

Hidden secrets of the Northern Adriatic: “Tegnúe”, peculiar reefs

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Abstract: Research carried out over the last 40 years has underlined the scientific importance of the rocky outcrops scattered on the Northern Adriatic Sea bed sometimes referred to as “tegnúe”. The zoobenthic biocenoses developing over these peculiar geological formations are as extraordinary as they are unique. A study carried out for an entire year in two sampling stations, at different distances from the coast, revealed a very high number of zoobenthic species, including those which have now become rare and are therefore protected in Italian seas. The water turbidity of the northern Adriatic Sea greatly reduces the quantity of light reaching these outcrops, limiting the activity of autotrophic organisms only to sciaphilous genera. Thus, the most represented trophic categories of zoobenthos are suspension, especially filter feeders. Biodiversity values calculated for the communities of these particular reefs are far higher than normally found in the soft seabed in nearby areas, but even higher than in other coralligenous outcrops in other marine ecosystem in the world. The ecological role played by the tegnúe in the Northern Adriatic is extraordinary because as well as being true oases of biodiversity, they are areas naturally protected against bottom trawl-fishing. Thus, they offer shelter and reproduction sites for a number of fish and invertebrate species, including some under stress due to severe fishing pressure. © Versita Warsaw and Springer-Verlag Berlin Heidelberg. All rights reserved.

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1 Introduction

Although it is widely known that the Northern Adriatic Sea is characterised by a rather monotonous seabed, mostly moulded in mobile, silty-sandy sediments, nevertheless its waters hide some peculiar outcrops, called “tegnúe”. These are submarine rocky substrates of biogenic concretions, irregularly scattered in the sandy or muddy seabed and, rather

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like oases in a desert, contain extraordinary zoobenthic biocenoses (Figure 1). The first report of these rocky outcrops on the bottom of the Adriatic go back as far as 1792, the year in which Giuseppe Olivi mentioned them, employing the term “tegnúe” in his “Zoologia Adriatica” [1]. From the scientific viewpoint, these hard natural substrates in the Northeastern Adriatic were only documented in 1966, when underwater explorations [2, 3] confirmed the presence of rocky outcrops off the seaside village of Caorle.

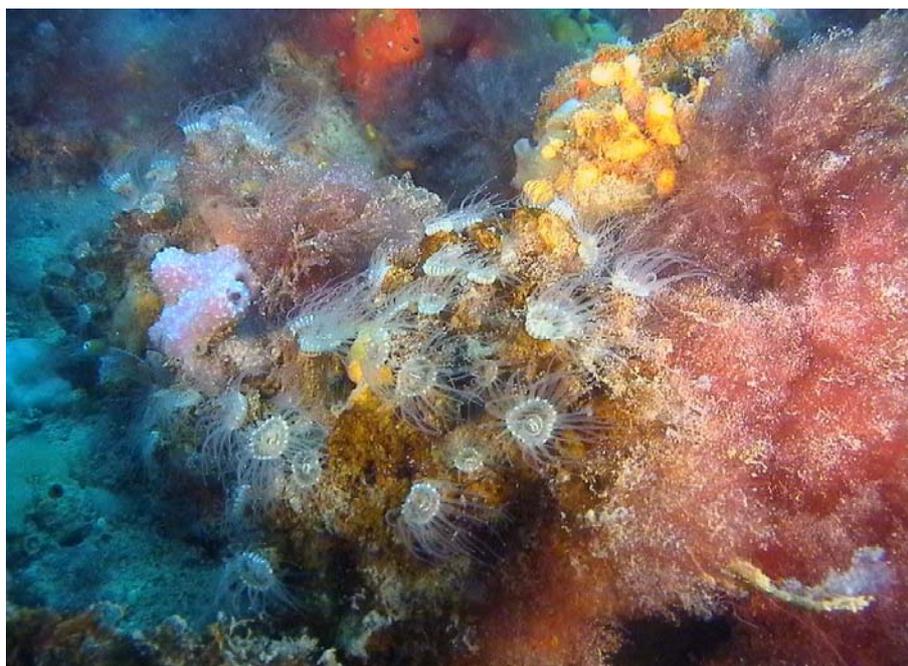


Fig. 1 An explored rocky outcrop at 23 meters depth in the Venice gulf.

In other parts of the world, similar structures have been reported in Southeast Florida, in the French-Italian Riviera, in Corsica, Sardinia and Sicily islands, along the southern Italian coasts, and Croatia, as well as in the northern Baltic areas, in the Oslo Fjord and in Greenland [4–17]. The authors who have described these structures were by no means in complete agreement on the definition of their peculiar characteristics; the term “reef”, used by Sigl [13] for the Manfredonia gulf, seemed at last to be suitable as a general term. The same term was more recently adopted by “Habitats Directive” of the EU 1992, Annex 1, No 1170 and by the “Interpretation Manual of European Habitats”, 1999, No 1170, which referred to “rocky substrates and biogenic concretions arising from the sea floor in the sublittoral zone...” [18].

In the last decades some studies [19–21] utilizing Scan Sonar techniques, showed that these formations are scattered irregularly over much of the northern basin of the Adriatic, at depths between 10 and 40 metres, with extremely variable morphologies and structures, and ranging in size from a few to several thousand square metres (Figure 2).

Geologically, these rocks, arising from the sediment, are not connected to the bedrock matrix of the continental plate. According to the best-supported theories, their rocky cores formed over the centuries - the result of the cementing of muddy sandy sediments

- by the precipitation of carbonates on beach sediments or after the ascent of methane from the sea bottom through the sediments themselves [22]. Methane most likely came from the microbial decomposition of fossil plant material, and also helped to form these complex structures in the Baltic Sea [23]. In particular, the term adopted by Habitats Directive of EU (Natura 2000, Interpretation Manual of European Union Habitats, Eur 25, October 2003, No 1180), for similar formations is “Submarine structure made by leaking gases”.

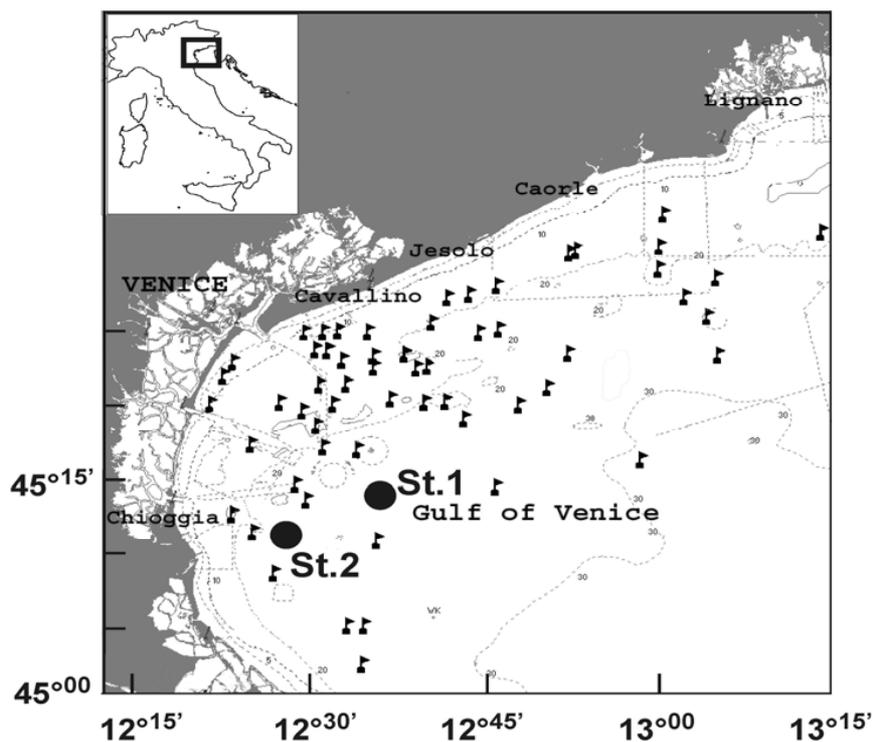


Fig. 2 Distribution of the rocky outcrops along the Gulf of Venice. The studied areas are indicated (St. 1 – station 1; St. 2 – station 2).

These extremely hard limestone substrates were suitable for the settlement and development of special assemblages of flora and fauna. In the Mediterranean Sea, these habitats were mainly produced by accumulation of calcareous incrusting algae, growing in environments with low light levels (sciaphilic), forming the first base on which fouling and building fauna developed, growing on top of each other and englobing sediments and shells, while the same shells and the calcareous skeletons of animals facilitated the settlement and development of further organisms. These complex biostructures, forming true organogenic reefs are known also as “coralligenous” [24]. Unlike the true warm water coral reefs, the bioconstruction of the organic rocks in the Mediterranean is not dependent on photosynthetic processes of the symbiotic zooxanthellae, but developed by the action of other building organisms, such as bryozoa, madreporae, anthozoa, serpulid polychaetes and calcareous algae. Actually, the Adriatic reefs differ from the classic “coralligenous” because they have very small concretions of coralline algae.

A series of underwater explorations, between August 2002 and June 2003, allowed us to define the qualitative and quantitative composition of the whole zoobenthic community of two of these numerous rocky outcrops off Chioggia, in the Gulf of Venice, including the epifaunal and endofaunal components. Also, the pelagic species related to this environment were detected by visual-census.

2 Experimental procedures

The two sampling stations were located at different distances from the coast (Figure 2). Station 1 was at 45°13.16 N, 012°29.67 E, at a depth of 22 meters, about 8 nautical miles from the coast, and was formed by a series of rocky outcrops of various sizes (from 1 to 10 m²), rising to a maximum height of 2.5 m from the seabed. Station 2 was 4.2 nautical miles from the coast, at 45°11.70 N, 012°25.20E, inside one of the largest now protected areas (Regione Veneto “Gazzetta ufficiale” n. 193 of 18/08/2002); It was a real reef, at a depth of 24 meters emerging about 3 meters from the seabed. These areas were recently mapped by employing side-scan sonar techniques [25, 26].

Three seasonal surveys of a few days were carried out in August 2002, February 2003 and May/June 2003. Scuba divers collected bottom samples in order to study the main environmental parameters; i.e., grain size of sediments and their contents of organic matter; turbidity, salinity, temperature and dissolved oxygen of the waters. These data were discussed in recent works [27, 28].

Samples of vagile and sessile fauna were taken: sampling units were 50 x 50-cm squares of ballasted line [29, 30] arranged randomly on the bottom. Three sampling replicates were carried out for each site (total sampled area = 0.75 m²) (totally 18 samples). In each replicate, first the vagile organisms were captured by a hydraulic lift with a 500- μ m mesh net [31], then the sessile organisms were manually collected, by scraping the rocky substrate with steel scrapers. Magnesium chloride, to act as an anaesthetic, was added to the water in which collected samples were kept at low temperature, until they were fixed in seawater with 4% borax-buffered formalin for subsequent analysis. To have a complete knowledge of the local fauna in each station and in each sampling period, a careful video filming of the natural environment was done, thus creating a kind of “visual census” for those species which are not exclusively benthic or which could not be collected owing to their extreme fragility.

2.1 Statistical analyses

To investigate the biodiversity of the studied communities, the Shannon-Weaver and Pielou Indexes were calculated, using qualitative and quantitative data.

To evaluate the significant differences of the faunal composition between the two studied reefs and among all replicates, the Sørensen Index and χ^2 Test were utilized. In particular, the χ^2 test was applied to the expected value (SSPS program, version 11.0), aggregating organisms at the phylum level.

Mollusca	<i>Bittium incile</i> (Watson, 1897)
	<i>Bulbus globosus</i> (Jeffreys, 1885)
	<i>Chauvetia brunnea</i> (Donovan, 1804)*
	<i>Chrysallida incerta</i> (Milaschewitch, 1916)*
	<i>Crepidula cataldi</i> (Parenzan, 1970)*
	<i>Fusceulima minuta</i> (Jeffreys, 1884)
	<i>Gari tellinella</i> (Lamarck, 1818)
	<i>Kleinella humboldti</i> (Risso A., 1826)
	<i>Pseudoacteon pusilinus</i> (Forbes, 1844)
	<i>Vitreolina perminima</i> (Jeffreys, 1883)
Polychaeta	<i>Eulalia bilineata</i> (Johnston, 1840)
	<i>Eunice floridana</i> (Portualès, 1867)
	<i>Exogone gommifera</i> (Pagenstecher, 1862)
	<i>Hydroides uncinata</i> (Philippi, 1844)
	<i>Laonome kroyeri</i> (Malmgren, 1866)
	<i>Lumbrinereis impatiens</i> (Claparède, 1868)
	<i>Micromaldane ornitochaeta</i> (Mesnil, 1897)
	<i>Myriochele heeri</i> (Malmgren, 1867)
	<i>Sabella spallanzani</i> (Gmelin, 1791)
	<i>Sabellaria alveolata</i> (Linneus, 1767)
	<i>Sabellonga disjuncta</i> (Hartmann, 1969)
	<i>Scalissetosus pellucidus</i> (Ehlers, 1864)
	<i>Sphaerosyllis bulbosa</i> (Southern, 1914)*
	<i>Stylarioides eruca</i> (Claparède, 1870)
<i>Syllis vivipara</i> (Krohn, 1869)*	
Crustacea	<i>Corophium aculeatum</i> (Chevreux, 1908)
	<i>Elminius modestus</i> (Darwin, 1854)
	<i>Eualus pusiolus</i> (Krøyer, 1841)
	<i>Leucon mediterraneus</i> (Sars, 1879)
	<i>Microdeutopus sporadhi</i> (Myers, 1869)

* not in the check list, but reported for the Adriatic Sea.

Table 1 Marine species collected in the study areas and not yet reported in the up-to-date version of the Marine Italian Fauna checklist of 2006, for the northern Adriatic Sea.

3 Results

Although the seabed at the two stations was not very deep, water turbidity greatly reduces the quantity of light reaching the surface of the outcrops, [28] limiting the activity of autotrophic organisms exclusively to sciaphilous genera (i.e. adapted to low light-intensity). At station 1, the only macroscopic vegetal forms found were calcareous algae belonging to the Corallinaceae (*Lithophyllum* and *Pseudolithophyllum*), typical of the studied areas, where little light reaches the bottom. At station 2, few Rhodophyceae of the family of Ceraminiaceae were observed in August 2002 and June 2003, but no macroalgae were found in February 2003.

A total of 317 different zoological taxa were collected, belonging to 11 phyla, including many new species for the Adriatic not yet reported in the Check-List of Italian Fauna [32] or in the up-to-date version of the checklist of the marine Italian fauna (www.sibm.it/CHECKLIST/principalechecklist.htm) (Table 1). Some are new to the entire Mediterranean basin, and one species of sponge, belonging to the Clionaidae family, was previously unknown (G. Corriero, pers.comm.). Only 110 taxa were common to both stations and 81 and 126 were found exclusively at stations 1 and 2 respectively (Figure 3).

At station 1, a total of 195 *taxa* were identified during the survey, with a peak of 115 in winter and a minimum of 80 in summer. At station 2, the total *taxa* identified throughout the study period was 236, with a peak during winter and summer samplings (118 and 119 *taxa* respectively) and a minimum during spring (107) (Figure 4).

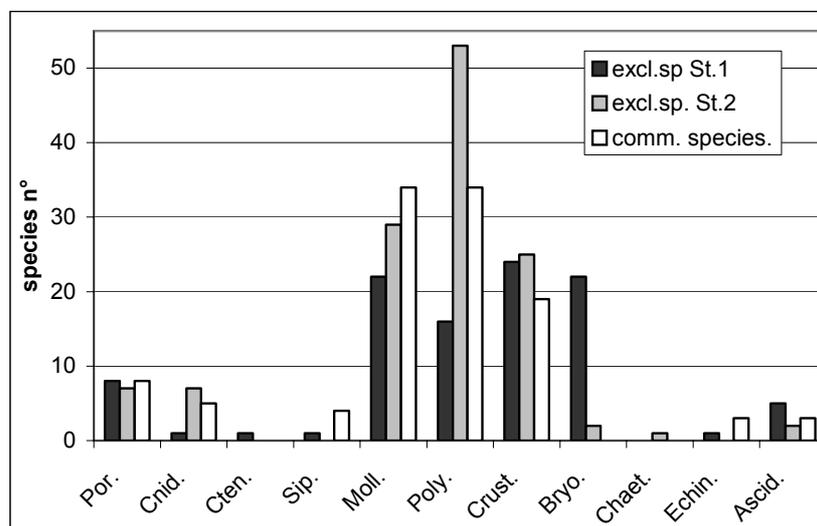


Fig. 3 Common and exclusive species present in the two explored areas. White bars indicate the number of species present in both explored sites (comm. species), black and grey bars indicate the species exclusive for site 1 (excl.sp.St. 1) and site 2 (excl. sp. St.2).

At both stations, molluscs, crustaceans and polychaetes were the most common *taxa* while ascidians and cnidarians had clearly different distributions. At station 1, eight species of ascidians were found, with *Polycitor adriaticus* being very abundant in all seasonal samples. Among cnidarians, represented by 6 *taxa*, only *Epizoanthus arenaceus* was abundant. At station 2, cnidarians were represented by 12 species, with the quite abundant *Leptopsammia pruvoti*, *Rolandia rosea*, *Epizoanthus arenaceus* and *Caryophyllia inornata*. Only 5 species of ascidians were present in this station, with low population density (Figures 4, 5). Overall, the population densities of the entire community varied from summer minimum of 485 ind/m² at station 1 and 2089 ind/m² at station 2, to winter peaks of 1094 ind/m² at station 1 and 3008 ind/m² at station 2.

The largest part of the living biomass in the Adriatic tegrùe assemblages consisted of suspension-feeders with high shares of filter feeders (from 24 to 60%), and herbivores and carnivores were far less abundant (Figure 6). Among suspension feeders, there were numerous sponges, often reaching considerable sizes. Examples were the unique *Tethya citrina*, and *Geodia cydonium*, *Axinella cannabina* and *A. damicornis*; there were also cnidarians, including *Cerianthus membranaceus*, several species of anemones and madrepores, *Parazoanthus axinellae*, dense colonies of hydrozoa, often preyed upon by brightly coloured nudibranchs, and both erect and encrusting colonies of bryozoa.

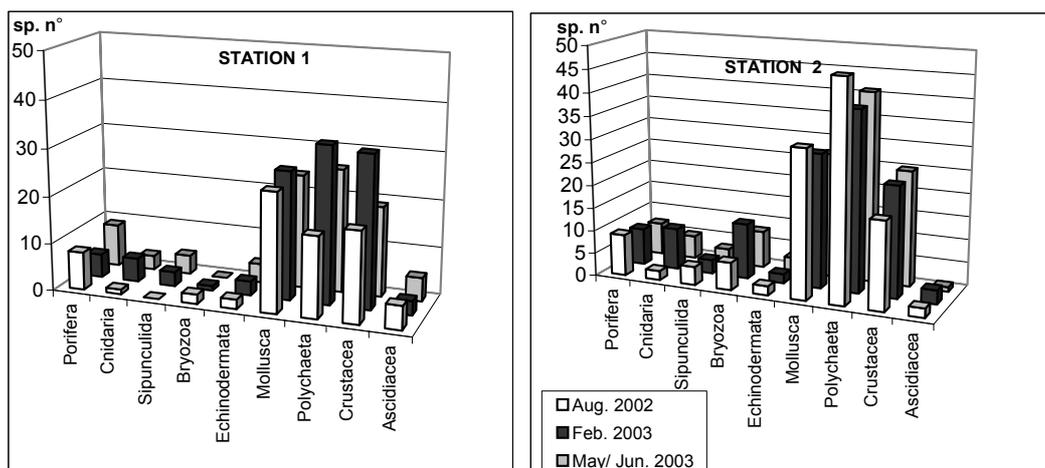


Fig. 4 Species number for each fauna and for each seasonal sampling in the two explored areas.

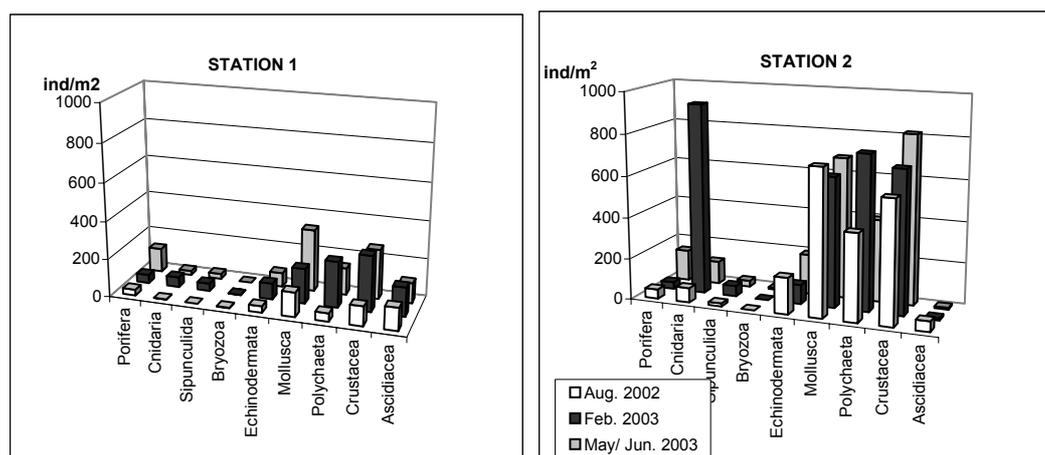


Fig. 5 Density for each species and for each seasonal sampling in the two explored areas (For ascidians, porifers and cnidarians, colonies are considered).

The very rich presence of both sessile and fouling species, together with a large variety of caves and holes as shelters, inevitably attracted great numbers of other organisms, including many pelagic fish and crustaceans, which found both food and refuge there. Twenty-seven more *taxa* (including also osteictheys, more numerous in station 1), were identified using the “visual census” method (Tables 2, 3).

The Shannon-Weaver index of the whole zoobenthic communities values ranged between 3.44 and 3.85, and those of Pielou between 0.72 and 0.85 (Figure 7).

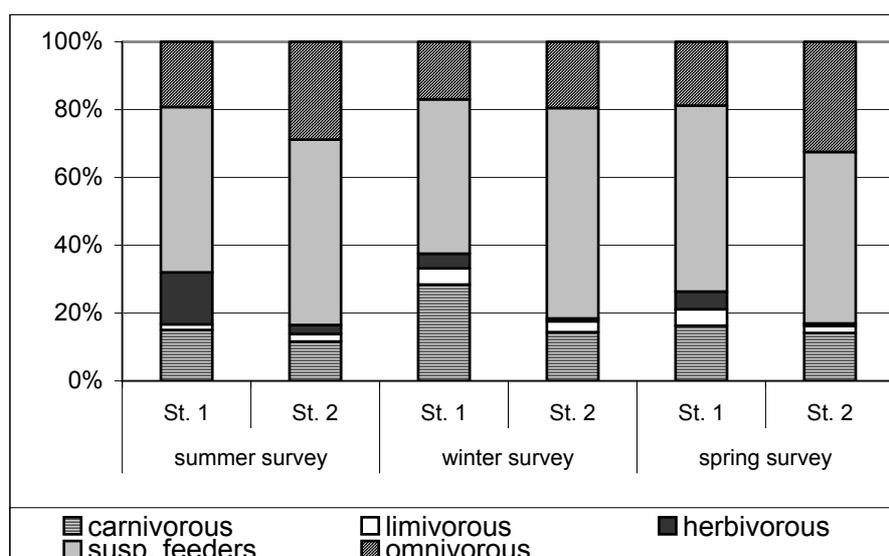


Fig. 6 Feeding guilds in the zoobenthic communities of the two study areas, in each sampling period.

Taxa	Rare	Frequent	Abundant
Porifera		*	
		*	
Cnidaria		*	
	*		
Ctenophora	*		
Echiurida			*
Mollusca	*		
	*		
Polychaeta	*		
Crustacea	*		
	*		
		*	
Echinodermata	*		
Osteichthyes			*
		*	
		*	
		*	
		*	
	*		
		*	
		*	
		*	*
		*	*
		*	

Table 2 Species identified by *visual census* in site 1, (rare: 1-5; frequent: 5-10; abundant: > 10).

Taxa		Rare	Frequent	Abundant
Porifera	<i>Aplysina aerophoba</i> Schmidt, 1862	*		
Cnidaria	<i>Cladocora caespitosa</i> (Linnaeus, 1767)	*		
	<i>Eudendrium racemosus</i> (Gmelin, 1791)			*
Mollusca	<i>Dendrodoris limbata</i> (Cuvier, 1804)	*		
	<i>Pinna nobilis</i> Linnaeus, 1758	*		
	<i>Tethys fimbria</i> Linnaeus, 1767	*		
	<i>Berthella ocellata</i> (Delle Chiaje, 1830)	*		
Polychaeta	<i>Spirographis spallanzani</i> (Viviani, 1805)	*		
Crustacea	<i>Galathea strigosa</i> (Linnaeus, 1761)	*		
	<i>Homarus gammarus</i> (Linnaeus, 1758)	*		
	<i>Maja squinado</i> (Herbst, 1788)	*		
Echinodermata	<i>Ocnus planci</i> (Brandt, 1835)	*		
Ascidacea	<i>Phallusia fumigata</i> (Grube, 1864)		*	
Osteichthyes	<i>Chromis chromis</i> (Linnaeus, 1758)			*
	<i>Blennius spp.</i>		*	
	<i>Conger conger</i> (Linnaeus, 1758)	*		
	<i>Serranus hepatus</i> (Linnaeus, 1758)			*

Table 3 Species identified by *visual census* in site 2, (rare: 1-5; frequent: 5-10; abundant: > 10).

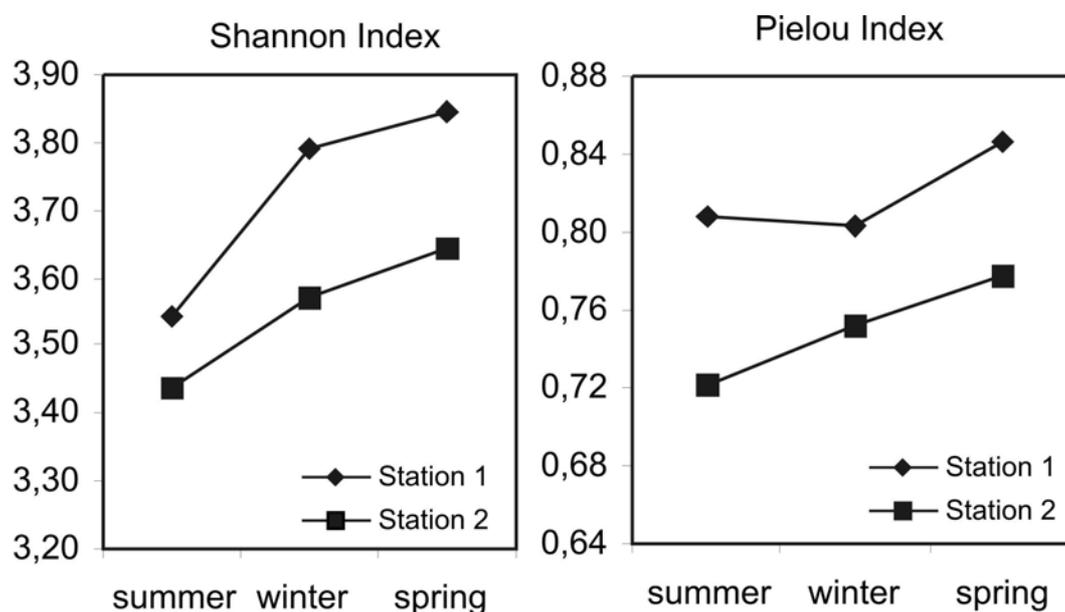


Fig. 7 Shannon and Pielou Indexes values in the two study areas.

3.1 Analysis of statistical distribution of samples

The great differences in qualitative and quantitative composition between the two outcrops was highlighted by Sørensen's Similarity Index [33] (Table 4). This index only reached 0.51 for the whole community, but was often lower, when fauna were considered separately. It was particularly low in the case of crustaceans and ascidians, a little higher for molluscs, cnidarians and poriferans. The highest values were observed for sipunculids

and echinoderms, but these groups were represented by few species common to the Adriatic area. Completely different organisms found at the two stations were bryozoans and chaetognates.

Faunistic group	Sørensen Index
Porifera	0.52
Cnidaria	0.55
Ctenophora	0.00
Sipunculida	0.88
Mollusca	0.59
Polychaeta	0.49
Crustacea	0.44
Bryozoa	0.00
Chaetognata	0.00
Echinodermata	0.86
Tunicata	0.46
Whole comm.	0.51

Table 4 Sørensen Index values calculated for each faunistic group and for the whole zoobenthic community.

A certain degree of variability was also found among samples from the same station. The χ^2 test applied to the replicates of the same sampling and to seasonal samplings for each of the two stations, showing that the frequency variations of the various faunistic groups were significant (Table 5).

	summer		winter		spring	
	St. 1	St. 2	St. 1	St. 2	St. 1	St. 2
Pearson χ^2	30.974	83.774	79.113	271.671	130.024	289
Freedom degrees	12	14	16	16	14	16
significance	0.002	<.0.000	<0.000	<0.000	< 0.000	< 0.000

Table 5 The χ^2 test results revealing a high variability among samples and among replicates.

4 Discussion

There is no real accord among scientists studying benthic communities of hard substrate in the Mediterranean Sea concerning the criteria in labeling a “coralligenous” habitat. The most recent definition [24] consider the coralligenous as “a hard substratum of biogenic origin, mainly produced by the accumulation of calcareous encrusting algae growing in dim light conditions” The biocenoses which develop on the “tegnúe” are slightly different from the classic “coralligenous”, because they have very small concretions of coralline

after algae, being the faunal component dominant throughout the year. They are as extraordinary as they are unique: our study revealed a very high number of species, including those which have now become rare and are therefore protected in Italian seas (Marine and brackish species protected in Italy, Annex II ASPIM; Table 6). The values of biodiversity (H') calculated for the communities of these reefs, were far higher than those in the soft seabed in nearby areas in Adriatic [34]. Many less species (135) was reported by Dahl and Dahl [16] in some stone reefs in Kattegat (Baltic Sea) and by Thobjørn and Petersen [17] for the epifauna (165 invertebrate species) on the carbonate reefs in the Greenland fjords.

Porifera	<i>Aplysina aerophoba</i> Schmidt, 1862 <i>Geodia cydonium</i> (Jameson, 1811) <i>Tethya citrina</i> Sarà & Melone, 1965
Cnidaria	<i>Astroides calycularis</i> (Pallas, 1766)
Mollusca	<i>Litophaga litophaga</i> (Linnaeus, 1758) <i>Pinna nobilis</i> (Linnaeus, 1758)
Crustacea	<i>Homarus gammarus</i> (Linnaeus, 1758)
Osteichthyes	<i>Sciaena umbra</i> Linnaeus, 1758

Table 6 Marine species protected in Italy, found in the explored sites in Adriatic.

The observed fauna in the tegnùe consisting of many species with high abundances was surprising in light of the role played by autotrophic organisms in these communities: at the base of the food chain of these extraordinary and rich community, there was no algae but a large amount of organic matter content in water. It was found that the great turbidity of the waters [28] of the Northeastern Adriatic was not due to mud or sediments, but to large quantities of dissolved and particulate organic matter, and suspended plankton [29]. The considerable amounts of food favoured the development of organisms which were mostly suspension feeders, capable of capturing this important source of energy and then making it available once again to the surrounding environment. Herbivorous and carnivorous organisms were greatly reduced in these coralligenous communities, as reported for other similar environments in the Mediterranean [35, 36].

The very turbidity of Adriatic Sea allowed the development and maintenance of these singular faunal assemblages. Our data thus support the hypothesis that they act as traps for organic matter in solution, capturing and condensing it, and then making it available again, either directly through macrophages or indirectly through the detritus chain [29, 37].

The ecological role played by the tegnùe in the northern Adriatic is extraordinary: as well as being true oases of biodiversity, they are areas, which are naturally protected against trawl fishing. This is because, on a local scale, their irregular profiles limit the use of highly profitable but destructive systems of fishing, like the *rapid* (large metal racks which furrow the seabed) or the hydraulic dredges, which plough the sea bottom with the aid of high-pressure jets of water. The tegnùe thus provide shelter for a large variety of marine invertebrates and act as a natural nursery for many species of fishes, which find

food, protection and, above all, suitable places for reproduction.

But such environments are extremely delicate: they may be negatively influenced by natural disturbances; i.e., episodes of water bottom water anoxia [38] or excessive sedimentation, but mainly by anthropogenic activities, such as pollution, trawl-fishing, dumping of waste, or damage due to anchors.

Another problem worth discussing is the great differences between the benthic communities of the two explored sites: they lie at approximately the same depth (22-23 m), their bottom water oxygen content (varying from 43% to 159%), did not differ throughout the year, except in summer [28], but one is slightly further offshore than the other, a point which influences the dynamics of supply from rivers run-off, and consequently changes water turbidity. The water of the station 2, nearer the coast, which receive organic particulate, sustains a richer community, both qualitatively and quantitatively. This finding fits the SAB (Species-Abundance-Biomass) curve, which indicates changes in the richness and abundance according to a gradient of organic matter [39].

Observed qualitative and quantitative seasonal variations in composition of fauna between the two study areas and among the replicates are not always due to the biological cycles of the species involved. This is mainly true for those *taxa*, which have long life cycles, like several cnidarians. The χ^2 test showed that the differences among the populations of the various replicates were significant, i.e., due to the existence of significant relationships among the various faunal groups and environments sampled. On one hand, this emphasises once more their high spatial-temporal variability; on the other hand, it indicates that hasty, superficial generalisations made about these environments must be avoided, because the obtained data are representative not of the overall community, but only of its sampled subpopulations at a special time. This is also substantiated by the low similarity values found among the replicates within the same station.

Comparison with other quantitative studies conducted on the hard bottom fauna of similar structures in other marine ecosystems (including Adriatic Sea) are difficult, because the available data in the literature refer to studies on only few selected phyla or to short observation periods in the year [29, 30, 40–46].

The present data makes up the most comprehensive quantitative study of the whole benthic community of the habitats of the *tegnúe* in different seasonal periods. The importance of studying the community as a whole (i.e. including all taxonomic groups) and its spatial-temporal variations, have been the objectives of this work and have led us to conclude that many other sites in the Venice Gulf have to be explored in order to clarify the biological and physical factors that are important in determining the composition of these faunal assemblages.

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