MONITORING AND ASSESSMENT OF THE ECOLOGICAL STATUS OF CORALLIGENOUS CLIFFS BY A STANDARDIZED PROTOCOL

Paola Gennaro, Luigi Piazzi, Enrico Cecchi, Carla Morri, Carlo Nike Bianchi, Monica Montefalcone

Abstract: Coralligenous reefs are the main biogenic construction of the Mediterranean Sea and one of the most sensitive habitats for which European legislation requires monitoring and quality assessment plans. The heterogeneity of reefs however requires the use of standardized habitat-specific methods allowing comparability of data over wide scale. Coralligenous cliffs are the reef type most widespread in shallow waters and are monitored by several ecological indices based on different approaches. This contribution summarizes the results of multi-year studies carried out on wide spatial scale with the aim of comparing and integrating the different methods into a single standardized sampling and data collection protocol. Downstream of a literature review, the STAndaRdized coralligenous evaluation procedure (STAR) was proposed and tested on subregion scale under different human pressures. Results confirmed the validity of descriptors chosen and the effectiveness of the protocol in assessing the ecological quality of coralligenous cliffs. STAR represents the first methodological guidelines proposed for the evaluation of the ecological quality of coralligenous cliffs in the Mediterranean Sea

Keywords: biogenic construction, ecological quality, evaluation, guidelines, Mediterranean Sea

Paola Gennaro, ISPRA - Italian Institute for Environmental Protection and Research, Italy, paola.gennaro@isprambiente.it, 0000-0002-4569-8209
Luigi Piazzi, University of Sassari, Italy, lpiazzi@uniss.it, 0000-0003-3061-0187
Enrico Cecchi, ARPAT, Italy, e.cecchi@arpat.toscana.it, 0000-0002-8910-891X
Carla Morri, Institute of Marine Biology, Italy, carla.morri.ge@gmail.com, 0000-0003-4520-2741
Carlo Nike Bianchi, Institute of Marine Biology, Italy, carlonike.bianchi.ge@gmail.com, 0000-0003-1071-3285
Monica Montefalcone, University of Genoa, Italy, monica.montefalcone@unige.it, 0000-0002-3851-1880

Referee List (DOI 10.36253/fup_referee_list)
FUP Best Practice in Scholarly Publishing (DOI 10.36253/fup_best_practice)

Paola Gennaro, Luigi Piazzi, Enrico Cecchi, Carla Morri, Carlo Nike Bianchi, Monica Montefalcone, *Monitoring and assessment of the ecological status of coralligenous cliffs by a standardized protocol*, pp. 228-239, DOI: 10.36253/979-12-215-0556-6.20

Introduction

Coralligenous reefs represent the most important circalittoral bioconstruction in the Mediterranean Sea for extent, biodiversity, and carbon dynamics [3,4]. They are an iconic underwater seascape providing multifarious ecosystem services, but they are also a very sensitive habitat vulnerable to both global and local disturbances; thus, coralligenous reefs are included in the European Red List of Habitats and their monitoring and quality assessment are required under European Directives and international treaties. The heterogeneity of the coralligenous habitat makes it difficult to identify unequivocal threats, study methods and ecological indicators [17], so the development of habitat-specific plans for monitoring and assessment based on standardized methods are strongly required, in order to allow data comparability over a wide space and time scale. Among different reef morphologies, the coralligenous cliff is the most widespread in the first 40 m depth, and the most exposed to the effects of climate change and anthropogenic pressures affecting coastal waters [19]. It is hence considered a sensitive bioindicator, as well as a habitat under high risk of degradation, for which many ecological indices were developed in the last decade to evaluate its health status [7]. However, these indices are based on different approaches and metrics which, in the absence of an integration/intercalibration process, could prevent the comparison of results obtained with different methods in different areas of the Mediterranean Sea; this may lead to greater difficulties in the application of shared intervention measures for the maintenance and restoration of good environmental status as required by European directives. This contribution summarizes the results of multi-year studies carried out through underwater surveys on a large spatial scale, aiming at comparing and integrating methods used at the Mediterranean level in a standardized single protocol for sampling and data collection.

Materials and Methods

The relevant literature on coralligenous reefs in the Mediterranean Sea was searched, together with the proceedings of the main Mediterranean workshops and other specialized symposia. Among the 95 scientific papers dealing with shallow coralligenous reefs, 52 studies reporting detailed information about sampling methods applied to assess the ecological quality of coralligenous cliffs were selected. Methods applied by different authors were compared to identify the best sampling strategy and to select the ecological descriptors common to most indices and most sensitive to human pressures. The information collected was synthesized in a STAndaRdized coralligenous evaluation procedure (STAR) performed by SCUBA divers, following a non-destructive protocol which allows obtaining information about most of descriptors used by different indices through a single sampling effort and data analysis [8,15].

The new procedure was first tested in 8 locations of the Italian coast [15] and then applied across the Western Mediterranean subregion for a total of 48 locations and 95 sites of coralligenous cliffs investigated to date along the Italian and French coasts (Fig. 1). To test the protocol on a large scale, 30 locations subject to different human pressures were selected along the Italian coasts. The level of human pressures was defined according to the anthropization index, which considered the nine main impact factors affecting coralligenous reefs (urbanization and urban waste, ports, tourism, industrial activities, sediment load, aquaculture, agricultural waste, fishing and anchoring) which were assigned a score from 0 (no impact) to 2 (strong impact) based on the presence and extent of the human pressure and distance of the sites from the source of impact [16].

For each site, the anthropization index, ranging from 0 to 13, was calculated as the sum of the values of each individual impact factor. Three plots of area 4 m^2, tens of metres apart, were sampled at each site on vertical bottoms at about 35 m of depth and 10 photographic samples of 0.2 m^2 were collected for each plot. The thickness of the calcareous layer was measured through a hand-held penetrometer (six replicated measures per each plot) and each measurement was assigned to a thickness class as follows: 1 for null penetration, as in the absence of biogenic substrate, 2 for a centimetric penetration, indicating a not yet consolidated bioconstruction, and 3 for a millimetric penetration, which occurs in the presence of active bioconstruction resulting in a calcareous biogenic layer [9].

The maximum height of the erect species was measured *in situ* and the percentage of necrosis/epibiosis of the erect anthozoans was assessed through a visual approach taking account the following percentage cover classes: 1 for $N > 75$ %, 2 for $10\% \leq N \leq 75$ % and 3 for $N < 10$ %. Photographic samples were analysed by the ImageJ software [18] to evaluate the presence and percentage cover of the main taxa or morphological groups and the sediment deposit [6]. A value of Sensitivity Level (SL) has been assigned to each taxon/morphological group, with values varying within a numerical scale, from the lowest ones corresponding to the most tolerant organisms to the highest values for the most sensitive ones [16,8]. To calculate the SL of study sites, each taxon was associated with a sensitivity value and with one of eight classes of abundance (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 [15]. The SL of each photographic sample was calculated as the sum of the values obtained by multiplying the sensitivity value of each taxon/group by its class of abundance and the SL of each study site was calculated by adding the SL values of all samples. The α-diversity was calculated as the mean number of taxa/morphological groups per photographic sample, and the β-diversity was calculated as heterogeneity of assemblages expressed as distance from centroids measured in a multivariate dispersion through PERMDISP analysis [1].

The data collected with the STAR protocol were used to calculate the ESCA (Ecological Status of Coralligenous Assemblages) [16] and COARSE (COralligenous Assessment by Reef Scape Estimate) [9] indices, in order to evaluate the ecological status of coralligenous cliffs through a biocenotic and seascape approach respectively. ESCA was expressed as Ecological Quality Ratio (EQR'), calculated as the mean of the EQRs obtained for the biocenotic descriptors compared to reference conditions [6], and its values provide the following ecological quality status classification: i) high ($EQR \geq 0.8$); ii) good ($0.6 \leq EQR < 0.8$); iii) moderate ($0.4 \leq EQR < 0.6$); iv), poor ($0.2 \leq EQR < 0.4$); and v) bad ($EQR < 0.2$) [16]. The COARSE index was expressed as Quality value for each site (Q'), calculated as the mean of the Qs obtained for the three layers characterizing coralligenous reefs (basal, intermediate and upper layer) [9], and classified as follows: i) high (2.55<Q'≤3); ii) good (2.35<Q'≤2.55); iii) moderate (2.05<Q'≤2.35); iv), poor (1.55<Q'≤2.05); and v) bad (Q'≤1.55). A linear regression was performed in order to test the response to human pressures of descriptors selected and of the ESCA and COARSE ecological indices. The degree of correlation was expressed as value of the square correlation coefficient (determination coefficient, R^2) and significance of regression was tested by means of the Fisher-Snedecor test performed by the Statistica 10 software.

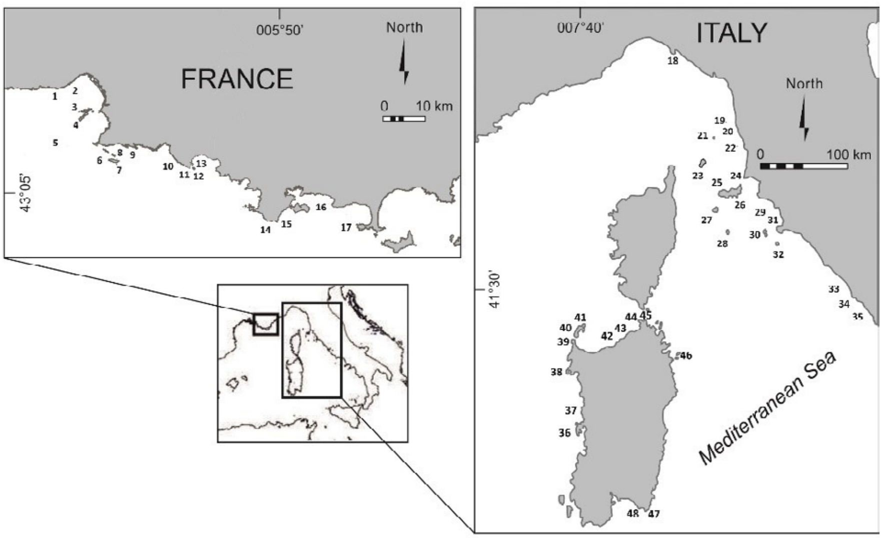

Figure 1 – Map of the 48 locations investigated: Méjean (1), Large Niolon (2), Tiboulen du Frioul (3), Ile du Planier (4), Cap Caveau (5), Moyade (6), Ile Plane (7), Impérial Milieu (8), Morgiou (9), Figuerolle (10), Bec de l'Aigle (11), Les Rosiers (12), Pierre du Levant (13), Sêche des Pêcheurs (14), Les Deux Frères (15), Large Oursinière (16), Formigue (17), Portofino (18), Meloria (19), Livorno (20), Gorgona (21), Vada (22), Capraia (23), Piombino (24), Elba N (25), Elba S (26), Pianosa (27), Montecristo (28), Formiche di Grosseto (29), Giglio (30), Argentario (31), Giannutri (32), Sant'Agostino (33), Santa Marinella (34), Civitavecchia (35), Catalano (36), Bosa (37), Capo Caccia (38), Stintino (39), Asinara S (40), Asinara N (41), Castel Sardo (42), Costa Paradiso (43), Capo Testa (44), Santa Teresa (45), Tavolara (46), Torre Stelle (47), Capo Carbonara (48).

Results

The regression model performed for the ecological descriptors selected always showed a significant negative correlation between values of the anthropization index and those of SL ($F < 0.001$), α-diversity ($F < 0.001$), β-diversity ($F < 0.001$), thickness of the calcareous matrix ($F < 0.01$) and necrosis/epibiosis ($F < 0.001$), while a significant positive relationship was highlighted for the turf/sediment descriptor ($F < 0.001$) (Fig. 2 a, b). A significant negative correlation was also highlighted for both the ESCA ($F < 0.001$) and COARSE ($F < 0.001$) relationship with the anthropization index (Fig. 3). Values of the ESCA index ranged between 0.98 and 0.45 and most of the locations investigated were in high and good ecological status, while six of these were in moderate ecological status (Fig. 4a).

The COARSE index showed a higher variability of the classification values, with locations ranging from high to bad ecological quality status (Fig. 4b).

Discussion

The results confirmed the validity of the descriptors chosen and the effectiveness of the STAR approach in assessing the ecological quality of coralligenous cliffs. Sediment deposition is one of the main physical alterations affecting coastal areas and coralligenous cliffs are particularly vulnerable to this kind of disturbance, as increasing sedimentation may affect assemblages by covering sessile organisms, clogging their filtering apparatus and inhibiting the rates of recruitment, growth and metabolic processes [2]. Many correlative and experimental studies highlighted severe shifts in the structure of coralligenous assemblages subjected to several kinds of stressors; thus, the species sensitivity to environmental alterations can be a valid descriptor of the environmental quality of the habitat [11]. Moreover, both the richness and the heterogeneity of the assemblages decrease under stressed conditions [2]. In fact, coralligenous assemblages are usually characterized by a high variability at small spatial scale and consequently by high values of β-diversity, which is related to the heterogeneity of the substrate and competition for space [3]; under stressed conditions, the loss of structuring perennial species and proliferation of ephemeral algae lead to a widespread biotic homogenization, with consequent loss of β-diversity [2].

Bioconstruction by coralline algae is considered highly vulnerable to most effects of climate change, such as global warming and ocean acidification, but also to other environmental alterations, such as mucilage blooms, increasing sedimentation and mechanical damages by anchoring and fishing [3]; therefore, structure and health of coralline algae represent a primary descriptor of the ecological status of coralligenous cliffs.

Erect anthozoans are long-living organisms which are considered key species of coralligenous cliffs; they are affected by physical and climatic factors and by several human activities acting locally, such as fishing, anchoring or scuba diving [10]. Thus, although the presence and abundance of erect anthozoans may be independent of the environmental quality and related to natural factors, where they are present they can be usefully used as ecological indicators through the measure of different variables, such as the cover of colonies and the occurrence of necrosis and epibiosis [9]. The selected descriptors proved to be effective indicators of anthropogenic disturbance and the application of the STAR protocol made it possible to collect and integrate into a common database, and through a single sampling effort, the information they conveyed for the calculation of different ecological indices developed up to date, even with different approaches.

The ESCA and COARSE indices, in fact, are based respectively on a biocenotic and seascape approach, and can be considered a particular case of application of the STAR method to the analysis of data coming from the field database. The two indices proved to be effective in classifying the quality status of the assemblages investigated, albeit with some discrepancies consistent with the two different approaches. In particular, ESCA, using biocenotic descriptors, provide information on the alterations affecting different aspects of biodiversity at different levels of biological organization. COARSE focuses on the coralligenous stratocenoses, providing information on different pressures affecting different layers in the investigated area; consequently, assemblages naturally devoid of erect layer may be penalized by the integration of the three stratocenoses.

Different indices can use different metrics, thus providing complementary information on the effects of different anthropogenic pressures; for this reason, the use of a standardized sampling protocol to collect information from different descriptors and ecological levels is fundamental for the effectiveness of the large scale monitoring plans, as the simultaneous use of different ecological indices allows for a more complete assessment of coralligenous ecological status in relation to both anthropogenic pressures and variability of assemblages [8].

STAR is a non-destructive, simple but effective protocol that combines the photographic approach with the *in situ* visual measurement, optimizing the balance between sampling effort and information obtained, in respect of the habitat investigated. This is particularly important in the context of monitoring protected habitats, where destructive techniques should be avoided.

Destructive methods are usually considered the most effective in evaluating some important ecological parameters, like species composition and diversity of assemblages [12,13], but they are also impactful and expensive in terms of analysis time and expertise required [14]. Anyway, the significant response of descriptors tested versus anthropogenic pressures confirmed previous studies on the negligibility of the information lost with the photographic approach [14]. Moreover, the information obtained from a mixed approach integrating photographic and visual sampling techniques was more complete than that provided by individual approaches, allowing to reduce the time and costs associated with data collection, which in fact represents the most expensive part of the monitoring plans [8].

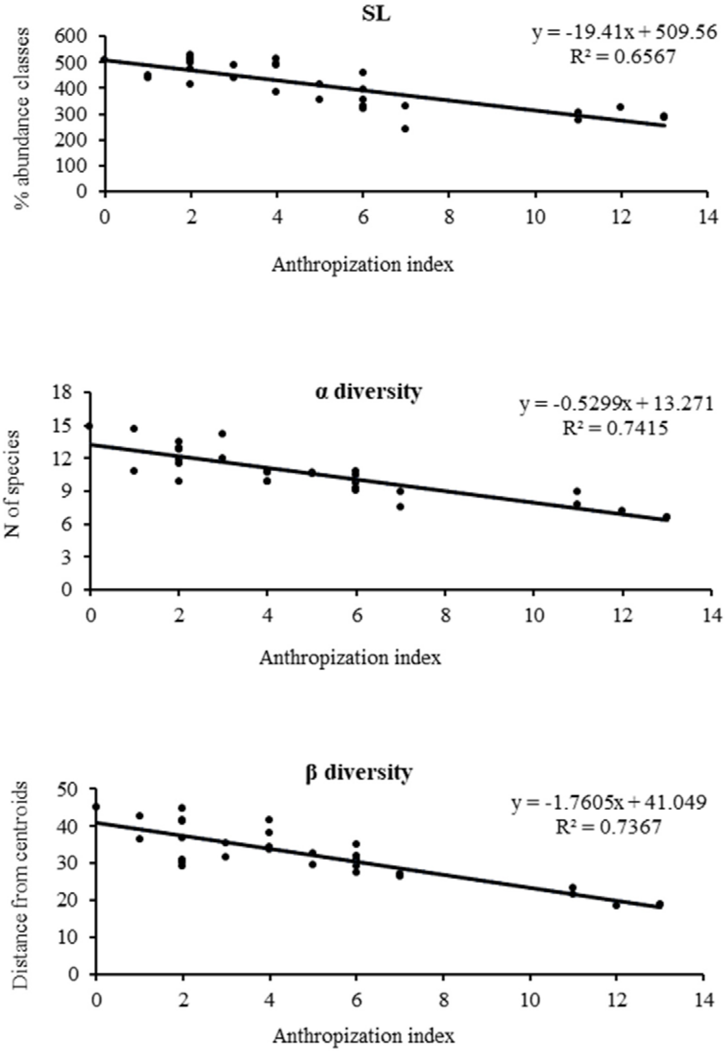

Figure 2a – Regression between the biocenotic descriptors and the anthropization index.

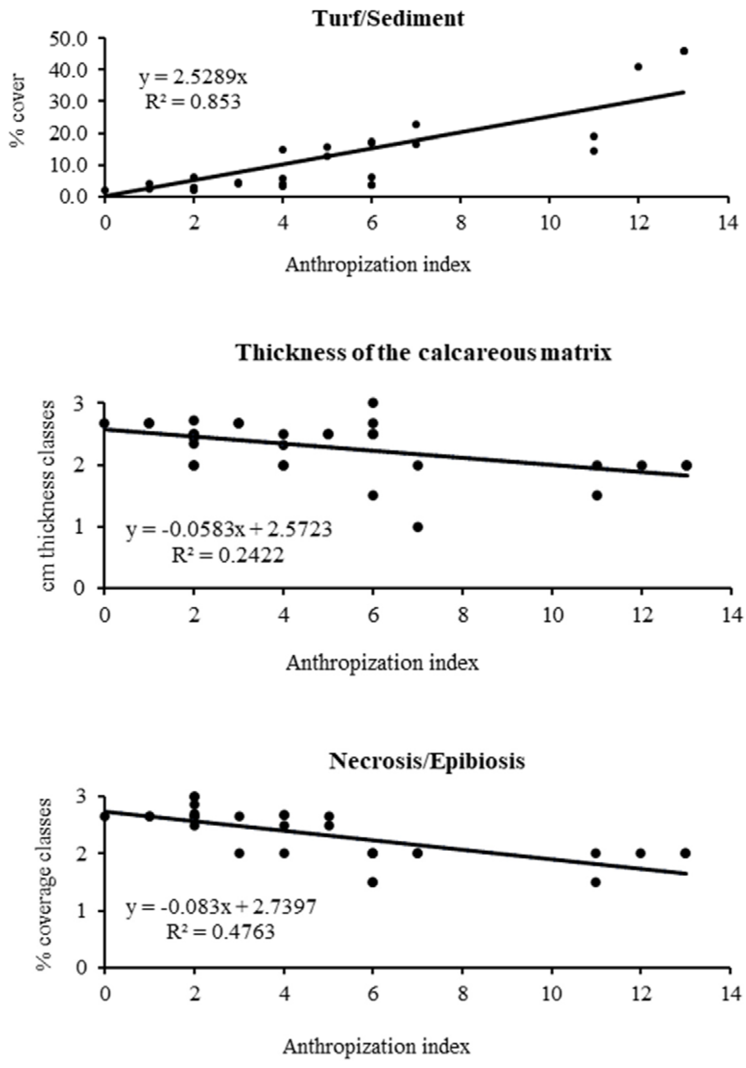

Figure 2b – Regression between the physical and biological descriptors and the anthropization index.

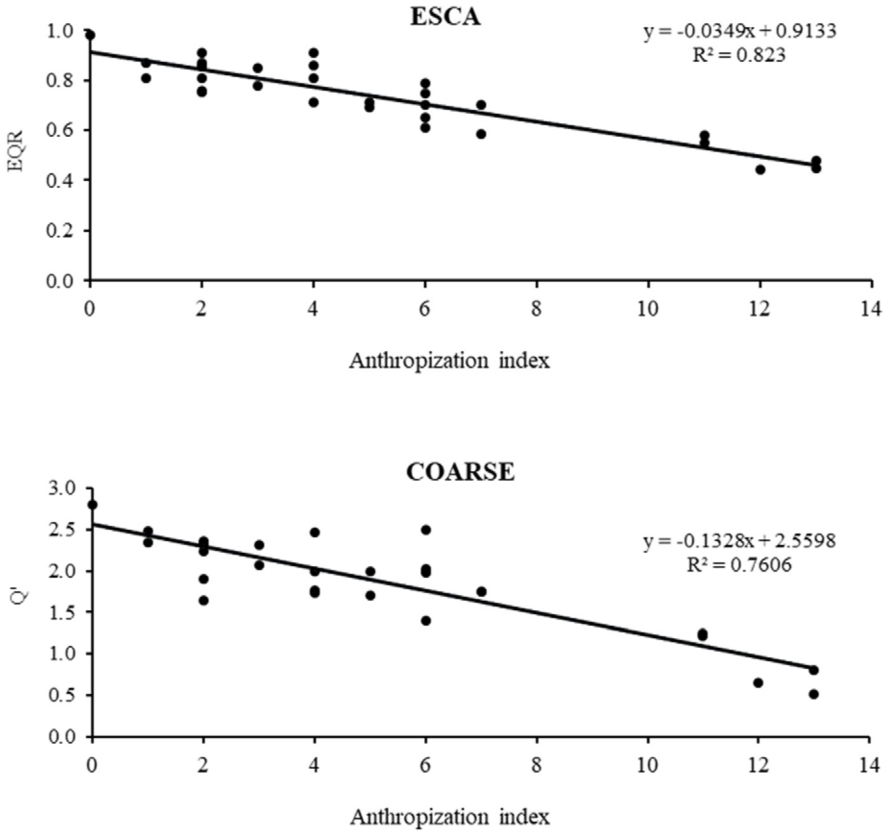

Figure 3 – Regression between values of the applied indices and the anthropization index.

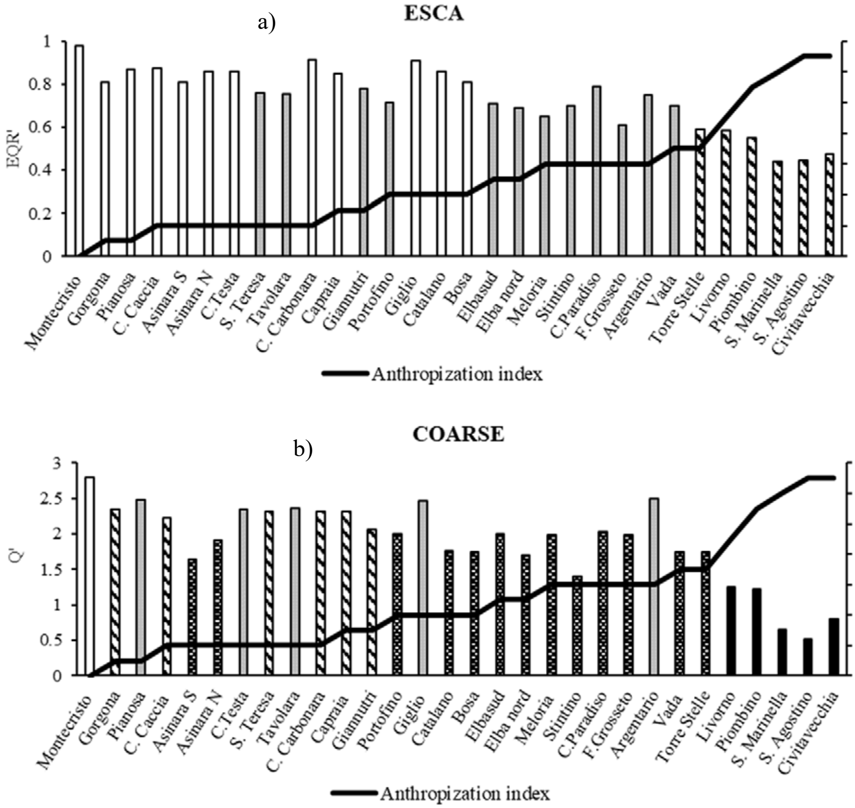

Figure 4 – Values of the anthropization index (black line) and the ESCA (a) and COARSE (b) indices (bars) in each of the 30 locations. White bars correspond to a high ecological quality, grey bars to a good one, the striped ones to moderate ecological quality, dotted bars to a poor ecological quality and black bars to bad ecological quality status of the coralligenous cliffs.

Conclusions

The European legislation recalls the need to develop standardized monitoring protocols for the acquisition of data and application of ecological quality indices, with the aim of promoting the intercalibration processes of methods and providing a common reference framework for comparison of the coralligenous ecological status among different areas of the Mediterranean Sea [8]. In this framework, the development of monitoring methods that take into account the heterogeneity of coralligenous habitat is recommended [20]. The STAR protocol aims at standardizing data collection on a particular type of coralligenous growing on vertical walls within 40 m of depth. This in order to monitor the health of the coralligenous habitat most widespread in surface waters and most sensitive to human disturbance, while responding to the need to separate the shallower habitats from the deeper ones. The STAR protocol was tested in the Western Mediterranean and it successfully integrated and standardized the monitoring methods for assessing ecological quality of shallow coralligenous reefs, thus favouring the development of an effective network for their conservation. In fact, the use of a standardized procedure may allow for the comparison among the information provided by different ecological indices applied throughout the Mediterranean Sea, favouring the intercalibration of the ecological quality values obtained on a large scale. The use of multiple descriptors and the integration of information from multiple ecological levels is the proper approach to identify change in ecosystem quality [5]; moreover, the simultaneous use of different ecological indicators allows for the detection of community responses to specific pressures, for better addressing the intervention measures and conservation plans under European legislation. In this framework, STAR represents the first methodological guideline proposed in the Mediterranean as a tool for environmental policies concerning protection of coralligenous habitats [8] and may constitute a milestone for the development of increasingly accurate and effective tools shared on a broader Mediterranean scale.

References

[1] Anderson M.J., Ellingsen K.E., McArdle B.H. (2006) - *Multivariate dispersion as a measure of β diversity.* Ecol. Lett. 9, 683-693.

[2] Balata D., Piazzi L., Benedetti-Cecchi L. (2007) - *Sediment disturbance and loss of beta diversity on subtidal rocky reefs*. Ecol. 88, 2455-2461.

[3] Ballesteros E. (2006) - *Mediterranean Coralligenous assemblages: a synthesis of present knowledge*. Oceanogr. Mar. Biol. Annu. Rev. 44, 123-195.

[4] Bianchi C.N. (2001) - *Bioconstruction in marine ecosystems and Italian marine biology*. Biol. Mar. Medit. 8 (1), 112-130.

[5] 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, 1-4.

[6] 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, 298-312.

[7] Di Camillo C.G., Ponti M., Storari A., Scarpa C., Roveta C., Pulido Mantas T., Coppari M., Cerrano C. (2023) - *Review of the indexes to assess the ecological quality of coralligenous reefs: towards a unified approach*. Front. Mar. Sci. 10, 1252969.

[8] Gennaro P., Piazzi L., Cecchi E., Montefalcone M., Morri C., Bianchi C.N. (2020) - *Monitoring and assessment of the ecological status of coralligenous habitat. The coralligenous cliff*. ISPRA, Manuali e Linee Guida n.191bis/2020.

[9] Gatti G., Bianchi C.N., Morri C., Montefalcone M., Sartoretto S. (2015) - *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.

[10] 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, 207–233.

[11] 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, 229-238.
[12] Morri C., Bianchi C. N., Cocito S., Peirano A., De Biasi A.M., Aliani S.,…, Dando P. (1999) - *Biodiversity of marine sessile epifauna at an Aegean island subject to hydrothermal activity: Milos, Eastern Mediterranean Sea*. Mar. Biol. 135, 729–739.
[13] Piazzi L., Balata D., Cecchi E., Cinelli F., Sartoni G. (2010) - *Species composition and patterns of diversity of macroalgal coralligenous assemblages of northwestern Mediterranean Sea*. J. Nat. Hist. 44, 1–22.
[14] Piazzi L., Balata D., Cecchi E., Gennaro P., Serena F. (2014) - *Effectiveness of different investigation procedures in detecting anthropogenic impacts on coralligenous assemblages*. Sci. Mar. 78, 319–328.
[15] Piazzi L., Gennaro P., Montefalcone M., Bianchi C.N., Cecchi E., Morri C., Serena F. (2019) - *STAR: an integrated and standardized procedure to evaluate the ecological status of coralligenous reefs*. Aquat. Conserv. Mar. Freshw. Ecosys. 29, 189-201.
[16] Piazzi L., Gennaro P., Cecchi E., Bianchi C.N., Cinti F., Gatti G., Guala I., Morri C., Sartoretto F., Serena F., Montefalcone M. (2021) - *Ecological Status of Coralligenous Assemblages: ten years of application of the ESCA index from local to wide scale validation*. Ecol. Ind. 121, 107077.
[17] Piazzi L., Ferrigno F., Guala I., Cinti M.F., Conforti A., De Falco G., De Luca M., Grech D., La Manna G., Pascucci V., Pansini A., Pinna F., Pireddu L., Puccini A., Russo G.F., Sandulli R., Santonastaso A., Simeone S., Stelletti M., Stipcich P., Ceccherelli G. (2022) - *Inconsistency in community structure and ecological quality between platform and cliff coralligenous assemblages*. Ecol. Ind. 136, 108657
[18] Schneider, C. A., Rasband, W. S., & Eliceiri, K. W. (2012) - *NIH Image to ImageJ: 25 years of image analysis*. Nat. Methods, 9(7), 671–675.
[19] SPA/RAC-UN ENVIRONMENT/MAP (2021) - *Interpretation manual of the reference list of marine habitat types in the Mediterranean of the Barcelona Convention*. UNEP/MAP-SPA/RAC publ., Tunis, 1-426.
[20] UNEP/MAP-RAC/SPA (2017) - *Action Plan for the conservation of the Coralligenous and Other Calcareous Bio-concretions in the Mediterranean Sea.* Athens, Greece: UNEP/MAP http://www.rac-spa.org/sites/default/files/action_plans/pa_coral_en.pdf