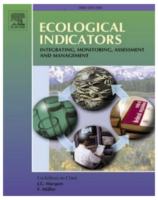
Ecological Indicators 136 (2022) 108657

Contents lists available at ScienceDirect

Ecological Indicators

journal homepage: www.elsevier.com/locate/ecolind



Inconsistency in community structure and ecological quality between platform and cliff coralligenous assemblages

Luigi Piazzi[a], Federica Ferrigno[b,c,*], Ivan Guala[d], Maria Francesca Cinti[a], Alessandro Conforti[e], Giovanni De Falco[e], Mario De Luca[f], Daniele Grech[d], Gabriella La Manna[a], Vincenzo Pascucci[f], Arianna Pansini[f], Federico Pinna[f], Laura Pireddu[f], Alessandra Puccini[f], Giovanni Fulvio Russo[b,c], Roberto Sandulli[b,c], Antonio Santonastaso[f], Simone Simeone[e], Myriam Stelletti[f], Patrizia Stipcich[f], Giulia Ceccherelli[a]

[a] *Dipartimento di Chimica e Farmacia, Università di Sassari, Via Piandanna 4, 07100 Sassari, Italy*
[b] *Department of Science and Technology, University of Naples "Parthenope", Centro Direzionale, Is. C4, 80143 Naples, Italy*
[c] *Consorzio Nazionale Interuniversitario per le Scienze del Mare (CoNISMa), 00196 Rome, Italy*
[d] *IMC-International Marine Centre, Loc. Sa Mardini, Torregrande, 09170 Oristano, Italy*
[e] *IAS-CNR Oristano, Loc. Sa Mardini, Torregrande, 09170 Oristano, Italy*
[f] *Dipartimento di Architettura, Design e Urbanistica, Università di Sassari, Via Piandanna 4, 07100 Sassari, Italy*

ARTICLE INFO

Keywords:
ESCA and CBQI indices
Spatial variability
Coralligenous platforms
Coralligenous cliffs
Mediterranean Sea

ABSTRACT

Coralligenous reefs are the main biogenic constructions of the Mediterranean Sea and they are considered indicators of the ecological quality of coastal systems and of "seafloor integrity" by the Marine Strategy Framework Directive. The two main coralligenous morphologies are the cliffs and platforms, the former developing in shallow waters (about 20–50 m) on vertical/subvertical rocky substrate and the latter built over horizontal substrates below 50 m depth also on detritic bottoms. The present study aims at assessing whether patterns of spatial variability and ecological quality of the coralligenous cliff assemblages reflect those of platform assemblages. At this aim, six geographic areas around Sardinia (western Mediterranean, Italy) were considered and, within each area, the structure of both the coralligenous cliffs and platforms was investigated by SCUBA and ROV methods, and their ecological quality was assessed by ESCA and CBQI indices, respectively. Overall, 20 morphological groups (seven macroalgae and thirteen invertebrates) were found but differences in community structure were evident both spatially and between systems, platforms vs cliffs. In fact, spatial variability in assemblages structure changed between the two morphologies across the areas. Moreover, a different spatial pattern in the ecological quality was found between platform and cliff assemblages. The results of the present study corroborate the individual peculiarity of coralligenous platforms and cliffs, highlighting the importance of the concurrent assessment of both systems in monitoring programs..

1. Introduction

Marine bioconstructions are permanent structures created by living benthic organisms that provide secondary substrates increasing the volume, complexity and heterogeneity of their habitat and modifying the seascape (Fox, 2005). The most evident examples of bioconstructions are tropical coral reefs, although biogenic habitats occur in all marine environments and represent key ecosystems providing main biological, ecological, climatic, and socioeconomic services (Kruzic, 2014; Ingrosso et al., 2018).

---

* Corresponding author.

E-mail addresses: l.piazzi00@gmail.com (L. Piazzi), federica.ferrigno@uniparthenope.it (F. Ferrigno), i.guala@fondazioneimc.it (I. Guala), mariafra.cinti@gmail.com (M.F. Cinti), alessandro.conforti@cnr.it (A. Conforti), giovanni.defalco@cnr.it (G. De Falco), delucamario16@gmail.com (M. De Luca), d.grech@fondazioneimc.it (D. Grech), gabriella.lamanna@gmail.com (G. La Manna), pascucci@uniss.it (V. Pascucci), apansini@uniss.it (A. Pansini), federicopinna27@gmail.com (F. Pinna), lpired@tiscali.it (L. Pireddu), alessandra.puccini@hotmail.it (A. Puccini), giovanni.russo@uniparthenope.it (G.F. Russo), roberto.sandulli@uniparthenope.it (R. Sandulli), alsantonastaso@uniss.it (A. Santonastaso), simone.simeone@cnr.it (S. Simeone), myrimy@hotmail.com (M. Stelletti), patriziastipcich@libero.it (P. Stipcich), cecche@uniss.it (G. Ceccherelli).

https://doi.org/10.1016/j.ecolind.2022.108657
Received 21 December 2021; Received in revised form 1 February 2022; Accepted 3 February 2022

In the Mediterranean Sea, coralligenous reefs are the main biogenic constructions which consist of endemic carbonatic bioherms with thickness ranging from a few centimeters to over 2 m and derive from multilayer calcium carbonate depositions, mostly due to the activities of some coralline macroalgae adapted to low light conditions (Ballesteros, 2006). They are among the most threatened habitats in the Mediterranean Sea, being characterized by the presence of organisms highly sensitive to human pressures (Piazzi et al., 2012; Gatti et al., 2015b; Betti et al., 2020). Coralligenous reefs are habitats of European Community interest (E.C., 1992) due to their extension, biodiversity, role in the balance of CO_2 and ecological services they provide for fisheries and tourism, together with their sensitivity to human pressures (Tribot et al., 2016; UNEP, 2017; Thierry de Ville d'Avray et al., 2019).

Coralligenous bioconstructions are threatened mostly by pollution, eutrophication, alien species and climate change (Piazzi et al., 2012; Gori et al., 2017); moreover, fishing activities are relevant stressors that lead to structural and functional changes at ecosystem level (Betti et al., 2020; Rendina et al., 2020). Fishing gear, in particular nets and longlines, could have a strong impact on benthic communities, directly by entangling and damaging the tissue of the erect organisms (Angiolillo et al., 2015; Giusti et al., 2019) and indirectly by increasing water turbidity and sediment accumulation (Althaus et al., 2009; Buhl-Mortensen and Buhl-Mortensen, 2018).

Recently, coralligenous reefs have been considered as indicators of the ecological quality of coastal systems and of "seafloor integrity" by the Marine Strategy Framework (MFSD, E.C. 2008). However, the use of coralligenous reefs as ecological indicator is complicated by the complexity of this habitat. In fact, coralligenous reefs are characterized by many different communities lumped together by a dynamic equilibrium between bioconstruction and biodestruction (Ingrosso et al., 2018) and may develop between 20 and 150 m of depth on both vertical walls and horizontal bottoms (Ballesteros, 2006). Several coralligenous morphologies have been described (Bracchi et al., 2017; Montefalcone et al., 2021); the two main types are cliffs and platforms, the former developing in shallower waters (about 20–50 m) on vertical/subvertical rocky substrate and the latter built over horizontal substrates below 40–50 m depth, also on detritic bottoms (Laborel, 1987; Ballesteros, 2006).

The heterogeneity of coralligenous reef systems makes it difficult to identify univocal threats, methods of study, and ecological indicators. After an early phase of monitoring within the MSFD program, different methodological approaches have been considered depending on the type of coralligenous assemblage (UNEP, 2019). In fact, coralligenous cliffs were sampled mostly by SCUBA divers, with both visual and photographic techniques (Piazzi et al., 2019b), while ROVs (Remotely Operated Vehicles) were usually utilized for coralligenous platforms (Cánovas-Molina et al., 2016; Ferrigno et al., 2018a; Piazzi et al., 2019c). Several indices have been developed to score the community quality of coralligenous cliffs: COARSE (Coralligenous Assessment by ReefScape Estimate, Gatti et al., 2012, 2015a) is based on a landscape approach, CAI (Coralligenous Assemblages Index, Deter et al., 2012), ESCA (Ecological Status of Coralligenous Assemblages, Cecchi et al., 2014; Piazzi et al., 2021b) and ISLA (Integrated Sensitivity Level of coralligenous Assemblages, Montefalcone et al., 2017) are based on a biocenotic approach, and INDEX-COR integrates the aforementioned approaches (Sartoretto et al., 2017). To assess the status of mesophotic coralligenous megabenthic assemblages, MAES (Mesophotic Assemblages Ecological Status index, Cánovas-Molina et al., 2016), CBQI (Coralligenous Bioconstruction Quality Index, Ferrigno et al., 2017) and MACS (Mesophotic Assemblages Conservation Status, Enrichetti et al., 2019b) indices have been elaborated on the basis of ROV photography and video footage.

The ecological quality of both cliff (Deter et al., 2012; Gatti et al., 2012, 2015a; Cecchi et al., 2014; Montefalcone et al., 2017; Piazzi et al 2021b, Sartoretto et al., 2017) and platform (Cánovas-Molina et al., 2016; Ferrigno et al., 2017, 2018a, Enrichetti et al., 2019b) coralligenous assemblages has been evaluated in many Mediterranean areas. However, these two main coralligenous systems have never been concurrently studied, likely due to their spatial segregation and the different methods employed. This gap of knowledge needs to be filled by comparing the responses of each system to human pressures and thus giving an exhaustive assessment of the ecological status of any single geographic area (Borja et al., 2009).

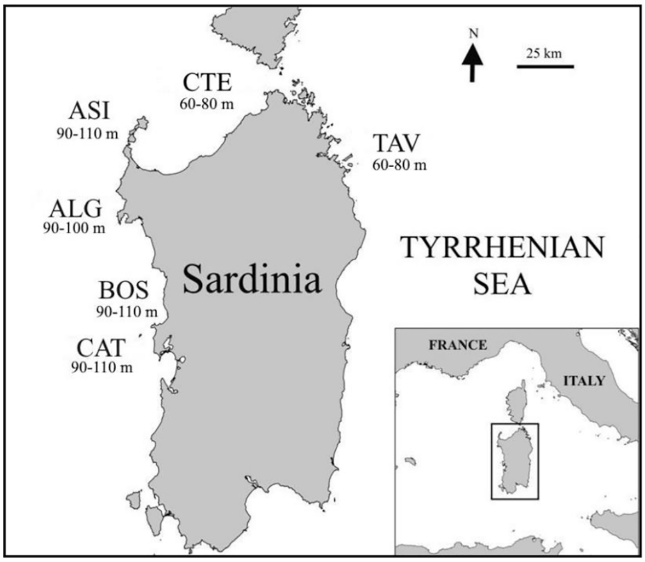


Fig. 1. Map of Sardinia with the study areas: Catalano = CAT, Bosa = BOS, Alghero = ALG, Asinara = ASI, Capo Testa = CTE and Tavolara = TAV. The depth range of coralligenous platform surveys is reported for each area.

The present study aims at assessing whether patterns of spatial variability and ecological quality of the coralligenous cliff reflect those of platform assemblages. At this aim, six geographic areas around Sardinia (western Mediterranean, Italy) were considered and, within each area, the structure of both coralligenous cliffs and platforms were investigated by SCUBA and ROV methods, respectively. The ecological quality of the cliff and platform assemblages was assessed by ESCA and CBQI index, respectively. We tested the hypothesis that cliffs and platforms may independently respond to anthropogenic pressures and, consequently, different ecological quality responses can be highlighted within the same area depending on the system considered.

2. Materials and methods

2.1. *Study areas and field sampling*

This study was performed in Sardinia (Italy, Western Mediterranean Sea) where coralligenous platforms develop on a surface of several hundreds of km^2 between 50 and 170 m of depth (De Falco et al., 2022). Six areas (Catalano = CAT, Bosa = BOS, Alghero = ALG, Asinara = ASI, Capo Testa = CTE and Tavolara = TAV) were selected (Fig. 1); each of them corresponds to about 25 km of coastline. All areas are characterized by low human pressure (Piazzi et al., 2021a) and only BOS does not include a Marine Protected Area (MPA) in the coastal zone. In each area, both coralligenous platforms (60–110 m of depth, Fig. 1) and cliffs (35 m of depth) were sampled. The distance from the coast of coralligenous platforms varied between 6 and 12 km.

Coralligenous platforms were sampled through Remote Operated Vehicle (ROV) surveys performed between 2014 and 2020. ROVs were equipped with a high-resolution camera and an acoustic positioning system for geo-localization of the video images. The ROV moved along linear tracks, in continuous recording mode, at constant slow speed (<0.3 m s^{-1}) and at a constant height from the bottom (<1.5 m). In each area three sites were randomly selected at a distance from the coast

Table 1
Mean percent cover of morphological groups on coralligenous platform and cliff.

	platform						cliff					
morphological groups	**CAT**	**BOS**	**ALG**	**ASI**	**CTE**	**TAV**	**CAT**	**BOS**	**ALG**	**ASI**	**CTE**	**TAV**
Macroalgae												
encrusting Rhodophyta	85.27	93.00	77.67	70.97	47.72	58.80	48.76	47.57	72.25	57.36	78.37	61.27
erect Rhodophyta	0.00	0.00	0.00	0.00	23.02	9.75	10.70	5.12	2.82	2.98	0.16	3.07
encrusting Chlorophyta	0.00	0.00	0.00	0.00	0.80	0.40	0.90	0.56	2.20	1.11	1.29	0.85
erect Chlorophyta	0.00	0.00	0.00	0.00	16.58	4.35	2.48	1.78	4.75	1.08	2.50	8.81
encrusting Ochrophyta	0.00	0.00	0.00	0.00	0.00	0.00	0.18	1.26	0.82	0.13	0.08	0.11
erect Ochrophyta	0.00	0.00	0.00	0.00	0.00	0.00	18.74	28.12	7.24	17.88	0.15	1.40
algal turf	0.00	0.00	0.00	0.00	0.00	0.00	4.9	4.65	1.73	4.25	3.43	9.44
Sessile invertebrates												
encrusting sponges	0.52	0.47	0.47	0.58	1.92	4.75	9.78	7.98	4.88	9.85	6.88	6.06
massive sponges	0.55	0.98	1.33	3.81	2.08	5.25	0.04	0.73	0.59	0.28	0.34	0.37
erect sponges	0.00	0.17	0.13	0.00	0.75	3.75	0.13	0.00	0.10	0.38	0.34	0.17
hydroids	0.00	0.00	0.20	0.35	0.42	0.15	0.01	0.01	0.01	0.01	0.01	0.01
solitary madrepores	0.03	0.00	0.00	0.81	0.00	0.10	0.07	0.20	0.21	0.05	0.45	0.34
soft coral	0.00	0.00	0.17	0.00	0.00	0.00	2.85	1.37	0.41	2.15	0.64	0.94
corals	0.02	0.00	0.73	0.42	0.00	0.00	0.01	0.27	0.00	0.00	2.34	0.00
fan corals	6.22	1.73	7.97	8.52	6.22	7.50	0.00	0.00	0.06	0.03	0.33	3.40
serpulids	0.00	0.00	0.00	0.00	0.03	0.70	0.00	0.00	0.01	0.03	0.07	0.19
encrusting bryozoans	0.00	0.00	0.00	0.00	0.02	0.10	0.00	0.16	0.11	1.76	1.11	1.14
erect bryozoans	0.03	0.00	0.17	0.03	0.20	1.55	0.44	0.20	1.73	0.64	1.18	2.04
colonial ascidians	0.00	0.15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
solitary ascidians	0.00	0.00	0.00	0.00	0.15	1.05	0.01	0.02	0.08	0.03	0.33	0.39

greater than 5 km, and in each site two transects 100 m long were sampled. Within each transect, 10 pictures targeting hard bottom were randomly selected from footages. The percent cover of all sessile organisms was quantified in each image by superimposing a grid of 100 equal-sized squares (Dethier et al., 1993). Soft bottom zones or portions covered by motile organisms were subtracted from the total surface of images while computing the percent cover. Fishing pressure was assessed as percentage of frames presenting fishing gear (longlines, nets, and other lost gear, such as anchors, ropes, moorings, etc.), while fishing impact was estimated as percentage of frames presenting fan coral colonies with necrosis/epibionts and gear covering/entangling coralligenous habitat (Ferrigno et al., 2017). Substrate slope was also estimated for each picture.

Coralligenous cliffs were sampled by SCUBA divers. In each area, three sites several kms apart were chosen. At each site, three plots of about 4 m^2 where randomly selected on a vertical rocky substrate at 35 m depth. In each plot, ten photographs of 0.2 m^2 areas were taken by a framed camera (Piazzi et al., 2019b). The percentage cover of the main groups was assessed by manual contour technique using the ImageJ software (Cecchi et al., 2014).

Groups of species belonging to the same taxon and showing similar morphology were merged into morphological groups (Ferrigno et al. 2017; Appolloni et al., 2020), for both coralligenous platforms and cliffs.

2.2. Index calculations

The ecological quality of coralligenous platforms was evaluated through the CBQI considering three groups of variables: coralligenous structuring (Group A), coralligenous stress (Group B), and bottom abiotic factors (Group C). Each group is represented by three variables, and each variable by three categories which are allocated a score ranging from 0 to 2 (Table S1). The score was assigned considering the maximum, the minimum and the average value obtained in each site and the values assigned by recent literature on coralligenous status index (Cánovas-Molina et al., 2016). The variables coralligenous cover (percentage), morphological groups (number), and fan corals density (number of individuals on square meters) are allocated in Group A; Group B includes fan corals with necrosis/epibiosis (percentage), covered/entangled (percentage), and fishing gear (percentage); finally, physical characteristics, such as depth (meters), slope (degree), and substrate type, are considered in Group C. The index is represented with the following equation consisting in a weighted mean among the total score of each group:

$$\mathrm{CBQI} = [(\mathrm{Group\ A} \times 3) + (\mathrm{Group\ B} \times 2) + (\mathrm{Group\ C} \times 1)] \times 3^{-1}$$

The CBQI score ranges between 0 and 12, classified in four classes: bad quality (0–3), medium quality (4–6), good quality (7–9), and optimum quality (10–12).

The ecological quality of coralligenous cliffs was evaluated through the ESCA index (Cecchi et al., 2014; Piazzi et al., 2021b). Three assemblage descriptors were used: i) “sensitivity level” (SL), based on the cover of different sensitive taxa; ii) diversity of assemblages expressed as “α-diversity”; and iii) heterogeneity of assemblages, expressed as “β-diversity”. To calculate the SL of study sites, each group was associated with a sensitivity value (from 1 to 10, with minimum values corresponding to the most tolerant organisms and maximum values to the most sensitive ones, (Table S2) and with an abundance class (1: $0 < \% < 0.01$; 2: $0.01 < \% < 0.1$; 3: $0.1 < \% < 1$; 4: $1 < \% < 5$; 5: $5 < \% < 25$; 6: $25 < \% < 50$; 7: $50 < \% < 75$; 8: $75 < \% < 100$) according to Piazzi et al. (2021b). The SL of each photographic sample was calculated as the sum of the values obtained by multiplying the sensitivity value of each group by its class of abundance. The SL of each study site was calculated as the sum of the SL values of all samples. Alpha-diversity was defined as the mean number of groups in each photographic sample, while beta-diversity was evaluated as the mean distance of all photographic samples from centroids calculated in the PERMDISP analysis (PERMANOVA; Anderson et al., 2006). ESCA was expressed as Ecological Quality Ratio (EQR), calculated as the mean of the three $\mathrm{EQR_S}$ obtained for the assemblage descriptors:

$$\mathrm{EQR} = ((\mathrm{EQR_{SL}} + \mathrm{EQR_{\alpha}} + \mathrm{EQR_{\beta}}) \times 3^{-1})$$

Individual $\mathrm{EQR_s}$ were calculated as the ratios between the values of SL, α-diversity and β-diversity, respectively, and the values obtained for the same descriptor in the reference condition (Montecristo Island for the considered geographic region; Cecchi et al., 2014), *i.e.* 550 for the sensitivity level, 15 for the α-diversity, and 20 for the β-diversity. The ecological quality of coralligenous reefs was then classified according to the following five classes (Piazzi et al., 2021b): i) high ($\mathrm{EQR} \geq 0.8$); ii) good ($0.6 \leq \mathrm{EQR} < 0.8$); iii) moderate ($0.4 \leq \mathrm{EQR} < 0.6$); iv) poor ($0.2 \leq \mathrm{EQR} < 0.4$); and v) bad ($\mathrm{EQR} < 0.2$).

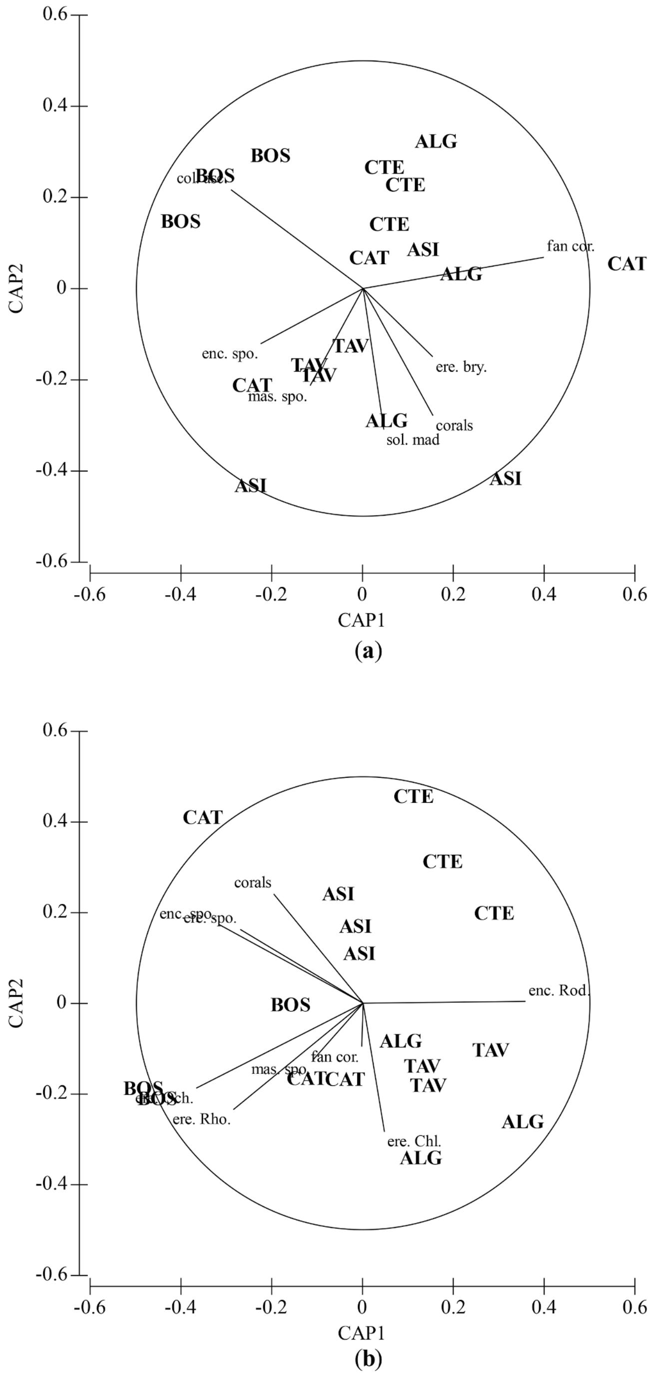


Fig. 2. CAP analysis of coralligenous platform (**a**) and cliff (**b**) assemblages. Catalano = CAT, Bosa = BOS, Alghero = ALG, Asinara = ASI, Capo Testa = CTE and Tavolara = TAV.

2.3. Data analyses

The structure (abundance of morphological groups) of both systems, coralligenous platform and cliff assemblages, were analysed by a permutational analysis of variance (PERMANOVA, Anderson, 2001) based on Bray Curtis similarity. Data were fourth root transformed before the analyses. A two-way model was used with Area as fixed factor and Site as random factor nested in Area. The Pair-wise test was used to discriminate among levels of significant factors. A canonical analysis of principal coordinates (CAP, Anderson and Robinson, 2003) was performed in order to discriminate the main morphological groups contributing to dissimilarities among areas. For the coralligenous platforms, the density of fan corals and the number of morphological groups were analysed by a PERMANOVA testing the effect of the Area with Site as replicates.

Furthermore, the variability in ecological quality among areas was evaluated by running a PERMANOVA (based on the Euclidean distance and using Sites as replicates) on the indices and their main descriptors.

3. Results

Overall, 20 morphological groups (seven macroalgae and thirteen invertebrates) were found but differences in community structure were evident both spatially and between systems, platforms vs cliffs (Table 1).

The coralligenous platforms were generally dominated by encrusting Rhodophyta, although distributed differently among areas. Erect Rhodophyta (mostly *Sebdenia monardiana* and *Osmundaria volubilis*), erect Chlorophyta (mostly *Halimeda tuna* and *Flabellia petiolata*) and sponges were more abundant at CTE and TAV, while fan corals (mostly *Eunicella cavolini, Callogorgia verticillata*, but also *Paramuricea clavata, Paramuricea hirsuta, Elisella flagellum* and *Antipathella subpinnata*) were present everywhere (Table 1, Figs. 2 and 3).

Colonial ascidians were more abundant at BOS, while erect bryozoans and corals at ALG (Fig. 2). CAT, BOS, ALG and ASI are significantly different from CTE and TAV; differences between these two latter were also significant (Table 2).

The number of morphological groups was higher in the shallower eastern areas (CTE and TAV) than in the western ones; among the latter, there was a ranking in the number of morphological groups with ASI and BOS higher than ALG, which in turn was higher than CAT. The highest density of fan corals was found at CAT, but it was also high at ASI compared to all other areas (Table 3, 4, Fig. 3).

The bioconstruction was high everywhere and the coralligenous stress was very low, both in terms of species necrosis/epibiosis and fishing gear covering/entangling portions of the coralligenous habitat (Table 3). CBQI classified all areas in good quality (Fig. 4) and no significant differences were detected among areas by PERMANOVA ($\text{Pseudo-F}_{5,12}$: 2.87, P(perm): 0.060).

In the coralligenous cliffs, encrusting Rhodophyta were the most abundant macroalgae everywhere, while erect Ochrophyta had a high percent cover at ASI, BOS and CAT. Encrusting sponges were the most abundant invertebrates; corals had a relevant cover at CTE and fan corals at TAV (Table 1, Fig. 2). The analysis identified differences among all areas except for CAT, BOS and ASI which were found similar (Table 2). The number of groups was lower at CAT while the beta diversity was more variable, with higher values at TAV and CAT and lower at ALG and CTE (Fig. 5, Table 5); the SL were high everywhere and no significant differences were detected among areas (Fig. 5, Table 5).

ESCA index varied between 0.76 and 0.91 (ALG and TAV, respectively); CAT, ASI and TAV were classified in high ecological quality and BOS, ALG and CTE in good ecological quality (Fig. 4). PERMANOVA and the pair wise test detected higher values of ESCA at TAV compared to the other areas (Table 5).

4. Discussion

The study compared for the first time the community structure and the ecological quality of both coralligenous platforms and cliffs in the same geographic areas. Results highlighted that spatial variability in assemblage structure and ecological quality changed between the two morphologies across the areas.

The structure of coralligenous assemblages differed between western and north-eastern areas in both systems. The spatial pattern found for the platform assemblages identified two main clusters of similarities: the western (ALG, BOS, CAT, ASI) and the north-eastern (CTE and TAV). The spatial pattern highlighted for cliffs distinguished ALG from the other western areas, and the northern CTE and eastern TAV also differed between them. The results obtained for the cliffs confirmed previous

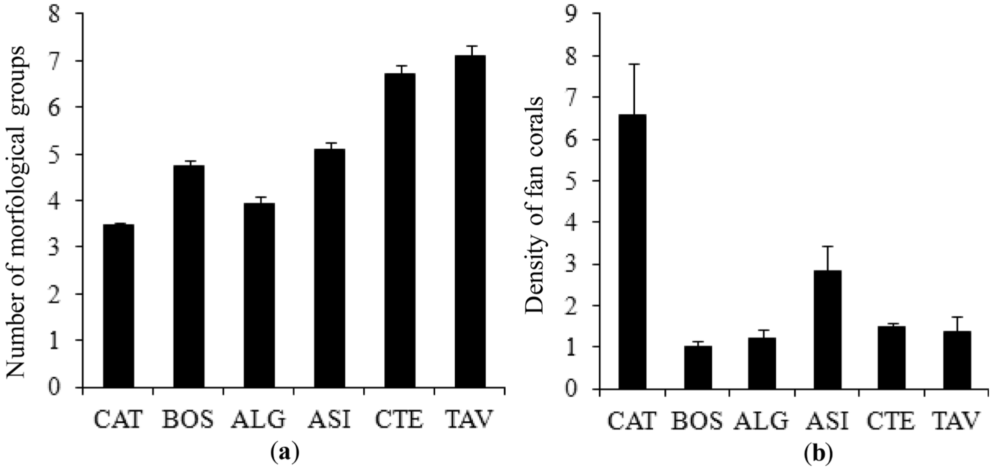


Fig. 3. The mean number of morphological groups (**a**) and the density of fan corals (number of individuals m^{-2}) (**b**) per sample of coralligenous platforms.

Table 2
PERMANOVA results on the effect of the Area and Site on coralligenous platform and cliff assemblages.

		platform			cliff		
Source	df	MS	Pseudo-F	P(perm)	MS	Pseudo-F	P(perm)
Area = A	5	20,499	10.52	0.001	19,595	6.76	0.001
Site (A)	12	1985	6.06	0.001	2947	5.95	0.001
Residual	274	327			495		
Pair-wise test (A)		ALG = BOS = CAT = ASI ≠ CTE = TAV			BOS = CAT = ASI ≠ ALG ≠ CTE ≠ TAV		

Table 3
CBQI descriptors in the six areas.

	CAT	BOS	ALG	ASI	CTE	TAV
coralligenous cover (%)	>70	>70	>70	>70	>70	>70
morphological groups (n.)	3.47	4.73	3.93	5.10	6.72	7.10
fan coral density (n./m^2)	6.57	1.10	1.22	2.84	1.47	1.35
necrosis/epibiosis (%)	<5	<5	<5	<5	<5	<5
covered/entangled (%)	<10	<10	<10	<10	<10	<10
fishing gear density (%)	<10	<10	<10	<10	<10	<10
depth (m)	>90	>90	>90	>90	60 < x < 90	60 < x < 90
slope (degree)	<45	<45	<45	<45	<45	<45
substrate type	rocky	rocky	rocky	rocky	rocky	rocky

Table 4
PERMANOVA results on the effect of the Area on the density of fan corals and on the number of morphological groups per sample of the coralligenous platform assemblages.

		Density of fan corals			Number of morfological groups		
Source	df	MS	Pseudo-F	P (perm)	MS	Pseudo-F	P (perm)
Area	5	273.4	5.39	0.001	128.8	27.50	0.001
Residual	12	50.8	2.28	0.011	4.7	3.09	0.003
Pair-wise test		ALG = BOS = CTE = TAV < ASI < CAT			CAT < ALG < BOS = ASI < CTE = TAV		

investigations performed through different taxonomic resolutions. These latter detected differences in coastal coralligenous assemblages among Sardinian geographic zones (Piazzi et al., 2021a; Pinna et al., 2021) which were mostly attributed to differences in water temperature related to the current regime characterizing the Sardinian coasts (Ceccherelli et al., 2020). On the contrary, coralligenous platforms dissimilarities are generally ascribed to changes in morphological features, sedimentation and larval dispersal (Bo et al., 2015; Grinyó et al., 2016), rather than to water temperature. For platform assemblages, the segregations hereby detected could be also due to the bathymetric patterns, as north and eastern areas are shallower than the westerns and depth is a main driver for the spatial variability also in mesophotic assemblages (Gori et al., 2017). In fact, erect macroalgae, which require higher irradiance condition and therefore generally abound in the shallower coralligenous reefs (Ballesteros, 2006), characterized the shallower eastern platforms (CTE and TAV) and were completely absent in the western platforms below 90 m depth. Although no inference about geographic patterns in coralligenous platforms may be made on the results of the present study, the general conclusion about the inconsistency in the spatial patterns between the structure of platform and cliff assemblages can be deduced. In particular, it seems that spatial discontinuities at the scale of the area are more likely for the cliff assemblages rather than for the platform. The reason for such uncoupling should not be surprising because drivers of species distribution may change between coastal cliffs and continental shelf mesophotic zone (Cerrano et al., 2019). Moreover, the two systems may be affected by different anthropogenic activities, as coralligenous platforms are mostly sensitive to fishing and large scale sedimentation (Ferrigno et al., 2018a; Piazzi et al., 2019c), while shallower coastal zones are subjected to a high number of pressures due to runoffs and human frequentation (Casoli et al., 2017; Piazzi et al., 2019a).

All the studied areas were found in good or high ecological quality, although a discrepancy in the spatial patterns of the two indices was identified between platform and cliff: CBQI placed all the areas in good quality, while ESCA showed higher values for areas including MPAs,

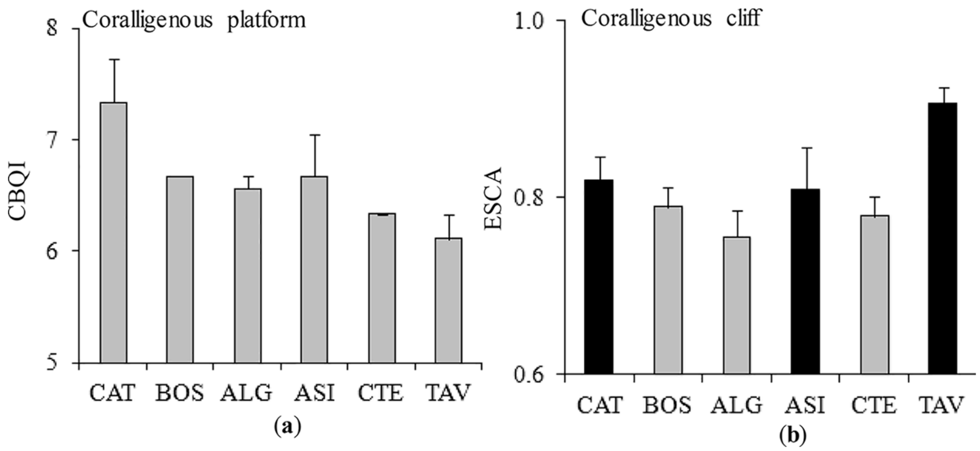


Fig. 4. Ecological quality of platform (CBQI index) (**a**) and cliff (ESCA index) (**b**) coralligenous assemblages. Black: high/optimum; grey: good; white: moderate/medium.

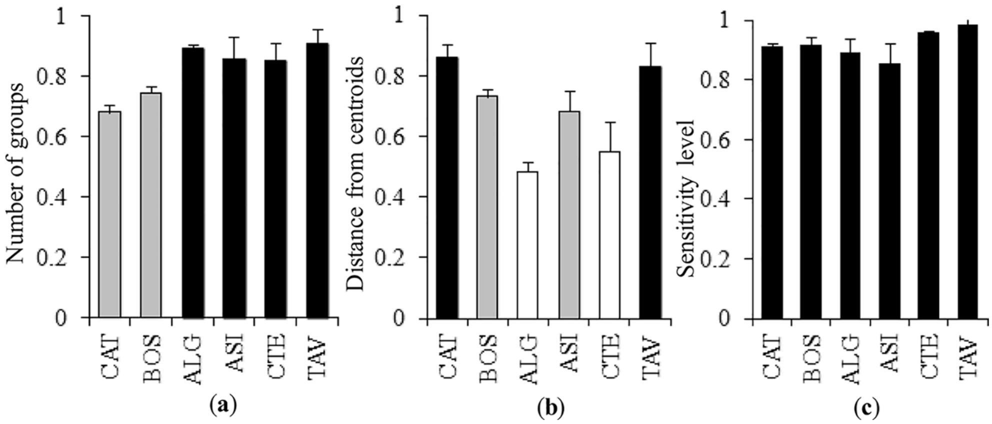


Fig. 5. Descriptors of the EQR values of ESCA: Number of groups (**a**); Distance from centroids (**b**); Sensitivity level (**c**). Black: high; grey: good; white: moderate.

Table 5
PERMANOVA results on the effect of the Area on ESCA and its main descriptors (alpha diversity, beta diversity and sensitivity levels).

		ESCA			Alpha diversity		
Source	df	MS	Pseudo-F	P (perm)	MS	Pseudo-F	P (perm)
Area	5	0.008	3.14	0.05	67.6	5.15	0.010
Residual	12	0.003			13.3	4.02	0.001
Pair-wise test		ALG = BOS = CAT = ASI = CTE < TAV			CAT < ALG = BOS = ASI = CTE = TAV		
		Beta diversity			**Sensitivity levels**		
Source	**df**	**MS**	**Pseudo-F**	**P (perm)**	**MS**	**Pseudo-F**	**P (perm)**
Area	5	0.068	5.83	0.008	0.006	0.95	0.507
Residual	12	0.012			0.007		
Pair-wise test		ALG = BOS = ASI = CTE < CAT = TAV					

except for ALG and CTE, recently established. The establishment of a status of protection (MPA) may have a positive influence on coralligenous reefs. Coralligenous cliffs may be affected by both large scale impacts, such as climate changes, blooms of mucilaginous aggregates and sedimentation (Cerrano et al., 2000; Balata et al., 2005; Garrabou et al., 2009; Piazzi et al., 2018), and more localized impacts, such as fishing, human frequentation and pollution (Piazzi et al., 2012; Casoli et al., 2017; Betti et al., 2020). The MPAs may partially contrast some of these latter impacts, representing a suitable tool to preserve the ecological quality of coralligenous cliffs.

A very low frequency of fishing gears was detected on platforms compared to other Mediterranean zones (Bavestrello et al., 1997; Angiolillo et al., 2015; Ferrigno et al., 2018b; Betti et al., 2020). This finding confirmed previous large spatial scale investigations which have reported the lowest density of fishing gears on Sardinian coralligenous banks (Angiolillo et al., 2015). Damages by fishing activities is considered a main threat for coralligenous reefs (Giusti et al., 2019; Betti et al., 2020), especially in the continental shelf zone (Bo et al., 2014; Ferrigno et al., 2018b; Enrichetti et al., 2019a). In fact, the increasing of water turbidity and sediment accumulation due to trawl fishing is particularly deleterious, causing smothering and involving on growth and survival of benthic organisms (Althaus et al., 2009; Buhl-Mortensen and Buhl-Mortensen, 2018). Moreover, most coralligenous organisms may be damaged or completely eradicated by fishing gear (Enrichetti et al., 2019a). Lost ropes, longlines, and demersal nets may entangle sessile organisms, causing necrosis and favoring the development of epibionts (Angiolillo et al., 2015). Due to their arborescent arrangement, branched organisms with a carbonate skeleton are the most threatened by fishing gear (Bo et al., 2014; Bavestrello et al., 2015; Ferrigno et al., 2020, Ferrigno et al., 2021) and, in zone subjected to high fishing pressure their distributions resulted confined to refuge zones, influencing the natural patterns of spatial variability of the whole assemblage (Appolloni et al., 2020). In Sardinian continental shelf, the low level of fishing pressure allows the presence of well-structured assemblages dominated by fan corals on a large portion of the investigated areas, representing an aspect to be highlighted and that deserves consideration from a conservation point of view (Bo et al., 2015; Cau et al., 2015, 2017). In fact, these animal forests play a key structural and functional ecological role in coralligenous systems, especially in the deepest part, where their complex three-dimensional structure enhances the spatial heterogeneity of the habitat, regulate the main environmental factors, and provide habitat, shelter and refuge for the associated assemblages (Gori et al., 2017; Paoli et al., 2017; Cerrano et al., 2010, 2019).

In conclusion, the study highlighted differences in both spatial variability of assemblages and ecological quality between the two systems. Interestingly, the spatial variability in structure of both cliff and platform assemblages did not correspond with spatial patterns of ecological quality. This finding confirms the ability of the two indices to evaluate the ecological quality of the habitat independently from geographical differences in the structure of assemblages, and thus by the dominance of different organisms. This requisite is crucial for indices which are to be employed at large spatial scale. Overall, the results of the present study corroborate the single peculiarity of coralligenous platforms and cliffs, highlighting the importance of the concurrent assessment of both systems in monitoring programs.

Funding

This research was funded by the scientific and technological cooperation between Regione Autonoma della Sardegna (RAS, Assessorato alla Difesa dell'Ambiente) and University of Sassari (settembre 2018, Resp. Giulia Ceccherelli) to solve the case EU Pilot 8348/16/ENVI and complete the designation of Natura 2000 sites in Italy".

CRediT authorship contribution statement

Luigi Piazzi: Conceptualization, Methodology, Investigation, Formal analysis, Writing – original draft. **Federica Ferrigno:** Conceptualization, Methodology, Formal analysis, Writing – review & editing. **Ivan Guala:** Conceptualization, Investigation, Writing – review & editing. **Maria Francesca Cinti:** Investigation. **Alessandro Conforti:** Investigation. **Giovanni De Falco:** Methodology, Investigation, Funding acquisition. **Mario De Luca:** Methodology, Investigation. **Daniele Grech:** Investigation. **Gabriella La Manna:** Investigation. **Vincenzo Pascucci:** Methodology, Funding acquisition. **Arianna Pansini:** Investigation. **Federico Pinna:** Investigation. **Laura Pireddu:** Investigation. **Alessandra Puccini:** Investigation. **Giovanni Fulvio Russo:** Conceptualization, Writing – review & editing. **Roberto Sandulli:** Conceptualization, Writing – review & editing. **Antonio Santonastaso:** Investigation. **Simone Simeone:** Investigation. **Myriam Stelletti:** Investigation. **Patrizia Stipcich:** Investigation. **Giulia Ceccherelli:** Conceptualization, Writing – review & editing, Funding acquisition.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgement

We are grateful to the MPAs of Capo Carbonara, Capo Testa-Punta Falcone, Isola dell'Asinara, Capo Caccia-Isola Piana, Tavolara-Punta Coda Cavallo, Penisola del Sinis-Isola di Mal di Ventre for providing permissions and logistic assistance. We wish to thank Porto San Paolo Diving Center, Roccaruja Diving Center, Diving Center Costa Paradiso and Diving Mediterraneo for support in field activity.

Appendix A. Supplementary data

The following supporting information can be downloaded at: www.mdpi.com/xxx/s1, Table S1: Variables with their categories and scores, within the three groups used for CBQI calculation (from Ferrigno et al., 2017) [34]; Table S2: Sensitivity Level (SL) of the main morphological groups in the coralligenous assemblages for ESCA index (from Piazzi et al., 2021b) [31]. Supplementary data to this article can be found online at https://doi.org/10.1016/j.ecolind.2022.108657.

References

Althaus, F., Williams, A., Schlacher, T.A., Kloser, R.J., Green, M.A., Barker, B.A., Bax, N. J., Brodie, P., Hoenlinger-Schlacher, M.A., 2009. Impacts of bottom trawling on deep-coral ecosystems of seamounts are long-lasting. Mar. Ecol. Prog. Ser. 397, 279–294.

Anderson, M.J., 2001. A new method for a non-parametric multivariate analysis of variance. Austr. Ecol. 26, 32–46.

Anderson, M.J., Robinson, J., 2003. Generalized discriminant analysis based on distances. Aust. N.Z. J. Statist. 45 (3), 301–318.

Anderson, M.J., Ellingsen, K.E., McArdle, B.H., 2006. Multivariate dispersion as a measure of beta diversity. Ecol. Lett. 9 (6), 683–693.

Angiolillo, M., Lorenzo, B.d., Farcomeni, A., Bo, M., Bavestrello, G., Santangelo, G., Cau, A., Mastascusa, V., Cau, A., Sacco, F., Canese, S., 2015. Distribution and assessment of marine debris in the deep Tyrrhenian Sea (NW Mediterranean Sea, Italy). Mar. Pollut. Bull. 92 (1-2), 149–159.

Appolloni, L., Ferrigno, F., Russo, G.F., Sandulli, R., 2020. β-Diversity of morphological groups as indicator of coralligenous community quality status. Ecol. Ind. 109, 105840.

Balata, D., Piazzi, L., Cecchi, E., Cinelli, F., 2005. Variability of Mediterranean coralligenous assemblages subject to local variation in sediment deposition. Mar. Environ. Res. 60 (4), 403–421.

Ballesteros, E., 2006. Mediterranean Coralligenous assemblages: a synthesis of present knowledge. Oceanogr. Mar. Biol. Annu. Rev. 44, 123–195.

Bavestrello, G., Cerrano, C., Zanzi, D., Cattaneo-Vietti, R., 1997. Damage by fishing activities in the gorgonian coral *Paramuricea clavata* in the Ligurian Sea. Aquat. Conserv. 7, 253–262.

Bavestrello, G., Bava, S., Canese, S., Cattaneo-Vietti, R., Cerasi, S., Profeta, A., Bo, M., 2015. Coralligenous assemblages and professional fisheries: a challenge for the marine spatial planning. Biologia Marina Mediterranea 22, 12–15.

Betti, F., Bavestrello, G., Bo, M., Ravanetti, G., Enrichetti, F., Coppari, M., Cappanera, V., Venturini, S., Cattaneo-Vietti, R., 2020. Evidences of fishing impact on the coastal gorgonian forests inside the Portofino MPA (NW Mediterranean Sea). Ocean Coast. Manage. 187 (2020), 105105.

Bo, M., Bava, S., Canese, S., Angiolillo, M., Cattaneo-Vietti, R., Bavestrello, G., 2014. Fishing impact on deep Mediterranean rocky habitats as revealed by ROV investigation. Biol. Conserv. 171, 167–176.

Bo, M., Bavestrello, G., Angiolillo, M., Calcagnile, L., Canese, S., Cannas, R., Cau, A., D'Elia, M., D'Oriano, F., Follesa, M.C., Quarta, G., Cau, A., Valentine, J.F., 2015. Persistence of pristine deep-sea coral gardens in the Mediterranean Sea (SW Sardinia). PLoS ONE 10 (3), e0119393.

Borja, A., Ranasinghe, A., Weisberg, S.B., 2009. Assessing ecological integrity in marine waters, using multiple indices and ecosystem components: challenges for the future. Mar. Pollut. Bull. 59 (1-3), 1–4.

Bracchi, V.A., Basso, D., Marchese, F., Corselli, C., Savini, A., 2017. Coralligenous morphotypes on subhorizontal substrate: A new categorization. Cont. Shelf Res. 144, 10–20.

Buhl-Mortensen, P., Buhl-Mortensen, L., 2018. Impacts of bottom trawling and litter on the seabed in Norwegian waters. Front. Mar. Sci. 5, 42.

Cánovas-Molina, A., Montefalcone, M., Bavestrello, G., Cau, A., Bianchi, C.N., Morri, C., Canese, S., Bo, M., 2016. A new ecological index for the status of mesophotic megabenthic assemblages in the Mediterranean based on ROV photography and video footage. Cont. Shelf Res. 121, 13–20.

Casoli, E., Nicoletti, L., Mastrantonio, G., Jona-Lasinio, G., Belluscio, A., Ardizzone, G.D., 2017. Scuba diving damage on coralligenous builders: bryozoan species as an indicator of stress. Ecol. Indic. 74, 441–450.

Cau, A., Follesa, M.C., Moccia, D., Alvito, A., Bo, M., Angiolillo, M., Canese, S., Paliaga, E. M., Orrù, P.E., Sacco, F., Cannas, R., 2015. Deepwater corals biodiversity along roche du large ecosystems with different habitat complexity along the south Sardinia continental margin (CW Mediterranean Sea). Mar. Biol. 162 (9), 1865–1878.

Cau, A., Follesa, M.C., Moccia, D., Bellodi, A., Mulas, A., Bo, M., Canese, S., Angiolillo, M., Cannas, R., 2017. *Leiopathes glaberrima* millennial forest from SW Sardinia as nursery ground for the small spotted catshark *Scyliorhinus canicula*. Aquat. Conserv. 27 (3), 731–735.

Ceccherelli, G., Pinna, F., Pansini, A., Piazzi, L., La Manna, G., 2020. The constraint of ignoring the subtidal water climatology in evaluating the changes of coralligenous reefs due to heating events. Sci. Rep. 10, 17332.

Cecchi, E., Gennaro, P., Piazzi, L., Ricevuto, E., Serena, F., 2014. Development of a new biotic index for ecological status assessment of Italian coastal waters based on coralligenous macroalgal assemblages. Eur. J. Phycol. 49 (3), 298–312.

Cerrano, C., Bavestrello, G., Bianchi, C.N., Cattaneo-vietti, R., Bava, S., Morganti, C., Morri, C., Picco, P., Sara, G., Schiaparelli, S., Siccardi, A., Sponga, F., 2000.

A catastrophic mass-mortality episode of gorgonians and other organisms in the Ligurian Sea (Northwestern Mediterranean), summer 1999. Ecol. Lett. 3 (4), 284–293.

Cerrano, C., Danovaro, R., Gambi, C., Pusceddu, A., Riva, A., Schiaparelli, S., 2010. Gold coral (*Savalia savaglia*) and gorgonian forests enhance benthic biodiversity and ecosystem functioning in the mesophotic zone. Biodivers. Conserv. 19 (1), 153–167.

Cerrano, C., Bastari, A., Calcinai, B., Di Camillo, C., Pica, D., Puce, S., Valisano, L., Torsani, F., 2019. Temperate mesophotic ecosystems: gaps and perspectives of an emerging conservation challenge for the Mediterranean Sea. Eur. Zool. J. 86 (1), 370–388.

De Falco, G., Conforti, A., Brambilla, W., Budillon, F., Ceccherelli, G., De Luca, M., Di Martino, G., Guala, I., Innangi, S., Pascucci, V., Piazzi, L., Pireddu, L., Santonastaso, A., Tonielli, R., Simeone, S., 2022. Coralligenous banks along the western and northern continental shelf of Sardinia Island (Mediterranean Sea). Journal of Maps 1–10. https://doi.org/10.1080/17445647.2021.2020179.

Deter, J., Descamp, P., Ballesta, L., Boissery, P., Holon, F., 2012. A preliminary study toward an index based on coralligenous assemblages for the ecological status assessment of Mediterranean French coastal waters. Ecol. Ind. 20, 345–352.

Dethier, M.N., Graham, E.S., Cohen, S., Tear, L.M., 1993. Visual versus random-point percent cover estimations: "objective'' is not always better. Mar. Ecol. Progr. Ser. 96, 93–100.

E.C., 1992. Council Directive 92/43/EEC (Habitat Directive) of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora. As amended by the Accession Act of Austria, Finland and Sweden. Official Journal of the European Commission L 1, 1.1, pp. 135.

E.C., 2008. Marine Strategy Framework Directive 2008/56/EC of the European Parliament and of the Council, of 17 June 2008, establishing a framework for Community action in the field of marine environmental policy (Marine Strategy Framework Directive). Official Journal of the European Commission G.U.C.E. 25/6/2008, L 164/19.

Enrichetti, F., Bava, S., Bavestrello, G., Betti, F., Lanteri, L., Bo, M., 2019a. Artisanal fishing impact on deep coralligenous animal forests: A Mediterranean case study of marine vulnerability. Ocean Coast. Manag. 177, 112–126.

Enrichetti, F., Bo, M., Morri, C., Montefalcone, M., Toma, M., Bavestrello, G., Tunesi, L., Canese, S., Giusti, M., Salvati, E., Bertolotto, R.M., Bianchi, C.N., 2019b. Assessing the environmental status of temperate mesophotic reefs: a new, integrated methodological approach. Ecol. Indicat. 102, 218–229.

Ferrigno, F., Russo, G.F., Sandulli, R., 2017. Coralligenous bioconstructions Quality Index (CBQI): a synthetic indicator to assess the status of different types of coralligenous habitats. Ecol. Ind. 82, 271–279.

Ferrigno, F., Russo, G.F., Semprucci, F., Sandulli, R., 2018a. Unveiling the state of some underexplored deep coralligenous banks in the Gulf of Naples (Mediterranean Sea, Italy). Reg. Stud. Mar. Sci. 22, 82–92.

Ferrigno, F., Appolloni, L., Russo, G.F., Sandulli, R., 2018b. Impact of fishing activities on different coralligenous assemblages of Gulf of Naples (Italy). J. Mar. Biol. Assoc. U.K. 98 (1), 41–50.

Ferrigno, F., Appolloni, L., Rendina, F., Donnarumma, L., Russo, G.F., Sandulli, R., 2020. Red coral (*Corallium rubrum*) populations and coralligenous characterization within "Regno di Nettuno MPA"(Tyrrhenian Sea, Italy). Eur. Zool. J. 87 (1), 203–213.

Ferrigno, F., Appolloni, L., Donnarumma, L., Di Stefano, F., Rendina, F., Sandulli, R., Russo, G.F., 2021. Diversity Loss in Coralligenous Structuring Species Impacted by Fishing Gear and Marine Litter. Diversity 13 (7), 331.

Fox, W.T., 2005. Bioconstruction. In: Schwartz, M.L. (Ed.), Encyclopedia of Coastal Science. Springer, pp. 186–188.

Garrabou, J., Coma, R., Bensoussan, N., Bally, M., Chevaldonné, P., Cigliano, M., Diaz, D., Harmelin, J.G., Gambi, M.C., Kersting, D.K., Ledoux, J.B., Lejeusne, C., Linares, C., Marschal, C., Pérez, T., Ribes, M., Romano, J.C., Serrano, E., Teixido, N., Torrents, O., Zabala, M., Zuberer, F., Cerrano, C., 2009. Mass mortality in Northwestern Mediterranean rocky benthic communities: Effects of the 2003 heat wave. Glob. Change Biol. 15 (5), 1090–1103.

Gatti, G., Montefalcone, M., Rovere, A., Parravicini, V., Morri, C., Albertelli, G., Nike Bianchi, C., 2012. Seafloor integrity down the harbor waterfront: the coralligenous shoals off Vado Ligure (NW Mediterranean). Adv. Oceanogr. Limnol. 3 (1), 51–67.

Gatti, G., Bianchi, C.N., Morri, C., Montefalcone, M., Sartoretto, S., 2015a. Coralligenous reefs state along anthropized coasts: application and validation of the COARSE index, based on a rapid visual assessment (RVA) approach. Ecol. Ind. 52, 567–576.

Gatti, G., Bianchi, C.N., Parravicini, V., Rovere, A., Peirano, A., Montefalcone, M., Massa, F., Morri, C., 2015b. Ecological change, sliding baselines and the importance of historical data: lessons from combining observational and quantitative data on a temperate reef over 70 years. PLoS ONE 10, e0118581.

Giusti, M., Canese, S., Fourt, M., Bo, M., Innocenti, C., Goujard, A., Daniel, B., Angeletti, L., Taviani, M., Aquilina, L., Tunesi, L., 2019. Coral forests and Derelict Fishing Gears in submarine canyon systems of the Ligurian Sea. Prog. Oceanogr. 178, 102186.

Gori, A., Bavestrello, G., Grinyó, J., Dominguez-Carrio, C., Ambroso, S., Bo, M., 2017. Animal Forests in deep coastal bottoms and continental shelf of the Mediterranean Sea. In: Rossi, S. (Ed.), Marine Animal Forests. The Ecology of Benthic Biodiversity Hotspot. Springer International Publishing, pp. 207–233.

Grinyó, J., Gori, A., Ambroso, S., Purroy, A., Calatayud, C., Dominguez-Carrió, C., Coppari, M., Lo Iacono, C., López-González, P.J., Gili, J.-M., 2016. Diversity, distribution and population size structure of deep Mediterranean gorgonian assemblages (Menorca Channel, Western Mediterranean Sea). Progr. Oceanogr. 145, 42–56.

Ingrosso, G., Abbiati, M., Badalamenti, F., Bavestrello, G., Belmonte, G., Cannas, R., Benedetti-Cecchi, L., Bertolino, M., Bevilacqua, S., Bianchi, C.N., Bo, M., Boscari, E., Cardone, F., Cattaneo-Vietti, R., Cau, A., Cerrano, C., Chemello, R., Chimienti, G., Congiu, L., Corriero, G., Costantini, F., De Leo, F., Donnarumma, L., Falace, A., Fraschetti, S., Giangrande, A., Gravina, M.F., Guarnieri, G., Mastrototaro, F., Milazzo, M., Morri, C., Musco, L., Pezzolesi, L., Piraino, S., Prada, F., Ponti, M., Rindi, F., Russo, G.F., Sandulli, R., Villamor, A., Zane, L., Boero, F., 2018. Mediterranean bioconstructions along the Italian Coast. Adv. Mar. Biol. 79, 61–136.

Kruzic, P., 2014. Bioconstructions in the Mediterranean: Present and Future. In: Goffredo, S., Dubinski, Z. (Eds.), The Mediterranean Sea: Its History and Present Challenges. Springer, Dordrecht, pp. 435–447.

Laborel, J., 1987. Marine biogenic constructions in the Mediterranean, a review. Sci. Rep. Port-Cros Nat. Park 13, 97–127.

Montefalcone, M., Morri, C., Bianchi, C.N., Bavestrello, G., Piazzi, L., 2017. The two facets of species sensitivity: stress and disturbance on coralligenous assemblages in space and time. Mar. Pollut. Bull. 117 (1-2), 229–238.

Montefalcone, M., Tunesi, L., Ouerghi, A., 2021. A review of the classification systems for marine benthic habitats and the new updated Barcelona Convention classification for the Mediterranean. Mar. Environ. Res. 169, 105387.

Paoli, C., Montefalcone, M., Morri, C., Vassallo, P., Bianchi, C.N., 2017. Ecosystem functions and services of the marine animal forests. In: Rossi, S., Bramanti, L., Gori, A., Orejas, C. (Eds.), Marine Animal Forests. Springer International Publishing, Cham, pp. 1271–1312.

Piazzi, L., Gennaro, P., Balata, D., 2012. Threats to macroalgal coralligenous assemblages in the Mediterranean Sea. Mar. Pollut. Bull. 64 (12), 2623–2629.

Piazzi, L., Atzori, F., Cadoni, N., Cinti, M.F., Frau, F., Ceccherelli, G., 2018. Benthic mucilage blooms threaten coralligenous reefs. Mar. Environ. Res. 140, 145–151.

Piazzi, L., Cecchi, E., Cinti, M.F., Stipcich, P., Ceccherelli, G., 2019a. Impact assessment of fish cages on coralligenous reefs: an opportunity to use the STAR sampling procedure. Medit. Mar. Sci. 20, 627–635.

Piazzi, L., Gennaro, P., Montefalcone, M., Bianchi, C.N., Cecchi, E., Morri, C., Serena, F., 2019b. STAR: an integrated and standardized procedure to evaluate the ecological status of coralligenous reefs. Aquat. Conserv. Mar. Freshw. Ecosys. 29 (2), 189–201.

Piazzi, L., Kaleb, S., Ceccherelli, G., Montefalcone, M., Falace, A., 2019c. Deep coralligenous outcrops of the Apulian continental shelf: biodiversity and spatial variability of sediment-regulated assemblages. Cont. Shelf Res. 172, 50–56.

Piazzi, L., Cinti, M.F., Guala, I., Grech, D., La Manna, G., Pansini, A., Pinna, F., Stipcich, P., Ceccherelli, G., 2021a. Variations in coralligenous assemblages from local to biogeographic spatial scale. Mar. Environ. Res. 169, 105375.

Piazzi, L., Gennaro, P., Cecchi, E., Bianchi, C.N., Cinti, F., Gatti, G., Guala, I., Morri, C., Sartoretto, F., Serena, F., Montefalcone, M., 2021b. Ecological Status of Coralligenous Assemblages: ten years of application of the ESCA index from local to wide scale validation. Ecol. Ind. 121, 107077.

Pinna, F., Piazzi, L., Cinti, M.F., Pansini, A., Stipcich, P., Ceccherelli, G., 2021. Vertical variation of coralligenous cliff assemblages in marine biogeographic areas. Estuar. Coast. Shelf Sci. 261, 107554.

Rendina, F., Ferrigno, F., Appolloni, L., Donnarumma, L., Sandulli, R., Fulvio, G.F., 2020. Anthropic pressure due to lost fishing gears and marine litter on different rhodolith beds off the Campania Coast (Tyrrhenian Sea, Italy). Ecol. Quest. 31, 1–17.

Sartoretto, S., Schohn, T., Bianchi, C.N., Morri, C., Garrabou, J., Ballesteros, E., Ruitton, S., Verlaque, M., Daniel, B., Charbonnel, E., Blouet, S., David, R., Féral, J.P., Gatti, G., 2017. An integrated method to evaluate and monitor the conservation state of coralligenous habitats: the INDEX-COR approach. Mar. Pollut. Bull. 120, 222–231.

Thierry de Ville d'Avray, L., Ami, D., Chenuil, A., David, R., Féral, J.-P., 2019. Application of the ecosystem service concept at a small-scale: The cases of coralligenous habitats in the North-western Mediterranean Sea. Mar. Pollut. Bull. 138, 160–170.

Tribot, A.S., Mouquet, N., Villéger, S., Raymond, M., Hoff, F., Boissery, P., Holon, F., Deter, J., 2016. Taxonomic and functional diversity increase the aesthetic value of coralligenous reefs. Sci. Rep. 6, 34229.

Unep, 2017. Action Plan for the Conservation of the Coralligenous and Other Calcareous Bio-Concretions in the Mediterranean Sea. UNEP/MAP Athens, GR.

UNEP, 2019. Monitoring protocols for IMAP Common Indicators related to biodiversity and non-indigenous species, which includes the guidelines for monitoring marine benthic habitats in the Mediterranean (WG.467/16). UNEP/MAP, Athens, GR.