiofauna from the surface area of 10 cm^2 and the depth of 5 cm with the sieving-decantation technique in 2 fractions (50 - 125 µm, 125 µm - 1 mm) of Wieser (1960) and conserved it in 4% formalin with seawater.

The basic physical and chemical characteristics of the water column (temperature, salinity, dissolved oxygen, chlorophyll *a*) were determined with CTD fine-scale profiler (University of Western Australia, Centre for water research) while at somewhat shallower localities classical methods were partially applied as well. Numerous other analysis techniques for the ecological measurement of the substrate are presented in greater detail in the ecological study made by Čermelj *et al.* (2000).

RESULTS

Qualitative survey of the meiofauna of the Strunjan Lagoon, Škocjan Inlet and their affluents

The first preliminary qualitative analysis (presence of major taxonomic groups and their rough quantitative assessment) of 6 meiofauna samples was carried out in mid-October 1999. The survey showed two groups of samples (Tab. 1).

Tab. 1: Meiofauna of the Strunjan Lagoon and the Škocjan Inlet, together with its affluents, October 1999. Taxa are ranking according to decreasing abundance. Stations: 1 - Škocjan Inlet's centre, 2 – mere, 3 - Rižana river's discharge canal, 4 - Badaševica stream, and 5 - Strunjan Lagoon (reference sample). Legend: RR-very rare, R-rare, C-common, CC-very common, and D-dominant.

Tab. 1: Meiofavna Strunjanske lagune in Škocjanskega zatoka ter njegovih pritokov, oktober 1999. Taksoni so urejeni po standardnem zaporedju običajne pogostosti. Postaje: 1 – center zatoka, 2 – jezerce, 3 – prelivni kanal Rižane, 4 - Badaševica in 5 Strunjanska laguna (referenčni vzorec). Legenda: RR-zelo redka, R-redka, C-običajna, CC-zelo običajna in D-dominantna.

	Škocjan Inlet				Strunjan
	1	2	3	4	5
Nematoda	CC	C	RR	R	D
Harpacticoida	R		R		CC
Polychaeta	CC	RR		RR	CC
Turbellaria	C	RR	RR	R	C
Gastropoda	RR				C
Bivalvia					R
Kinorhyncha					RR
Acarina					RR
Hydroidea					RR
Ostracoda	D	RR	D	R	
Tanaidacea	R				
Isopoda	RR		R		
Amphipoda	R		R		R

The meiofauna of the three marginal water bodies of the Škocjan Inlet (the Badaševica stream, the mere, and the Rižana river discharge canal) with distinct signs of ecologically degraded environment (large quantities of decaying black detritus in the sediment) was taxonomically, and particularly quantitatively, very poor in comparison with the fauna of the Škocjan Inlet and the Strunjan Lagoon. The samples taken in the Inlet and Lagoon showed a higher diversity and abundance of individuals.

A comparison between the Inlet and the Lagoon, however, showed somewhat lower abundance in the meiofauna of the Škocjan Inlet, particularly in respect of the Nematoda and Harpacticoida groups. The meiofauna of the Strunjan Lagoon served as a reference for a less affected environment.

Quantitative survey of the meiofauna of the Strunjan Lagoon and the Škocjan Inlet

The analysis of the meiofauna's samples taken on March 8th 2000 at two stations in the Škocjan Inlet and comparatively in the Strunjan Lagoon, showed a great difference between the two aquatories than the preliminary qualitative survey carried out in 1999 (Tab. 2).

Tab. 2: Meiofaunal structure and abundance (No. ind. /10 cm²) of the Škocjan Inlet and the Strunjan Lagoon, March 2000. Taxa are ranking according to abundances.
Tab. 2: Struktura in abundanca (št. os./10 cm²) meiofavne Škocjanskega zatoka in Strunjanske lagune, marec 2000. Taksoni so urejeni po zaporedju abundanc.

	Strunjan Lagoon (St. 5)				Škocjan Inlet (St. 1)			
taxa	a	b	c	mean	a	b	c	mean
Nematoda	541	692	837	**690**	403	307	343	**351**
Harpacti-coida	139	289	341	**256**	38	36	69	**48**
Polychaeta	68	201	93	**121**	75	12	21	**36**
Turbellaria	27	28	38	**31**	8	8	8	**8**
Gastropoda	-	1	-	**0.3**	-	-	1	**0.3**
Bivalvia	1	-	-	**0.3**	-	-	1	**0.3**
Kinorhyncha	-	2	4	**2**	1	-	-	**0.3**
Acarina	1	-	-	**0.3**	-	-	1	**0.3**
Hydroidea	75	2	-	**26**	-	-	-	-
Ostracoda	6	20	22	**16**	73	87	130	**97**
Amphipoda	3	-	1	**1.3**	-	-	1	**0.3**

In terms of diversity, and particularly as far as its quantity is concerned, the Škocjan Inlet's meiobenthos is much poorer than that in the Strunjan Lagoon. In the majority of the faunistic groups, the quantitative differences are also great. In otherwise numerous nematods (Nematoda), present in both environments, the abundances in the Škocjan Inlet were by half as low than in the referential lagoonar environment, in Turbellaria four times lower, in harpacticoids (Harpacticoida) five times lower, and in polychaets (Polychaeta) even seven times lower than at the referential station.

The only exception were ostracods (Ostracoda), which with their no less than six times greater abundance than the prevalent meiobenthic group of the Škocjan Inlet mark this specific, although undoubtedly degraded association.

DISCUSSION

In comparison with the Strunjan Lagoon, the assessed smaller diversity of the Škocjan Inlet's meiofauna is not particularly explicit and is in fact based merely on the first observations. During the first (preliminary) survey of the Inlet, we did not manage to register no less than four groups: bivalves (Bivalvia), kinorhynchs (Kinorhyncha), acarins (Acarina) and colonies of hydroid polyps, which all happen to be common in the Strunjan Lagoon. Particularly symptomatic is the almost total absence of molluscs (bivalves and gastropods), which were hardly registered yet again during the second and much more thorough survey of the Škocjan Inlet. A further supplement to the assessment about a poorer diversity of the Inlet's meiofauna is represented by harpacticoid copepods (Harpacticoida), where representatives of only three genera were prevalent: *Amphiascus*, *Bulbamphiascus* and *Tisbe*. Especially in the last two, some distinct indicators of eutrophic as well as organically polluted environments can be found (Marcotte & Coull, 1974; Vrišer, 1986).

Much more distinct between the compared associations of both lagoonar environments are the quantitative differences, where the spans of higher abundances in the individuals of the Strunjan Lagoon are even several times greater in some of the groups. So far, much has been written about the meiofauna of the Strunjan Lagoon (Vrišer, 1979, 1982). At this point let us underline that we are dealing with meiobenthos, closely associated on sea grasses, in which some stenovalent species are missing in many groups due to the severe oscillation of ecological factors (particularly temperatures and salinity). But then again it is distinguished for its bioproductivity, which is higher than in the open sea, which is reflected in greater, especially summer abundances of its dominants. Otherwise it is more or less still comparable with the ordinary meiobenthos of the coastal sea meadows.

However, our assessment of the species diversity in meiobenthic associations in both environments can be unfortunately merely preliminary without a detailed study of the species diversity and a greater spatial covering of the sampling stations.

There is no doubt that all the stated faunistic differences between the two compared environments result from the great ecological differences between them, particularly from the absence of the ruined sea meadow of the Škocjan Inlet and from the anoxic collapses in the summer. It is our impression that the great quantities of decomposing detritus of sea lettuce hypoxically (and in a later phase anoxically) cover and pollute the surface of the bottom to such extent that the meiofauna can survive, in the short run, only inside this already thinner (max. 1 cm thick) but still aerobic layer and in up to 5 cm deeper capillary network of burrows of the meiofauna's burrowing component. The latter is indeed capable of surviving (for up to few weeks) in the hypoanoxic conditions of this kind as well, to which macrobenthos succumbs in a very short time (as confirmed by numerous foreign and domestic anoxia researchers, *e.g.* Josefson & Widbom, 1988; Austin & Widbom, 1991; Vrišer & Malačič, 1992; Vrišer, 1995; Moodley *et al.*, 1997), *i.e.* in the ecological conditions, when after a week or two the macrofauna has long been destroyed. We presume that early in the autumn life conditions improve in the Inlet due to heavy rains and winds (when decomposing aggregations of algae are washed away), as shown by our October and March samplings. The colder half of the year most probably presents a more favourable ecological period for the fauna of the Škocjan Inlet.

The mentioned survey of processes is probably not utterly uniform even in the period of the most intense summer putrification, but is most likely mosaic: it is a mixture of hydrodinamically more stagnant (ecologically severed) and intertidally more intense (ecologically more favourable) localities with less polluted aggregations. For this purpose, a network of stations would be necessary.

On the other hand it has been noted that the registered faunistic differences between the compared Škocjan Inlet and the Strunjan Lagoon are certainly smaller than the ecological differences, or smaller than expected in view of the latter. All this yet again confirms the meiofauna's well-known ecological resistance as well as its flexibility and "belated" response to the environment's unfavourable ecological extremes.

The Škocjan Inlet's benthic conditions could be perhaps explained with the following working hypothesis. It is possible that the decisive role in the incurred meiofaunal differences in both compared environments is played by the very substrate endofraction of macrobenthos (over 1 mm large organisms living on the bottom, *i.e.* bivalves, nemerteans, polychaets, oligochaets), which in the critical summer hypoxia cannot survive in the long run and is therefore hard to be found any longer in the Škocjan Inlet. This directly means its loss or absence as well as a reduced presence of "temporary" meiofauna, *i.e.* juvenile stadia of the future macrofauna. At the same time this indirectly means – due to the consequential loss of macrobenthic capillary network of oxygenated burrows as oxygen lacunas within the top 5cm – a fatal reduction of the disposable life niches for the remaining "permanent" meiofauna, which is reflected not only in the diversity of species but also in their abundance. In the meiofaunistic literature we have not found an ecosystem that would be ecologically fully comparable to the Škocjan Inlet. Some authors (*e.g.* Coull, 1969; Sikora & Sikora, 1982), on the other hand, are breaking down the biological processes of the surface layer in the substrate of the shallow lagoonar environments also in the direction of the above mentioned hypothesis.

The other objective of our research was to find an answer to the question, whether there exists, in the Škocjan Inlet and particularly on its margins, a specific and to sulphuretted hydrogen adapted meiobenthic association, the so-called "thiobioses". Certain sources have placed this (in the opinion of some researchers disputable) association in sulfide dependent chemocline which presumably have an ecologic requirement for sulfide (Powell *et al.*, 1983). Thiobios communities no longer needs the necessary oxygen for its survival (Reise & Ax, 1980; Meyers *et al.*, 1988), in contrast to the normal meiobenthos, therefore, which is (at least in a long run, *e.g.* a few weeks) certainly still dependant on surface oxygen, also in deeper burrows within anaerobic substrate, even though below a depth of 10 cm.

Of the four investigated localities we can immediately exclude the Inlet itself, which does not fully meet the searched conditions (for the major part of the year its surface sediment is oxygenated), and the brackish mere protected from the decaying aggregations of the organic detritus by the railway embankment. The remaining two localities, *i.e.* the discharge canals of the Rižana river and the Badaševica stream, are, on the other hand, heavily stagnant and at the bottom burdened with the earlier on defined characteristics of decaying nature and, according to our measurements, with confirmed high sulphide concentrations. This environment is ecologically thus fairly congruent with "thiobiosity", while our faunistic data show somewhat mixed picture and only partially correspond to the previously mentioned specialist sources that classify such associations. Similarity with them is shown mainly in the exceptionally sparse harpacticoid copepods (Harpacticoida) and polychaets (Polychaeta) of our samples – in such environments these groups are normally rare – but not in ostracods (Ostracoda), which are even predominant in the discharge canal of the Rižana river and the second most common group in the Škocjan Inlet. The very multitude of ostracods in our samples of this environment is a faunistic peculiarity, discordant with thiobiotic associations, and for the time being difficult to explain. The groups Turbellaria and Kinorhyncha, characteristic of

decaying environments, were also missing in the two canals.

At the moment, the present survey of these margins of the Škocjan Inlet does not enable us a final judgement, and an answer could only be given upon a more extensive research.

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MEIOFAVNA DVEH ZAVAROVANIH MOKRIŠČ SLOVENSKE OBALE: ŠKOCJANSKEGA ZATOKA IN STRUNJANSKE LAGUNE

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POVZETEK

Primerjali smo meiofavno dveh plitvih, zaprtih priobalnih lagun, obe s statusom naravovarstveno zaščitenega območja. Škocjanski zatok, ki je danes skoraj že zasut preostanek nekdanjega estuarija reke Rižane, je primer skrajno degradiranega in hidrodinamično stagnantnega neritičnega okolja, močno obremenjenega z občasnimi poletnimi anoksijami. Morski travnik tu ni več ohranjen. Povzročajo jih razpadajoče agregacije morske solate Ulva lactuca. *Ugotovili smo, da so združbe v Škocjanskem zatoku vrstno in količinsko siromašnejše od združb v Strunjanski laguni. Ugotovljene favnistične razlike pa so bile vendarle manjše od pričakovanih in občutno manjše od ekoloških. Meiofavna dveh stranskih pritokov zatoka, močno zaznamovanih z gnijočim sedimentom, kaže nekaj delnih znakov specifičnih, na sulfidno okolje prilagojenih tiobioznih združb.*

Ključne besede: meiofavna, Škocjanski zatok, Strunjanska laguna, zavarovana mokrišča

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