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Coralligenous cliffs: distribution and extent along the Tuscany coasts and spatial variability of the associated assemblages

Luigi PIAZZI[1], Enrico CECCHI[2], Maria Francesca CINTI[3], Giacomo MARINO[2], Andrea NICASTRO[2], Lorenzo PACCIARDI[3], Marco PERTUSATI[3], Michela RIA[2] and Anna Maria DE BIASI[3]

[1] Department of Chemical, Physical, Mathematical and Natural Sciences
University of Sassari, 07100 Sassari, Italy
[2] ARPAT - Agenzia Regionale per la Protezione Ambientale della Toscana, Via Marradi 114, 57126 Livorno, Italy
[3] Centro Interuniversitario di Biologia Marina ed Ecologia Applicata, v.le N. Sauro 4, Livorno, Italy

Corresponding author: Luigi PIAZZI; lpiazzi@uniss.it

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Abstract

Coralligenous reefs are the main biogenic constructions of the Mediterranean Sea. The two main coralligenous morphologies are cliffs and platforms. Coralligenous cliffs mostly develop in shallower waters (about 20-50 m) on vertical/sub vertical rocky substrates. Coralligenous platforms are mostly distributed on horizontal substrates below 40-50 m depth on detritic bottoms and rocky outcrops of the continental shelf. The present study aims at contributing to the knowledge of coralligenous cliffs through the assessment of their distribution and extent in a wide geographic zone of northwestern Mediterranean Sea, focusing on the structure and the spatial variability of the associated assemblages. To achieve these objectives, coralligenous cliffs of Tuscany coasts were mapped through Multibeam and Remotely Operated Vehicles. The area of coralligenous cliffs was also manually calculated for each study site using linear extent and bathymetric range of the habitat. In addition, the structure of the associated assemblages was investigated by a multifactorial sampling design taking into account spatial scales ranging from meters to tens of kilometres. Coralligenous cliffs were present in all the study sites, with a linear extent of about 20% of Tuscany's rocky coastline and an area of about 20% of the Tuscan coralligenous reefs. The difference between data manually calculated and those obtained by Quantum-GIS software was about 33% of the total area. A continental-to-island gradient and a latitudinal gradient were the main factors driving the structure of the associated assemblages. Results highlighted that coralligenous cliffs represent a considerable part of circalittoral biogenic habitat, suggesting that their relevance may be greater than what normally emerges from seabed mapping and that they should be considered separately in monitoring programs, impact assessment studies and management plans.

Keywords: biodiversity; coralligenous reefs; mapping; Mediterranean Sea; spatial variability.

Introduction

Coralligenous reefs are the main biogenic constructions of the Mediterranean Sea and consist of carbonate structures with variable thickness (Ballesteros, 2006). These structures are produced by the deposition of thalli and calcareous structures of encrusting coralline algae and several invertebrates, mostly Cnidaria, Polychaeta and Bryozoa (Ballesteros, 2006). Coralligenous reefs are a habitat of European Community interest (EU, 1992) due to their extent, biodiversity, role in the balance of CO_2 and ecological services provided (Paoli *et al*., 2017; Thierry de Ville d'Avray *et al*., 2019). Moreover, they are among the most threatened habitats in the Mediterranean Sea, being characterized by the presence of organisms that are sensitive to human pressure (Gatti *et al*., 2015a). Biogenic structures are largely threatened by pollution, eutrophication, sediment deposition, alien invasive species, climate change and direct habitat destruction through fishing, anchoring and coastal construction activities (Piazzi *et al*., 2012; Gori *et al*., 2017; Betti *et al*. 2020). Hence, the state of conservation of coralligenous reefs has been considered as an indicator both of the ecological quality of coastal systems and of "seafloor integrity" by the Marine Strategy Framework Directive (MSFD, EU, 2008).

Several coralligenous morphologies have been described (Montefalcone *et al*., 2021; UNEP/MAP-SPA/RAC, 2021). Coralligenous cliffs mainly develop in shallower waters (about 20-50 m) on vertical/sub vertical rocky substrates. Coralligenous platforms are mostly distributed on horizontal substrates below 40-50 m depth, on detritic bottoms and rocky outcrops of the continental shelf (Ballesteros, 2006; Montefalcone *et al*., 2021; UNEP/MAP-SPA/RAC, 2021). Moreover, coralligenous outcrops consist of individual metric structures, which may be isolated or clustered in tens or hundreds (UNEP/MAP-SPA/RAC, 2021) and are often included in coralligenous platforms in seabed mapping and monitoring surveys.

Coralligenous cliffs and platforms are considered different habitats each requiring specific methodological approaches when they are investigated (UNEP/MAP, 2017; 2019). Coralligenous cliffs are sampled mostly by SCUBA divers, with both visual and photographic techniques (Piazzi *et al*., 2019a), while ROVs (Remotely Operated Vehicles) are usually utilized for coralligenous platforms' investigations (Canovas-Molina *et al*., 2016; Ferrigno *et al*., 2018; Piazzi *et al*., 2019b). Moreover, different indices have been developed to score the ecological quality of cliffs (Deter *et al*., 2012; Gatti *et al*., 2015b; Montefalcone *et al*., 2017; Sartoretto *et al*., 2017; Piazzi *et al*., 2021a) and platforms (Gatti *et al*., 2015a; Ferrigno *et al*., 2017; Sartoretto *et al*., 2017; Enrichetti *et al*., 2019). However, the two coralligenous morphologies have rarely been distinguished in sea-floor mapping programs. Cliffs, due to their development on vertical bottoms, are not usually considered or are under-estimated (Vassallo *et al*., 2018; De Falco *et al*., 2021), despite their economic and ecological relevance being widely recognized (Chimienti *et al*., 2017). Thus, the relative importance of these two habitats and their different ecological contribution within the same geographic zone is poorly or not at all evaluated.

Therefore, the present study aims at deepening the knowledge of coralligenous cliffs through the assessment of their distribution and extent, taking into account a wide geographic zone of the northwestern Mediterranean Sea. Special attention has been devoted to investigating the structure and the patterns of spatial variability of the associated assemblages. To achieve these objectives, coralligenous cliffs of the continental and insular coasts of Tuscany (north-western Mediterranean Sea, Italy) were mapped through Multibeam and ROVs and the structure of the associated assemblages was assessed using a multifactorial sampling design. The extent of the habitat was compared to that of the coralligenous platforms in Tuscany.

Material and Methods

Study sites

Tuscany has 633 km of coastline, running mainly along the continental border of Italy (397 km); whereas about 30% (230 km) of the coastline belongs to islands. A little less than 60% (approximately 360 km) of the coastline is rocky, and is distributed in ten sectors. Two sectors are sited along the continent (Livorno and Argentario) and eight sectors on the islands of the Tuscan Archipelago (Gorgona, Capraia, Elba, Pianosa, Montecristo, Formiche di Grosseto, Giglio and Giannutri). A large rocky shoal (Meloria) is also present at about 6 kms off the Livorno coast (Fig. 1).

Mapping

The rocky sectors from ~20 m down to ~100 m depth were mapped using Multibeam echosounder (MBES). MBES data were verified and integrated through video images of the seabed recorded using a Remote Operating Vehicle (ROV) equipped with a high-resolution camera and with an acoustic positioning system to geo-localize the video images.

The bottom slope (the angle of inclination to the horizontal for each cell) and depth were used to discriminate between coralligenous cliffs and platforms through

Fig. 1: Map of the study sites.

the Quantum-GIS (www.qgis.org) software. The hard bottoms at 30-40 m depth with a slope of 60-90° were considered as coralligenous reefs, while the hard bottoms at 40-100 m depth with a slope of 10-60° as coralligenous platforms.

However, the method is not able to evaluate the real area of coralligenous cliffs due to their distribution on vertical and sub-vertical bottoms. Thus, the area of coralligenous cliffs was also manually calculated for each sector using linear extent and bathymetric range of the habitat.

Structure and spatial variability of the assemblages

According to previous knowledge, 12 sites were selected along the coast of Tuscany (Mediterranean Sea, Italy) (Fig. 1). In each site, two areas several km apart were chosen. In each area, three plots of about 4 m^2 were randomly selected on vertical coralligenous cliffs at 35 m depth and sampled by SCUBA divers using the STAR method (Piazzi *et al*., 2019a). In each plot, ten photographs of 0.2 m^2 area were taken with a frame camera (Piazzi *et al*., 2019a). Organisms that were easily identifiable in photos were considered as taxa, while the others were assembled into homogeneous groups on morphological basis (Piazzi *et al*., 2021a). The percentage coverage of the main taxa/morphological groups was assessed in each photo by manual contour technique using ImageJ software (Piazzi *et al*., 2021a).

Spatial differences in the structure of assemblages (presence and abundance of taxa/morphological groups) were analyzed by permutational analysis of variance (Primer6 + PERMANOVA, Anderson, 2001) based on the Bray-Curtis similarity matrix of the fourth root transformed data. A 3-way model was used with Site as a fixed factor, Area (three levels) as a random factor nested in the Site and Plot (three levels) as a random factor nested in the Area. The Pair-wise test was used to discriminate between levels of significant factors. Pseudo-variance components were also calculated for each spatial scale considered. A canonical analysis of principal coordinates (CAP) was performed on the fourth root transformed Bray-Curtis similarity matrix (Anderson & Robinson, 2003) to discriminate the main categories (i.e., taxa/morphological groups) contributing to dissimilarities between areas.

The diversity of assemblages was assessed as the number of taxa/morphological groups per sample and analyzed through PERMANOVA based on Euclidean distance, using the same multivariate model.

Results

Mapping

Coralligenous cliffs were present in all the study sites, with a linear extent of about 62.5 km (Fig. 2). A total area of coralligenous cliffs of 0.12 km^2 emerges through the Quantum-GIS software, while the area manually calculated was 0.18 km^2. The surface of coralligenous cliffs was about 20% of that of the Tuscan coralligenous reefs, although values were highly variable according to the site. In fact, over 60% of the coralligenous platforms are concentrated in the Meloria shoals and Giglio Island. By contrast, in most of the other sites, the spatial extent of coralligenous cliffs and platforms is comparable or even coralligenous cliffs overwhelm the coralligenous platforms as observed in Livorno, Capraia, Elba, Argentario, Pianosa and Giannutri (Fig. 3).

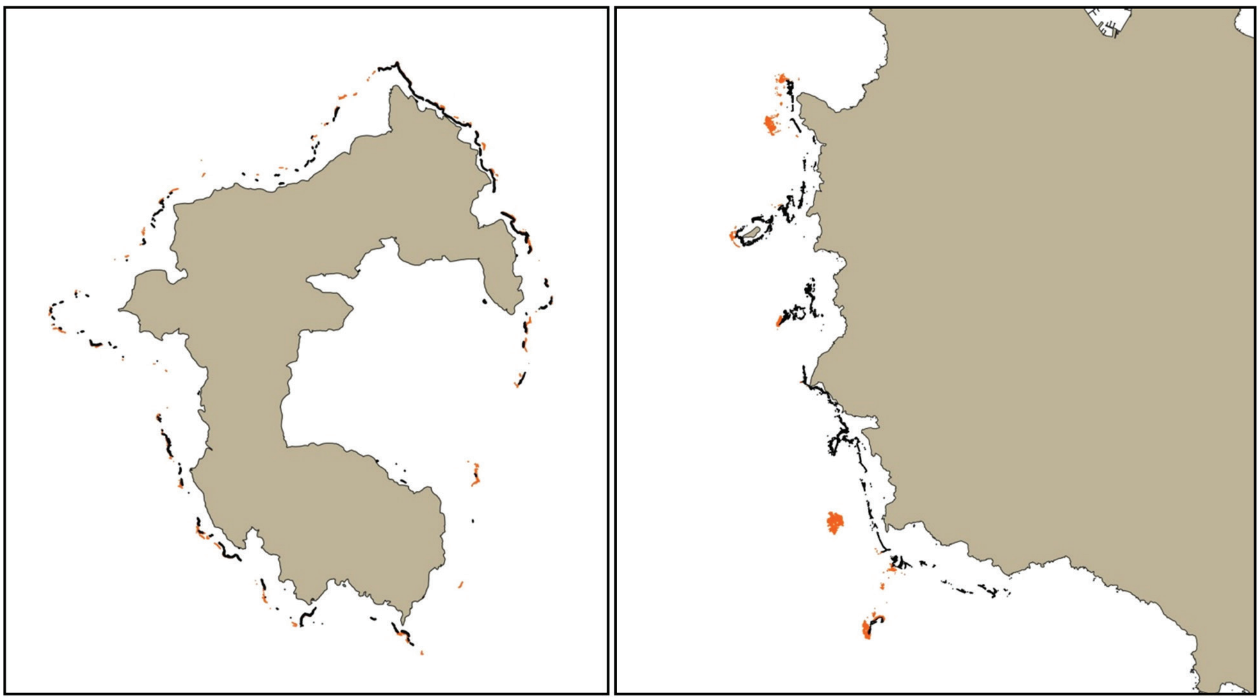

Fig. 2: Distribution of coralligenous cliffs (black) and platform (orange) at Giannutri (left) and Argentario (right).

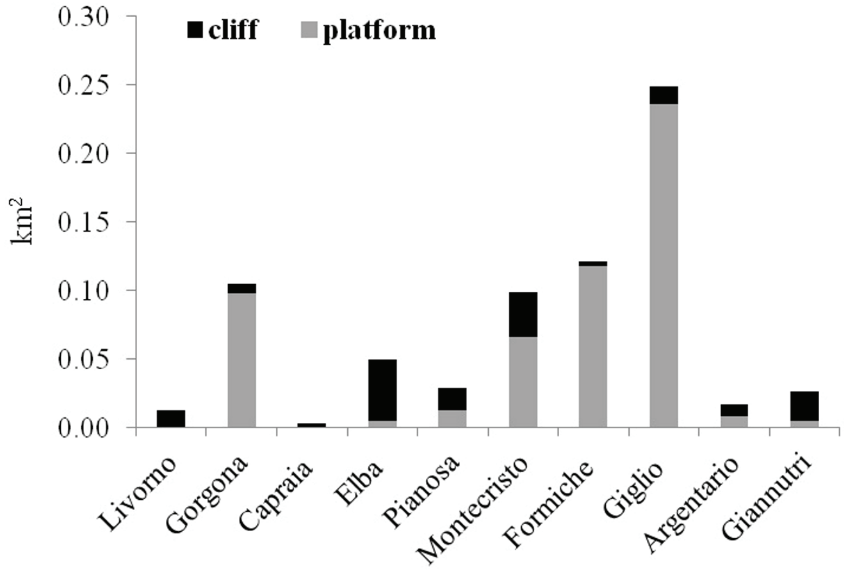

Fig. 3: The spatial extent of coralligenous cliffs and platforms along Tuscany coasts.

Structure and spatial variability of assemblages

Tuscany's coralligenous reef assemblages varied significantly at the spatial scales considered (PERMANOVA, Table 1) and seven main groups of sites can be highlighted (Pair-wise test, Table 1). The two continental sites (Livorno and Argentario) and the shoal (Meloria) differed from the island sites; the latter formed a main group with the exception of Gorgona, Capraia and Giannutri which segregated independently (Fig. 4).

Coralligenous assemblages of continental coasts were dominated by algal turf, *Parazoanthus axinellae*, *Corallium rubrum*, encrusting and massive sponges. Most islands were characterized by *Palmophyllum crassum*, *Eunicella cavolini* and erect bryozoans. Udoteaceae (*Flabellia petiolata* and *Halimeda tuna*) were abundant on Capraia and Giannutri, and erect Rhodophyta on Gorgona. *Paramuricea clavata* was distributed on the southern islands (Elba, Pianosa, Montecristo, Formiche, Giannutri and Giglio) and at Argentario (Table 2, Fig. 4).

The number of taxa/groups per sample varied from 6.2 ± 02 at Meloria to 15.5 ± 0.5 at Pianosa (Fig. 5). PERMANOVA found significant differences between sites ($F_{13,14}$ = 3.097; P(perm) = 0.016).

Discussion

This study compared, for the first time, the area of coralligenous cliffs and platforms in a wide geographic zone, highlighting that the extent of coralligenous cliffs has traditionally been underestimated. Overall, the area of coralligenous cliffs was about 20% of that of Tuscan coralligenous reefs and the linear extent of the habitat can be estimated at around 20% of Tuscany's rocky coastline. The difference between data obtained through the Quantum-GIS software and those calculated manually was about 33% of the total area. The approach used in the study showed that coralligenous cliffs represent a considerable part of the circalittoral biogenic habitat, suggesting that their significance may be greater than what normally emerges from seabed mapping. However, the real extent of coralligenous cliffs could be still underestimated as reefs with a slope >80° are not completely identified by traditional acoustic methods. The use of finer methods of seabed mapping, such as stereo photogrammetry, photomosaic elaboration and 3D modelling (Zapata-Ramírez *et al*., 2013; Casoli *et al*., 2021) should be employed to overcome this information gap.

The results also confirmed the high level of biodiver-

Table 1. PERMANOVA on coralligenous cliff assemblages of Tuscany.

Source	df	MS	Pseudo-F	P(perm)
Site = S	11	48283	3.655	0.001
Area(S) = A(S)	12	13207	7.555	0.001
Plot(A(S))	48	1747	2.969	0.001
Residual	648	588		
Pair-Wise test (S):	LIV≠ARG≠MEL≠PIA=MON=GIG=FOR= EL-E= EL-N ≠ CAP ≠GIA≠GOR			

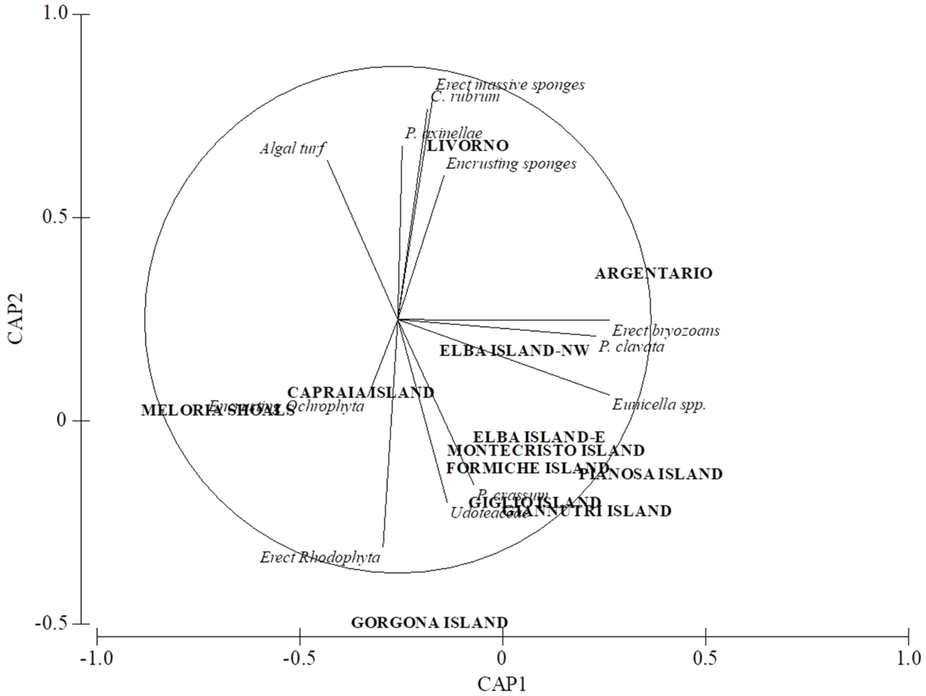

Fig. 4: CAP ordination on coralligenous cliff assemblages of Tuscany.

sity and spatial heterogeneity of the coralligenous cliff assemblages, as already described in other Mediterranean areas (Ponti *et al*., 2011; Casas-Guell *et al*., 2015; 2016; Doxa *et al*., 2016).

The high biodiversity of coralligenous reefs has been considered mostly related to the heterogeneity of the biogenic substrate which generates a high number of available ecological niches, providing organisms a substrate for settlement, a refuge from predation and a variety of feeding opportunities (Cocito, 2004; Piazzi *et al*., 2022a).

The variability in coralligenous assemblages at a small scale is not novel, being widely described and attributed to biogenic substrate heterogeneity and to the effects of biological interactions (Cocito, 2004; Piazzi *et al*., 2016). On a large scale, two main factors of variability have been recognized: a continent-to-island gradient and a latitudinal gradient. Continental sites clearly differ from the island counterpart, probably because they are more exposed to the coastal pressures (Holon *et al*., 2015). In areas subjected to sedimentation, eutrophication and pollution (Balata *et al*., 2005; Piazzi *et al*., 2011, 2019c, 2021b), coralligenous assemblages tend to be dominated by tolerant and opportunistic organisms, such as algal turf and encrusting sponges. However, the two continental sites were significantly different, which induces one to consider other causes of variability (Holon *et al*., 2014) to explain these differences. These may be related both to geographical features, due to the distance between the continental sites, and to a different exposure to the anthropogenic pressures. For example, the northern sites are closer to urban and industrial areas while the southern ones are affected by agricultural waste only. The Meloria shoal is even more different from island and continental sites. According to Piazzi *et al*. (2004) its intermediate distance from the continent may account for this pattern. The islands were mostly characterised by well-structured assemblages, dominated by sensitive organisms, such as fan corals and erect bryozoans, as expected in areas subjected to very low levels of pressure (Gatti *et al*., 2015a; Montefalcone *et al*., 2017; Casoli *et al*., 2020). The islands also showed a geographical pattern, as the northern and southern islands were segregated from each other. Both northern islands were devoid of *Paramuricea clavata* and Capraia also of *Eunicella* spp.; on the contrary, they were characterised by sensitive macroalgae, such as Udoteaceae and erect Rhodophyta (Balata *et al*., 2011). The southern islands showed an abundance of erect bryozoans and flattened Rhodophyta. These results suggest that the similar levels of pressure are not a convincing explanation of the spatial variability of the study sites. Other drivers, such as temperature, currents or natural history may contribute to select peculiar assemblages (Ponti *et al*., 2014; Ceccherelli *et al*., 2020; Pinna *et al*., 2021) irrespective of a similar level of anthropogenic pressure.

The spatial patterns highlighted in the present study, in agreement with previous observations in other Mediterranean areas (Piazzi *et al*., 2021c), should not be underestimated in monitoring programs. In fact, the assessment of the ecological quality of the habitat should take into account the geographic differences in the assemblages. Moreover, the high levels of quality can be obtained with very different assemblages dominated by both invertebrates and macroalgae (Piazzi *et al*., 2021a).

Coralligenous cliffs are the best known mesophotic habitat and the most iconic spot for recreational SCUBA diving (Tribot *et al*., 2016; Chimienti *et al*., 2017). On the other hand, their proximity to the coasts exposes them to human pressures affecting coastal systems (Holon *et al*., 2015), such as pollution, eutrophication, sedimentation, and mechanical damage due to tourism, fishing and anchoring (Piazzi *et al*., 2012; Casoli *et al*., 2017; Betti *et al*., 2020). Moreover, the relatively low bathymetric

Table 2. List and abundance (mean percent cover per sample) of taxa/morphological groups of coralligenous cliffs' assemblages of Tuscany.

TAXA/MORPHOLOGICAL GROUPS	LIV	ARG	GIA	PIA	CAP	MON	GIG	FOR	EL-E	EL-W	MEL	GOR
Macroalgae												
Algal turf	13.4	11.4	0.5	3.9	4.7	4.8	6.1	20.0	22.3	6.1	19.9	0.9
Pseudochlorodesmis furcellata	0.0	0.0	3.7	2.3	0.0	0.9	2.7	1.9	0.9	0.0	0.1	2.1
Palmophyllum crassum	0.0	0.2	1.2	0.5	0.3	1.2	1.2	0.5	0.1	0.2	0.2	0.1
Valonia macrophysa	0.0	0.0	0.0	0.2	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.1
Flabellia petiolata	0.1	0.2	3.6	3.7	7.1	2.0	2.7	2.0	2.9	1.0	0.2	3.3
Halimeda tuna	0.0	0.0	6.8	4.1	3.5	0.1	0.3	0.1	0.1	0.0	0.0	3.2
Dictyotales	0.0	0.0	0.0	0.1	0.3	1.7	0.1	0.1	0.1	0.2	7.7	4.5
Zanardinia typus	0.0	0.7	0.1	0.1	0.1	0.1	0.0	0.0	0.1	1.0	0.5	0.6
Erect Ochrophyta	0.0	0.0	0.0	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.1
Peyssonnelia spp.	9.0	71.9	8.2	58.1	4.8	10.4	5.8	4.4	3.1	13.5	8.0	46.8
Flattened Rhodophyta	0.0	0.0	1.7	1.3	0.1	1.1	0.0	0.0	0.0	0.1	0.0	0.4
Terete Rhodophyta	0.0	0.0	0.3	1.1	0.0	1.1	4.9	2.4	0.5	0.1	1.2	10.6
Articulated Rhodophyta	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.2	0.0	0.1
Macro-invertebrates												
Encrusting sponges	2.2	2.9	1.1	1.6	3.7	4.1	1.3	0.9	1.7	2.3	1.0	0.5
Massive sponges	0.9	0.6	0.2	0.4	0.0	0.4	0.0	0.0	0.1	0.5	0.1	0.1
Erect sponges	1.9	0.6	0.0	0.4	0.2	0.0	0.0	0.0	0.1	0.3	0.0	0.0
Hydrozoans	0.0	0.0	0.1	0.1	0.0	0.2	0.0	0.0	0.0	0.2	0.0	0.0
Parazoanthus axinellae	0.3	0.2	0.0	0.1	0.6	0.1	0.1	0.0	0.0	1.3	0.0	0.0
Scleractinians	0.1	0.2	0.0	0.2	0.0	0.5	0.1	0.6	0.2	0.1	0.0	0.0
Corallium rubrum	4.9	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Paramuricea clavata	0.0	3.4	0.3	0.2	0.0	0.2	0.2	0.2	0.3	0.0	0.0	0.0
Eunicella cavolini	0.0	2.2	0.5	1.0	0.0	1.3	0.3	0.3	0.0	0.4	0.0	0.2
Serpulids	0.0	0.0	0.0	0.0	0.1	0.1	0.0	0.1	0.0	0.0	0.0	0.0
Encrusting bryozoans	0.2	0.1	0.1	0.2	0.1	0.1	0.0	0.1	0.2	0.2	0.1	0.0
Thin ramified bryozoans	0.0	0.1	0.1	0.0	0.2	0.2	0.0	0.0	0.1	0.1	0.0	0.1
Myriapora truncata	0.1	0.1	0.1	0.2	0.1	0.1	0.1	0.1	0.0	0.2	0.0	0.2
Pentapora fascialis	0.0	0.1	0.2	0.0	0.0	0.3	0.0	0.0	0.0	0.1	0.0	0.0
Reteporella spp.	0.1	0.2	0.5	0.2	0.0	0.0	0.1	0.1	0.1	0.6	0.0	0.0
Smittina cervicornis	0.0	0.2	0.1	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Erect ascidians	0.0	0.0	0.0	0.0	0.1	0.1	0.0	0.0	0.0	0.0	0.1	0.0

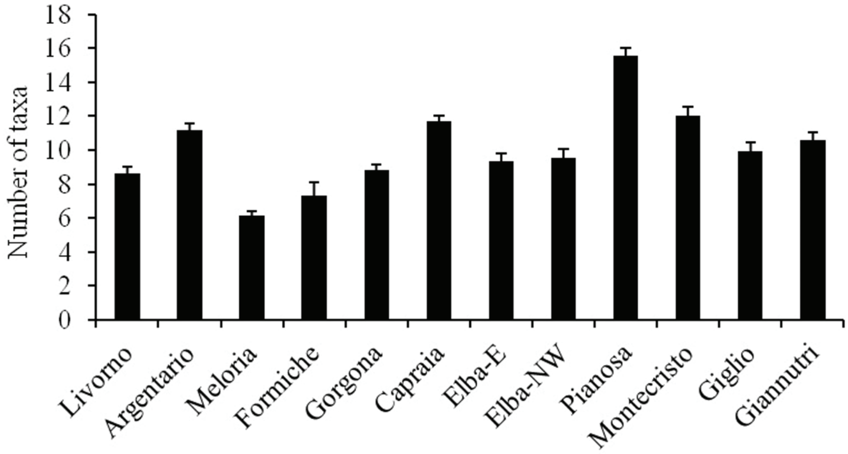

Fig. 5: Mean number of taxa/morpholgical groups per sample of Tuscany coralligenous cliff assemblages.

range at which coralligenous cliffs develop exposes the habitat to the effects of climatic changes, such as heat waves or mucilage blooms (Cerrano *et al*., 2000; Garrabou *et al*., 2022; Verdura *et al*., 2019; Piazzi *et al*. 2018). Thus, coastal and continental shelf coralligenous reefs on one hand provide different ecosystem services and on the other hand are subject to a wide range of human threats. These features combine to separate coastal coralligenous cliffs from other coralligenous habitats, such as platforms, banks and outcrops distributed on continental shelves (Montefalcone *et al*., 2021; Piazzi *et al.* 2022b). In this context, the assessment of their extent, structure and variability patterns is a fundamental starting point for adequate and forward-looking conservation prospects. Accordingly, coralligenous cliffs should be considered separately in monitoring programs, impact assessment studies and management plans (UNEP/MAP, 2017; 2019). In the present study, the assemblages of coralligenous platforms were not assessed, thus it is not possible to compare the biotic features of the two habitats. A concurrent study of both cliff and platform coralligenous assemblages may provide a complete assessment of mesophotic habitats within a determined geographic area (Piazzi *et al*., 2022b) and it may be considered an interesting topic for further investigations and a useful approach to be developed.

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