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An integrated method to evaluate and monitor the conservation state of coralligenous habitats: The INDEX-COR approach

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1. Introduction

The endemic biogenic habitat known as “coralligenous” represents an array of species diversity in the Mediterranean Sea (Boudouresque, 2004). Despite the lack of knowledge of the diversity of certain taxonomic groups, the first preliminary global estimation gave a total number of 1666 species (Ballesteros, 2006). Such extraordinary biodiversity is mainly due to the considerable structural complexity of the coralligenous bioconstruction, the most important in the Mediterranean Sea (Bianchi, 2002), and the high environmental heterogeneity at small scales, which allows for the coexistence of different habitats (Kipson et al., 2011). The presence of a canopy of large sessile invertebrates (e.g., gorgonians and erect sponges) further increases this complexity. Coralligenous habitats harbour several species of interest for artisanal fishing, such as crustaceans, fishes and the emblematic red coral (Corallium rubrum). Finally, they constitute a remarkable and typical Mediterranean underwater seascape, highly attractive for recreational activities (e.g., scuba-diving), but also greatly affected by anthropogenic pressures locally (Ballesteros, 2006). Human activities may cause physical impacts and inputs of organic matter, sediment and pollutants. Physical impacts (anchoring, fishing and diving) damage both the large sessile invertebrates of the canopy and the associated fragile calcareous organisms, such as erect bryozoans (Garrabou et al., 1998; Linares et al., 2010). Organic matter inputs may lead to an increase of bioeroders such as clionaid sponges (Ballesteros, 2006), while sediment deposition can modify the composition of assemblages and associated biodiversity (Balata et al., 2005, 2007). Finally, the presence of pollutants in the water column has been shown to cause a decrease in biodiversity (Hong, 1983; Ballesteros, 2006). Among the environmental factors affecting coralligenous habitats, extremely high temperature events have became more frequent during the last decades (Garrabou et al., 2009), and have led to mass mortalities of long-living and structuring species (Cerrano et al., 2000; Pérez et al., 2000; Garrabou et al., 2009; Lejeusne et al., 2010). The acidification of seawater caused by the increased concentration of atmospheric CO2 has been shown to reduce the growth and calcification rates of calcareous algae involved in the bioconstruction (Martin and Gattuso, 2009; Lacoue-Labarthe et al., 2016), and can finally lead to the total disappearance of coralligenous reefs (Linares et al., 2015).

Paradoxically, despite their ecological and economical importance, European legislation never refers directly to coralligenous habitats. Annex I of the Habitat Directive (HD, 92/43/EEC) takes into account a generic “Reefs” category in the list of habitats of community interest. Only recently, coralligenous reefs have been included by the European Union in a Red List of marine habitats (Gubbay et al., 2016). The Water Framework Directive (WFD, 2000/60/EC) mentions the assessment of the composition and abundance of benthic flora and fauna only as a means to evaluate the quality of water bodies. A list of Biological Quality Elements (BQE) is defined by the WFD (phytoplankton, benthos, etc.), but only the best known benthic habitats have been considered to date: soft substrates (Borja et al., 2000; Simboura and Zenetos, 2002; Rosenberg et al., 2004; Muxika et al., 2007), upper infralittoral rocky reefs (Orfanidis et al., 2001; Ballesteros et al., 2007) and Posidonia oceanica seagrass meadows (Romero et al., 2007; Gobert et al., 2009; Lopez y Royo et al., 2009). Finally, the Marine Strategy Framework Directive (MSFD, 2008/56/EC) introduces the concept of “seafloor integrity” as an indicator of the Ecological Status (ES) of marine environments, and studies addressing all benthic habitats, with especial attention given to biogenic substrates, are strongly encouraged. This has allowed pinpointing gaps in knowledge on the geographical and bathymetrical distribution, taxonomy, functioning and dynamics of coralligenous habitats (UNEP-MAP-RAC/SPA, 2008), thus underlining the difficulties in developing methods and indices to measure their ES.

To assess ES of a habitat, Borja and Dauer (2008) distinguished three steps: (i) the definition of the reference conditions or of the environmental targets to define good status, (ii) the selection of the metrics and the definition of an index formula including these metrics, and (iii) the classification of the ecological status of the habitat through the application of the index. Concerning coralligenous habitats, the paucity of knowledge (Gubbay et al., 2016), coupled with their high heterogeneity both at small (e.g. 1–100 m) and large (0.1–100 km) scales and with the diffused problem of shifting baselines (Hobday, 2011; Al-Abdulrazzak et al., 2012; Gatti et al., 2015b), hampers defining general reference conditions and setting targets. In this context, a possible solution is to provide a large-scale current baseline as a reference for future evaluations of habitat state (Sala et al., 2012) for infralittoral rocky reefs.

In recent years, different methods and indices focused on coralligenous habitats have been proposed (Bavestrello et al., 2016). The Ecological Status of Coralligenous Assemblages index (ESCA index) (Cecchi and Piazzi, 2010; Cecchi et al., 2014) and the Coralligenous Assemblages Index (CAI) (Deter et al., 2012) both adopt the state of coralligenous communities as an ES indicator of coastal waters according to the WFD. They are based on data collected by photographic sampling and subsequent image analysis using free software (CpCe-Coralligenous Assemblages Version, Image J). The Rapid Visual Assessment (RVA method) and the associated COARSE index (Gatti et al., 2012, 2015a) aim at assessing the quality of coralligenous reefs as an indicator of seafloor integrity according to the MSFD; this method is based on a seascape approach through direct SCUBA diving surveys. Ruitton et al. (2014) developed an ecosystem approach, based on the identification of the major components at different trophic levels, whereas the OCI index (Paoli et al., 2016) combines structural and functional measures to evaluate the overall ecological complexity of coralligenous ecosystems.

In this paper, a non-destructive approach for the evaluation of the ecological status of coralligenous habitats is proposed, with special consideration given to the needs of stakeholders (e.g., MPAs, Marine Protected Areas). The approach is based on the integration of three metrics: (i) the sensitivity of species to fine sedimentation and organic matter input; (ii) the taxonomic richness; and (iii) the structural complexity of the assemblages. The first objective of this paper is to describe and illustrate the method. The second is to propose a new index to assess the ecological status of coralligenous habitats, the INDEX-COR. Finally, the third objective is to test its efficiency according to different levels of anthropogenic pressure affecting the marine environment.

2. Materials and methods

2.1. Study area

The study area is located along the French continental Mediterranean coast. The western zone, from the Gulf of Fos to Marseilles, is characterized by high turbidity and considerable sediment inputs due to the estuary of the Rhône River: thus coralligenous reefs can be found starting from relatively shallow depths (12–15 m). On the contrary, the eastern zone, from Toulon to Saint-Raphaël, is generally characterized by clear waters which allow coralligenous habitats to develop down to 100–110 m depth.

From the geological viewpoint, the study area is mainly characterized by rocky coasts composed of limestone in the Marseille area, conglomerates at La Ciotat, and phyllites from Toulon to Saint-Raphaël. The coastal waters (between the surface and the continental shelf) are dominated by the northern current (Millot and Taupier-Letage, 2005), flowing westwards; however, coastal circulation is also constrained by two dominant winds, the north-western (upwelling favourable) and the south-eastern (downwelling favourable) (Pairaud et al., 2011). Locally (e.g., around Marseille), upwelling can lower surface water temperature by > 5 °C (Millot, 1990). The area is characterized by the presence of two densely populated cities, Marseille (1.6 million inhabitants) and Toulon (560,000 inhabitants). Major sources of human pressure along the coast are the sewage outfalls associated with urban zones. In all, six large waste water treatment plants discharge their effluents in the study area. Outfalls are on the surface, such as at Calanque of Cortiou (Marseilles), Cap Sicié (Toulon W), Figuerolle (La Ciotat), while others are located between 35 m and 45 m depth: Sainte Marguerite (Toulon east), Cavalaire and Bonne-Terrasse (Saint-Tropez south). These sewage outfalls directly affect benthic communities of both soft and hard substrates. Human activities, such as SCUBA diving and yachting, may also be a source of disturbance, especially during summer. Other sources of impacts are professional and recreational fisheries, industry and the anchoring of tankers (mainly restricted to the Gulf of Fos).

Besides these pressures, marine protected areas are present in the study area (e.g., the Côte Bleue Marine Park, the National Park of Calanques and the National Park of Port-Cros). Human activities in these areas are forbidden (only in marine reserves) and/or regulated.

2.2. Field work

In all, 53 stations undergoing different degrees of human pressure were sampled from December to March (2012–2013 and 2013–2014), in order to reduce seasonal variability (Fig. 1). In each station, two transects (15 m long × 1 m large) indicated by graduated rubber bands were randomly placed at the same depth, orientation and type of dominant facies (e.g., gorgonians and macroalgae). Data were collected by two SCUBA divers: a photographer and an observer. The first diver shot at least 30 photographs (hereafter called "photoquadrats"), 15 along each transect, using a 60 cm × 40 cm frame. The number and size of photoquadrats were selected according to the recommendations made by previous studies (Cecchi and Piazzi, 2010; Kipson et al., 2011;

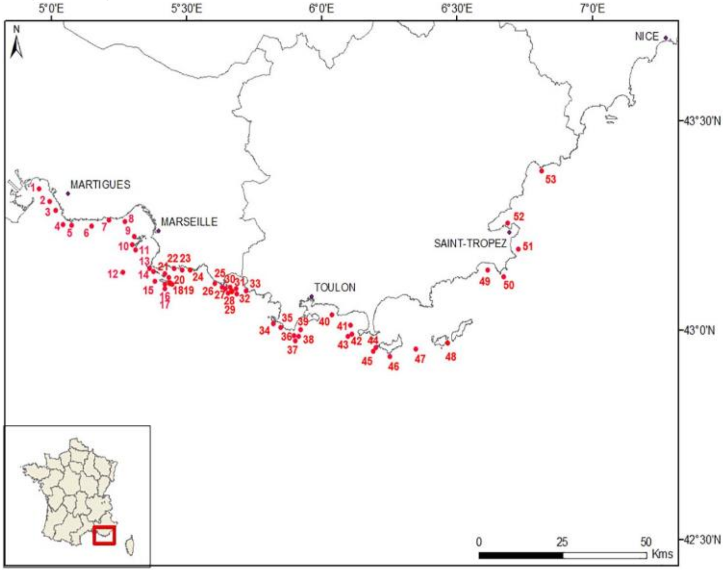


Fig. 1. Study area with the sampling stations represented by a numeric code as in Table 3.

Deter et al., 2012; Cecchi et al., 2014). A digital camera (Sony Alpha Nex-5 with a 16–3.5 mm zoom-lens) equipped with housing and dome was fixed over the quadrat frame using a metal structure; 4 SOLA lamps were installed at the top of each vertical side of the structure. The second diver focused on taking notes along each transect on: (i) general parameters, i.e. depth, orientation, slope (vertical, inclined and sub-horizontal), presence of marine litter, dominant facies; (ii) conspicuous benthic sessile and mobile (echinoderms, crustacean decapods and nudibranchs) species recognizable visually without sampling; (iii) the percent cover of large erect species (gorgonians and sponges) (cf. Section 2.3.3). Percent cover was estimated considering five classes: 0 (absent); 1 (isolated colonies); 2 (10% < cover ≤ 25%); 3 (25% < cover ≤ 50%); 4 (50% < cover ≤ 75%); 5 (cover > 75%). The percentage of necrotic gorgonian colonies was also considered when > 10% of their surface was affected. According to the number of necrotic colonies, the values of cover classes were adjusted. The observation of > 50% of affected colonies along a transect thus implied a downgrade (e.g., from 5 to 4).

2.3. Data management

2.3.1. Characterization of stations and assessment of pressure level

A comprehensive definition of each sampling station, based on geomorphological, abiotic and bionomic features, is summarized in Table 1. Facies and associations characterizing the stations were identified according to the conspicuous species dominating the assemblages.

In the absence of specific criteria for quantifying the impact of human pressures affecting coralligenous habitats, a Level of Pressure (LP) was estimated for each station according to an ‘expert judgment’ based on distance from potential sources and field observations. Four main pressures were taken into account: (i) organic matter and sediment inputs, (ii) diving/anchoring, (iii) fishing, and (iv) litter (Ballesteros, 2006). The intensity of the pressures was assessed considering 4 levels: 0 (no pressure), 1 (low), 2 (moderate) and 3 (high). Then, the LP was calculated for each station as the sum of the values obtained for the four pressures. The LP theoretically varies from 0(‘pristine’) to 12 (highly impacted).

2.3.2. Image analysis

Photoquadrats were analyzed with the free software photoQuad (Trygonis and Sini, 2012), using the uniform point count technique. The number of points necessary to obtain a good estimation of taxonomic richness was tested beforehand. Rarefaction curves based on the asymptotic model of Michaelis-Menten (Keating and Quinn, 1998) were used to assess the variation of taxonomic richness according to the number of points. Finally, 100 uniform points were chosen for the analyses of the photoquadrats. A library of species (or higher taxa) (Appendix A) and abiotic elements (e.g., sediment, bare rock, and black shadow) was created and uploaded in the software, then each point was directly labelled with the name of the element beneath it. Therefore the percent relative abundance of each taxon/abiotic element was obtained for each image.

2.3.3. Selection and definition of metrics

To assess the conservation state of coralligenous assemblages, it is necessary to consider the combined effects of human activities and environmental changes, as already suggested for Paramuricea clavata populations (Linares et al., 2010).

In this study, three metrics were selected to define a synthetic index:

(i) Taxa Sensitivity (TS), considering only sensitivity to organic matter and sediment input;
(ii) Observable Taxonomic Richness (OTR), reflecting the biodiversity of coralligenous assemblages;

(iii) Structural Complexity (SC), considering the stratified structure of coralligenous habitats.

TS is inspired by the existing indexes for characterizing soft substrate benthic communities, particularly the AMBI and related indexes (Borja et al., 2000; Pinedo et al., 2015). The AMBI index considers the succession of 5 groups of species showing different levels of sensitivity to the input of organic matter (Pearson and Rosenberg, 1978; Glémarec and Hily, 1981). Compared to soft substrate, knowledge on coralligenous assemblages is too scarce to allow identifying a similar succession (Montefalcone et al., 2017). To overcome this problem, we selected a subset of 10 sampling stations where the pressure due to organic matter and sediment input was known,

Table 1
Characterization of geomorphology, mesology and level of pressure for each station (identified by a numeric code, as in Fig. 1). Morphotype: O -outcrop, LIP -low inclination platform, SC -steep cliff . Level of pressure: O/S -organic matter/sedimentinputs, D/A -diving/anchoring, F -fishing activities, ML -marine litter, LP -level of pressure; 0: no impact 1: low impact, 2: moderate impact, 3: high impact.

Code Station Geomorphology/mesology Level of

pressure Code Station Geomorphology/mesology Level

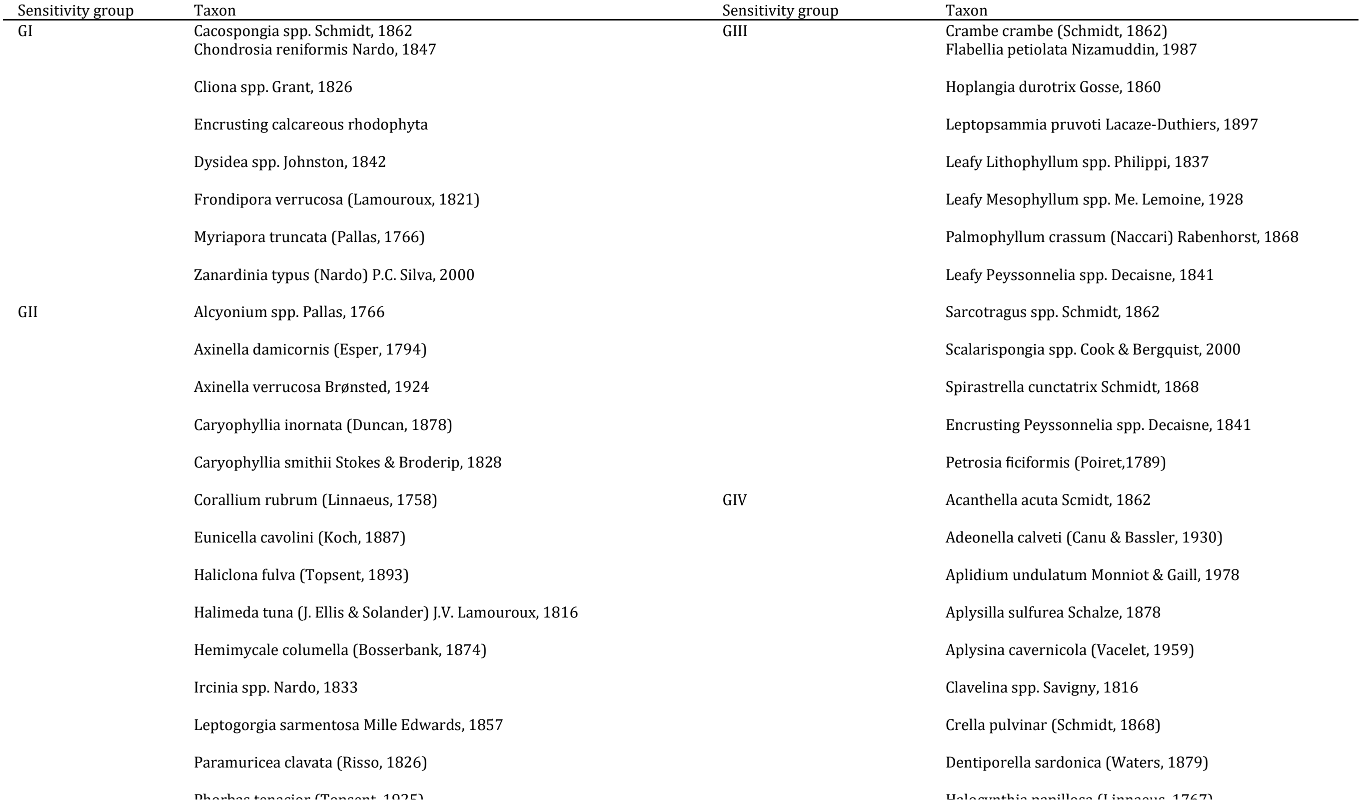
of pressure Morphotype Depth (m) Exposure O/S D/A F

ML LP Morphotype depth (m) exposure O/S D/A F ML

LP

1 Fd Golfe Fos O 15–20 225° 3 3 3 3 12 28 PetitMourre SC 30–35 315° 13 206 2 Auguette O 15–20 270° 3 3 3 3 12 29 GrdMourre SC 34–36 315° 13 105 3 Bonnieu O 15–20 270° 2 1 32830 Rosier O 33 270° 0 3 227 4 Arnette O 15–20 180° 2 1 32 831 PainSucre SC 37 135° 1 3 22 8 5 San Christ O 34–36 180° 3 1 12 732 Levant SC 42–43 90° 03 126 6 Le Bois O 33–35 270° 2 1 1 0 4

33 PteDéfend LIP 34–37 45° 21 238 7 Méjean SC 31–33 180° 2 2 2 1 7 34 P.christian LIP 39–42 0° 13105 8 Large Niolon O 35–39 180° 2 1 33 935 Mourret SC 34–36 45° 10 214 9 Tiboulen SC 36–40 45° 1 3 10536 SêcheW O 34–36 270° 22 239 10 Pte Luque LIP 33–36 270° 2 1 23 837 SêcheS O 35–39 180° 12 205 11 Cap Caveau SC 34–36 90° 1 3 11 638 SêcheE SC 34–36 90° 02 215 12 Planier SC 33–36 270° 0 2 0 1 3 39 Deuxfrères SC 29–33 45° 13 206 13 Fromage LIP 31–33 90° 2 3 12 8 40 Oursinière O 34–36 225° 21 216 14 Matelot O 43–45 90° 3 1 331041 Armoire SC 42 45° 2 1 216 15 Moyade SC 35 90° 0 3 00 3 42 Fourmigue LIP 33 180° 2 3 22 9 16 Imp. Milieu SC 33–35 270° 0 3 0 0 3 43 S.Fourmigue SC 34–36 45° 21 227 17 Imp. Large SC 41–45 180° 0 3 0 0 3 44 W Porquerolle LIP 39–42 45° 12 115 18 Caramassaigne SC 33–38 270° 0 2 0 0 2 45 SW Porquerolle LIP 39–42 270° 22 105 19 Grd Congloue SC 39 45° 0 3 0 1 4 46 Cap d'arme SC 49–51 45° 01 113 20 Sud Plane SC 36–40 135° 2 2 02647 Sarranier O 38 180° 0 2 114 21 Nord Plane LIP 34–36 90° 3 1 02 6 48 PteVaisseau O 37–39 90° 22 004 22 Sormiou LIP 35–38 225° 2 1 32 8 49 Maconnais O 39–41 180° 21 104 23 Morgiou SC 35 90° 2 2 10 5 50 Quairol SC 34–36 90° 12 115 24 Devenson SC 36–39 0° 0 2 02 4 51 RocheRousso SC 48–51 90° 01 113 25 Figuerolle O 28–30 225° 2 2 2 2 8 52 BasseRabiou SC 36–39 90° 22 116 26 N Bec de l'Aigle SC 34–36 270° 1 1 2 3 7 53 RocheMérou SC 38–42 90° 22 206 27 S Bec de l'Aigle SC 36–40 270° 12 216



Sensitivity group	Taxon	Sensitivity group	Taxon
GI	Cacospongia spp. Schmidt, 1862	GIII	Crambe crambe (Schmidt, 1862)
	Chondrosia reniformis Nardo, 1847		Flabellia petiolata Nizamuddin, 1987
	Cliona spp. Grant, 1826		Hoplangia durotrix Gosse, 1860
	Encrusting calcareous rhodophyta		Leptopsammia pruvoti Lacaze-Duthiers, 1897
	Dysidea spp. Johnston, 1842		Leafy Lithophyllum spp. Philippi, 1837
	Frondipora verrucosa (Lamouroux, 1821)		Leafy Mesophyllum spp. Me. Lemoine, 1928
	Myriapora truncata (Pallas, 1766)		Palmophyllum crassum (Naccari) Rabenhorst, 1868
	Zanardinia typus (Nardo) P.C. Silva, 2000		Leafy Peyssonnelia spp. Decaisne, 1841
GII	Alcyonium spp. Pallas, 1766		Sarcotragus spp. Schmidt, 1862
	Axinella damicornis (Esper, 1794)		Scalarispongia spp. Cook & Bergquist, 2000
	Axinella verrucosa Brønsted, 1924		Spirastrella cunctatrix Schmidt, 1868
	Caryophyllia inornata (Duncan, 1878)		Encrusting Peyssonnelia spp. Decaisne, 1841
	Caryophyllia smithii Stokes & Broderip, 1828		Petrosia ficiformis (Poiret,1789)
	Corallium rubrum (Linnaeus, 1758)	GIV	Acanthella acuta Scmidt, 1862
	Eunicella cavolini (Koch, 1887)		Adeonella calveti (Canu & Bassler, 1930)
	Haliclona fulva (Topsent, 1893)		Aplidium undulatum Monniot & Gaill, 1978
	Halimeda tuna (J. Ellis & Solander) J.V. Lamouroux, 1816		Aplysilla sulfurea Schalze, 1878
	Hemimycale columella (Bosserbank, 1874)		Aplysina cavernicola (Vacelet, 1959)
	Ircinia spp. Nardo, 1833		Clavelina spp. Savigny, 1816
	Leptogorgia sarmentosa Mille Edwards, 1857		Crella pulvinar (Schmidt, 1868)
	Paramuricea clavata (Risso, 1826)		Dentiporella sardonica (Waters, 1879)
	Phorbas tenacior (Topsent, 1925)		Halocynthia papillosa (Linnaeus, 1767)

Table 2
List of the species and higher taxa ordered alphabetically within their sensitivity group. Group I (GI): taxa indifferent to organic matter and sediment input; Group II (GII): opportunistic taxa; Group III (GIII): tolerant taxa; Group IV (GIV): sensitive taxa.

measured by sediment traps, or assessed by models (Sartoretto, 1996; Arfi et al., 2000). Then, a Delta-Gamma model (Stefansson, 1996) was applied to the relative abundance of each taxon (obtained from image analyses) according to the pressure of the sampling stations. This statistical approach allowed distinguishing 56 taxa distributed in four groups of sensitivity (Table 2)(Pinedo et al., 2015):

- Group I (GI): taxa indifferent to organic matter and sediment input;
- Group II (GII): opportunistic taxa;
- Group III (GIII): tolerant taxa;
- Group IV (GIV): sensitive taxa.

The computation of TS is based on a formula inspired from the AMBI index (Borja et al., 2000):

TS=(0.25× % Group I+0.5× % Group II+1× % Group III
+ 2 × % Group IV)where % Group is obtained, for each station, by adding the percent relative cover of the species belonging to each group.

The identification of certain benthic species from images is often difficult or even impossible, especially for those taxonomic groups for which microscopic morphological studies are required. Consequently, the second metrics – OTR – refers to the total number of those conspicuous taxa that were recognizable visually on photoquadrats and in situ. Sessile and mobile macrobenthic organisms (echinoderms, nudibranchs, crustaceans) having high patrimonial value or a particular ecological role were also considered.

Finally, the third metrics – SC – is based on the assumption that the impact of human activities may reduce the structural complexity of coralligenous

Sensitivity group	Taxon	Sensi
GI	Cacospongia spp. Schmidt, 1862	GIII
	Chondrosia reniformis Nardo, 1847	
	Cliona spp. Grant, 1826	
	Encrusting calcareous rhodophyta	
	Dysidea spp. Johnston, 1842	
	Frondipora verrucosa (Lamouroux, 1821)	

habitats, with the progressive reduction of the long-living erect (e.g., gorgonians, sponges) and fragile (e.g., bryozoans, foliaceous Corallinaceae) species (Zabala, 1999; Gatti et al., 2012). This assumption was also tested on our dataset (see Section 3.1). Following the approach proposed by Gatti et al. (2012), three layers were considered to characterize the structure of coralligenous assemblages: (i) a basal layer, composed of encrusting organisms and those with limited vertical growth, (< 5 cm); (ii) an intermediate layer, characterized by sessile organisms with moderate vertical growth (5 cm to 15 cm); and (iii) an upper layer, constituted by sessile macrobenthic species with considerable vertical growth (> 15 cm). The scores for basal and intermediate layers were defined as the total percent abundance of the taxa belonging to them, estimated from the photoquadrats. The score of the upper layer was defined as the percent cover of gorgonians and large sponges (e.g., Axinella polypoides) observed in situ, along the transects (see Section 2.2).

To summarize the layer scores in a structural complexity (SC) value, a Principal Component Analysis (PCA) was performed with the species abundances of the layers of all the stations; axes 1 and 2 explained 47.4% and 33.6% of the total variance, respectively. The formulas for calculating the coordinates of each layer along the two axes were defined by simplifying the results of the PCA (see appendix B for details) (Table 3). Then, the coordinates of each station (C1station and C2station) were calculated as the sum of the coordinates of the three layers along the axes:

$$C(1,2)station=C(1,2)basal+C(1,2)intermediate+C(1,2)upper$$

The coordinates of a hypothetical reference station (RS) with scores equal to zero for each layer were calculated according to the formulas shown in Table 3 (C1RS = 2.108 and C2RS = 1.980). The SC value was then defined as the distance of each station from the RS, on the plane formed by the two axes:

Table 3
Formulas for the calculation of layers' coordinates along the Axes 1 and 2, for each station. BL: basal layer score (% of points measured on photoquadrats), IL: intermediate layer score (% of points measured on photoquadrats), UL: upper layer score (% cover measured in situ along the transects). For further technical details about the formulas see Appendix B.

$$22SC=O[(2.108-C1station)+(1.980-C2station))]$$

2.3.4. Definition of a synthetic index of conservation state

After verifying the non-redundancy of the three abovementioned metrics (TS, OTR and SC) (Pearson's r < 0.48 with a multiple correlation matrix), the INDEX-COR (IC) formula was defined using a linear model based on these metrics. The results (multiple $r^2 = 0.56$, $p < 0.0001$) allowed proposing the following formula:

$$IC=0.62\times TS+0.6\times TR+1.7\times SC$$

Finally, the correlation between IC and LP was tested using Kendall's tau coefficient, which is more robust for non-normal data, outliers and tie observations than Pearson's r and Spearman's rho coefficients.

All statistical analyses were performed using R software (R Development Core Team, 2011).

3. Results

3.1. Characterization of assemblages and pressure levels

The coralligenous communities sampled in this study were mainly characterized by (i) facies with gorgonians (Paramuricea clavata and Eunicella cavolini); (ii) facies with sciaphilic to hemisciaphilic green algae, dominated by Codium spp., Flabellia petiolata and Halimeda tuna; (iii) facies with sciaphilic algae dominated by Phaeophyceae and Rhodophyceae; and (iv) “facies of impoverishment”, showing highly degraded assemblages. The facies with gorgonians were mainly found on steep cliffs, which represented the most diffused geomorphological type among the sampling stations. The other facies were mainly associated with gently inclined platforms and coralligenous outcrops. The sampling stations were distributed between 15 m and 51 m depth, because of the extreme variability of the environmental conditions characterizing the study area (see Section 2.1).

In all, 23 stations were characterized as slightly impacted (LP = 2 to 5). They were mainly located in the National Park of Calanques (i.e. stations 18, 19 and 23) and within or near the National Park of Port-Cros (e.g. stations 46, 48 and 50). 24 stations were characterized by a moderate level of pressure (LP = 6 to 8), whereas the highest values of LP (9 to 12) mainly corresponded to stations located in the Gulf of Fos (e.g., stations 1 and 2) or directly exposed to sewage outfalls (e.g., stations 14 and 36) (Table 4).

3.2. Metrics and INDEX-COR assessment, correlation with LP

TS varied from 7.7 (station 1) to 76.1 (station 9). The lowest values (TS < 30) corresponded to stations particularly exposed to sediment inputs and to the Cortiou sewage outfall. On the contrary, the highest values (TS > 60) were linked to the stations located far from the coastline and to high steep cliffs(Table 4).

In total, 152 different taxa were identified for the full dataset. At each site, OTR varied from 17 (station 2) to 76 taxa (stations 12 and 46) (Table 4). In a few cases, high numbers of taxa were observed in highly impacted stations (29 taxa in station 14 and 31 in station 1, with an LP = 10 and 12, respectively).

Finally, the values of SC ranged between 0.7 (station 2) to 5.6 (station 12) (Table 4). The lowest values (SC <

2) corresponded to highly impacted stations (sediment input or all pressures combined). On the contrary, the highest values (SC > 5) corresponded to slightly impacted sites or sites “protected” from sedimentation (high steep cliffs or reefs far from the coast). The results obtained for the three metrics are detailed in Table 4 (see appendix C for further details. The whole database is available here: https://www.dropbox.com/s/a7rj0ckcarkwbbh/INDEXCOR.accdb?dl=0).

The INDEX-COR (IC) varied from 26.4 (station 1) to 97.1 (station 12) (Table 4). The lowest IC values corresponded to the most impacted stations, the highest to the least impacted ones. Five classes of conservation state were proposed (maximum IC values: 100) to respond to stakeholders' needs:

IC < 20: bad status;
20 ≤ IC < 40: poor status;
40 ≤ IC < 60: moderate status;
60 ≤ IC < 80: good status;
IC ≥ 80: high status.

Based on this classification, the majority of the sampled stations (38 sites) obtained a good or high conservation state (Fig. 3).

The poorest conservation state (IC < 40) mainly corresponded to the stations located in or close to the Gulf of Fos (West of Marseilles), characterized by its proximity to the Rhone river (input of sediment) and by the dense concentration of human activities (industries, fishing, anchorage of large tankers). On the contrary, the healthiest coralligenous habitats (IC > 80) were observed in 11 stations located within the boundaries of marine protected areas or offshore, mainly characterized by high steep cliffs.

The significant negative correlation between SC and LP ($\tau = -0.504$, $p < 0.0001$) confirms the starting assumption that the structural complexity of coralligenous habitats decreases with the impact of the pressures on them. Also TS and OTR showed significantly correlated with LP (respectively $\tau = -0.513$ and -0.480, $p < 0.0001$). Nevertheless, the best correlation resulted between IC, which integrated the three aforementioned metrics, and LP ($\tau = -0.642$, $p < 0.0001$) (Fig. 2).

4. Discussion

4.1. Metrics and INDEX-COR assessment

The application of the INDEX-COR method proved effective in discriminating the conservation state of coralligenous habitats along the French Mediterranean coast. The accuracy of species identification can be an issue of concern, as for many groups (e.g., sponges, bryozoans, etc.) identification at species level often requires sampling and taxonomic studies in the laboratory. Nevertheless, there are plenty of examples where the monitoring of benthic assemblages has been based on photographic and video sampling (e.g., Edgerton, 1967; Garrabou et al., 2002; Mumby et al., 2014; Gatti et al., 2015b). Besides, in situ observations made at the same place and time as the photographs taken may partially offset the problem. Whatever the case, when direct identification at a specific level is not possible, the use of higher taxonomic levels (genus or family) is still appropriate, as pointed out in other studies (Bacci et al., 2009; Brind'Amour et al., 2014). However, taxonomic sufficiency should be applied with caution when using benthic species as ‘bioindicators’ (Maurer, 2000; De Biasi et al., 2003).

The use of species or higher taxa as bioindicators of organic matter input, as proposed for the TS metrics, also forms the computational basis of the AMBI and related WFD-compliance indexes (Borja et al., 2000; Pinedo et al., 2015). However, precise information about the sensitivity to sedimentation and organic matter inputs are almost nonexistent for species thriving in coralligenous assemblages (Montefalcone et al., 2017). Only scant information on the sensitivity of certain species of algae, sponges, bryozoans and ascidians is available (Muricy, 1991; Carballo et al., 1994; Naranjo et al., 1996; Harmelin and Capo, 2002; Balata et al., 2005; Cecchi et al., 2014). The Delta-Gamma model applied to the dataset, which allowed classifying species into four different groups of sensitivity to organic matter and sediment inputs, is based on a limited number of study sites and should be considered as a preliminary approach. Another concern is the quantification of sediment and organic matter inputs, since they may be very

Table 4
INDEX-COR (IC) values, metrics (TS = Taxa Sensitivity; OTR = Observed Taxonomic Richness; SC = structural complexity) scores, level of pressure (LP) and conservation status defined with 5 classes, for the 53 stations sampled along the French Mediterranean coast. Classes' boundaries: bad (IC < 20), poor (20 ≤ IC < 40); moderate (40 ≤ IC < 60); good (60 ≤ IC < 80); high (IC ≥ 80).

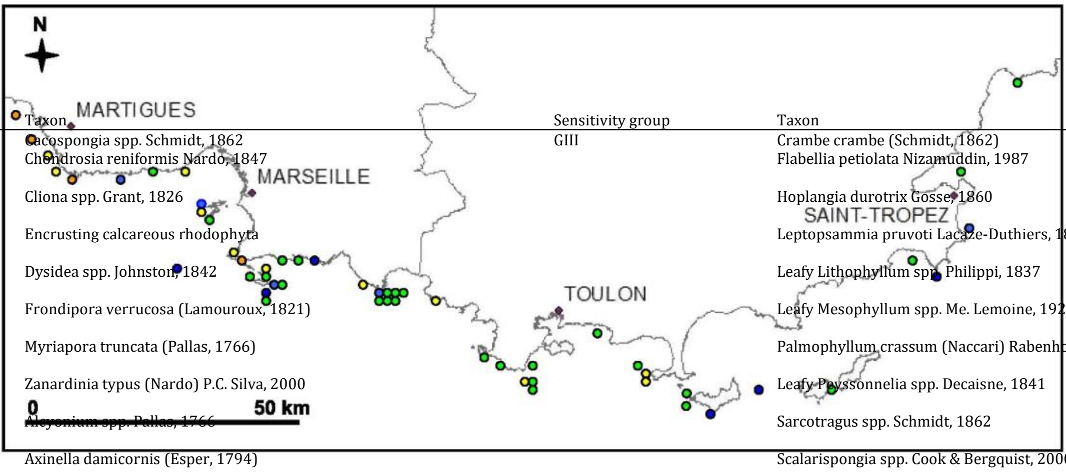


Fig. 3. Color-coded representation of the conservation state of coralligenous habitats along the coasts of Provence. Orange: poor status; yellow: moderate status; green: good status; blue: high status. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Sensitivity group	Taxon	Sensitivity group	Taxon
GI	Cacospongia spp. Schmidt, 1862	GIII	Crambe crambe (Schmidt, 1862)
	Chondrosia reniformis Nardo, 1847		Flabellia petiolata Nizamuddin, 1987
	Cliona spp. Grant, 1826		Hoplangia durotrix Gosse, 1860
	Encrusting calcareous rhodophyta		Leptopsammia pruvoti Lacaze-Duthiers, 1897
	Dysidea spp. Johnston, 1842		Leafy Lithophyllum spp. Philippi, 1837
	Frondipora verrucosa (Lamouroux, 1821)		Leafy Mesophyllum spp. Me. Lemoine, 1928
	Myriapora truncata (Pallas, 1766)		Palmophyllum crassum (Naccari) Rabenhorst, 1868
	Zanardinia typus (Nardo) P.C. Silva, 2000		Leafy Peyssonnelia spp. Decaisne, 1841
GII	Alcyonium spp. Pallas, 1766		Sarcotragus spp. Schmidt, 1862
	Axinella damicornis (Esper, 1794)		Scalarispongia spp. Cook & Bergquist, 2000
	Axinella verrucosa Brønsted, 1924		Spirastrella cunctatrix Schmidt, 1868
	Caryophyllia inornata (Duncan, 1878)		Encrusting Peyssonnelia spp. Decaisne, 1841
	Caryophyllia smithii Stokes & Broderip, 1828		Petrosia ficiformis (Poiret,1789)
	Corallium rubrum (Linnaeus, 1758)	GIV	Acanthella acuta Scmidt, 1862
	Eunicella cavolini (Koch, 1887)		Adeonella calveti (Canu & Bassler, 1930)
	Haliclona fulva (Topsent, 1893)		Aplidium undulatum Monniot & Gaill, 1978
	Halimeda tuna (J. Ellis & Solander) J.V. Lamouroux, 1816		Aplysilla sulfurea Schalze, 1878
	Hemimycale columella (Bosserbank, 1874)		Aplysina cavernicola (Vacelet, 1959)
	Ircinia spp. Nardo, 1833		Clavelina spp. Savigny, 1816
	Leptogorgia sarmentosa Mille Edwards, 1857		Crella pulvinar (Schmidt, 1868)
	Paramuricea clavata (Risso, 1826)		Dentiporella sardonica (Waters, 1879)

patchy. Expert judgment was used as the main criterion to assess these inputs as precise quantitative data were difficult to obtain in situ.

Coralligenous habitats represent a ‘hotspot’ of biodiversity in the Mediterranean. Spatial competition is strong and epibiosis is extremely frequent (Ballesteros, 2006). These features led Laubier (1966) to consider coralligenous habitats as an ecological crossroads rather than as a single ‘biocoenosis’. Consequently, it could be very difficult to perceive and measure species loss due to human activities (Hong, 1983) and to define adequate metrics to this purpose. The second metrics of INDEX-COR (OTR), considering visually recognizable species, gives an image of the richness of coralligenous assemblages. The level of identification of the organisms adopted for OTR is in accordance with the taxonomic sufficiency recommended for the study of macrobenthic assemblages (Bacci et al., 2009). In addition, the OTR values followed, with few exceptions, the impact due to human activities measured as LP (Level of Pressure). OTR was quite high in two highly impacted stations (1 and 14, LP = 12 and 10 respectively): these values are likely due to cryptic species present in cavities sheltered from sediment inputs and physical impacts.

Finally, the third metrics (SC) is based on the structural approach proposed for the COARSE index, aimed at evaluating the state of conservation of coralligenous habitats (Gatti et al., 2012, 2015a). This metrics combines the information obtained from both in situ observations (as in the RVA method) and image analysis. The SC value was obtained by combining the three layers recognizable in the coralligenous structure (basal, intermediate and upper layers) and it was shown to be correlated with the level of pressure on coralligenous habitats, as seen for the COARSE index (Gatti et al., 2015a). This correlation is particularly influenced by sensitivity to physical impacts (e.g., diving, fishing and anchoring) and the mass mortality events of sessile invertebrates composing the intermediate and upper layers, like bryozoans, ascidians and gorgonians (Garrabou et al., 1998; Linares et al., 2007; Di Franco et al., 2009; Luna-Pérez et al., 2010; Pairaud et al., 2014). At last, a negative influence of sedimentation can be observed on the basal and the upper layer of coralligenous assemblages due to the balance between algae and invertebrate cover (Irving and Connell, 2002; Balata et al., 2005).

The integration of different metrics in a unique index may be criticized because of the loss of information, which makes the interpretation of index values difficult (Moss,

Fig. 2. Correlation between INDEX-COR and the level of pressure (LP). τ: Kendall's coefficient.

Fig.3.Color-codedrepresentationoftheconservationstateofcoralligenoushabitatsalongthecoastsofProvence.Orange:poorstatus;yellow:moderatestatus;green:goodstatus;blue:highstatus.(Forinterpretationofthereferencestocolorinthisfigurelegend,thereaderisreferredtothewebversionofthis article.)

2007). By contrast, other authors support that only a synthetic index can detect departure from biological integrity caused by anthropogenic pressures (Karr, 1999). This is the case of INDEX-COR, which resulted to respond to the overall level of pressure on coralligenous assemblages better than the individual metrics. This result underlines the complementarity of TS, OTR and SC metrics despite the lower weight given to the SC metrics in the linear model used to define the IC.

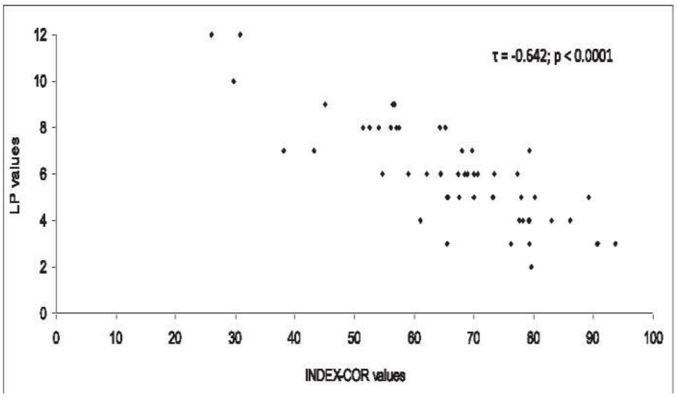
4.1.1. Reference conditions and robustness of INDEX-COR

Building a relevant index to assess the conservation state of a marine habitat requires: (i) defining reference conditions, and (ii) estimating the level of pressure affecting it. The definition of reference conditions mainly depends on the availability of 'pristine' areas, historical references, or models based on extrapolations of the biological attributes characterizing a certain zone in natural conditions (Borja et al., 2012). If none of the previous criteria is applicable, reference conditions can be determined by 'best professional judgment' (expert judgment), or statistically from available datasets (Romero et al., 2007; Gobert et al., 2009; Teixeira et al., 2010). Considering coralligenous habitats, it would be possible to obtain theoretical reference values of INDEX-COR by combining the highest values obtained for each metric and for each ecoregion. Unfortunately, as already underlined, a larger dataset would be necessary to better define the possible range of variation of each metric. It is necessary to take into account that the reference conditions of coralligenous habitats situated close to areas with a naturally high sediment and organic matter inputs (i.e. Gulf of Fos) are different from those situated offshore or far away from river mouths (e.g. Curiel et al., 2012; Falace et al., 2015). Furthermore, coralligenous assemblages are characterized by long-lived species with parsimonious population dynamics (e.g., low growth and mortality rates) (Ballesteros, 2006; Teixidó et al., 2011). Due to these features, assemblages can display both limited resilience in the case of impact from strong disturbances and apparent stability in the absence of disturbances, even when they are in fact immersed in declining trajectories (Hughes et al., 2013; Gatti et al., 2017). Therefore, the assessment of conservation state is a basic step for the management of coralligenous habitats. INDEX-COR provided the first assessment in a specific area as a 'current baseline' that can be used to compare future evaluations of state (Sala et al., 2012). Stakeholders should take care to ensure management in view not to drop below it. This solution implies the definition of an acceptable range of variation of the index independently of the variation of the level of pressure. The results obtained during the present study constitute the first dataset for the INDEX-COR. The acquisition of other annual datasets in the same sampling stations with no notable variations of human impact will allow estimating the robustness of the index. Thus, future perspectives include the enlargement of the dataset, tests on local variability and bias due to operators, in order to improve the index and to make it as robust as possible.

To link the results of an index of conservation to human pressures, it is necessary to quantify the level of the impact affecting the habitat. One or several pressures can be considered. On soft bottoms, the main source of pressure is the presence of organic matter in the sediment, which is directly measured in samples and can be easily compared between sites (Borja et al., 2000). In the case of hard substrates, and especially for coralligenous reefs, benthic assemblages are affected by different human pressures (Cánovas Molina et al., 2016). Unfortunately, their characterization in a complex three dimensional habitat is very difficult, because their impact can differ according to the scale considered. Furthermore, many species belonging to coralligenous communities are also affected by extreme high temperatures, which may cause extensive mortality events (Cerrano et al., 2000; Pérez et al., 2000; Cupido et al., 2008; Coma et al., 2009; Garrabou et al., 2009). Other species such as coralline algae, the main builders of the calcareous substrate, may also be impacted by water acidification (Martin and Gattuso, 2009; Noisette et al., 2013). In this context, Elliott et al. (2015) emphasized that marine management has to accommodate 'shifting baselines' caused by changes at planetary scale, such as warming and acidification. In our opinion and in the absence of quantitative data for each pressure, the expert judgment seems to be the only solution possible at present.

4.2. Practical use

The INDEX-COR approach proposes a methodology and an index to assess the conservation state of coralligenous reefs. Its application requires SCUBA diving experience and knowledge of marine organisms. More or less 2 days are required for each station to acquire and analyze the data. Moreover, the level of efficacy of an index is directly linked to knowledge of the habitat considered (e.g., distribution, natural dynamics, functionality, response to the different pressures, etc.). Unfortunately, little knowledge is available on coralligenous habitats and their associated communities (Ballesteros, 2006). Basic studies to fill these gaps in knowledge are strongly recommended.



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