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A preliminary study toward an index based on coralligenous assemblages for the ecological status assessment of Mediterranean French coastal waters

Julie Deter[a,b,*], Pierre Descamp[c], Laurent Ballesta[c], Pierre Boissery[d], Florian Holon[c]

[a] L'OEil d'Andromède, 7 place Cassan, 34280 Carnon, France
[b] Institut des Sciences de l'Evolution (ISEM) – UMR 5554, Université de Montpellier 2, 34095 Montpellier cedex 5, France
[c] Andromède Océanologie, 7 place Cassan, 34280 Carnon, France
[d] Agence de l'Eau Rhône-Méditerranée-Corse, Délégation de Marseille, Immeuble le Noailles, 62 La Canebière, 13001 Marseille, France

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ABSTRACT

Despite the great contribution of coralligenous communities to Mediterranean biodiversity (second key-ecosystem after *Posidonia oceanica* meadows), they were never considered in the establishment of multimetric indices for ecological status assessment of marine environment. In this paper, we describe a method to evaluate the ecological status of coralligenous assemblages along Mediterranean French coasts. Several metrics were selected from literature for coralligenous assemblage description and include functional and structural information: percent cover of visible non-vagile species (using photographic quadrats along a transect) and gorgonian demography. Thirty eight field stations were sampled for these metrics in PACA (Provence-Alpes-Côte-d'Azur) region in June 2010 and considered for their morphology (bank, rim), geographical orientation and principal current direction (North, East, West, South) and depth (from −30 to −84 m). Metrics found to be linked to human pressures using ANCOVA and multiple correlation matrix were selected to be included in the index. The index (Coralligenous Assemblage Index, CAI) that we proposed was based on three selected metrics (Bryozoa percent cover, sludge percent cover, builder species percent cover) and considers depth; it was positively and significantly linked to anthropization (related to water quality). The 38 stations studied with theoretically good to bad environmental conditions were classified in levels of status in accordance with our field work knowledge. CAI variation was validated with three stations sampled with 30 other photos. This index could be an effective tool for the assessment of the ecological quality of coralligenous communities. It could be applied in the context of the Marine Strategy Framework Directive as well as in conservation and sustainable management of the marine environment.

1. Introduction

Coralligenous concretions are primarily produced by the accumulation of encrusting algae growing at low light levels and secondarily by bio-constructor animals as polychaetes, bryozoans and gorgonians; they represent the unique calcareous formations of biogenic origin in Mediterranean Sea (Ballesteros, 2006). The resulting complex structure allows the development of a patchwork of communities dominated by living algae, suspension feeders, borers or soft-bottom fauna (in the sediment within cavities). Two main morphologies can be distinguished (Ballesteros, 2006) for coralligenous frameworks: banks (built over more or less horizontal substrata) and rims (in the outer part of marine caves and on vertical cliffs). In terms of richness, biomass and production, coralligenous assemblage value is high and comparable to tropical reef assemblages (Bianchi, 2001). The other side of the coin is the important attract exerted over divers and fishermen and their damaging consequences (Ballesteros, 2006). Moreover, submarine outfalls (with their urban and industrial discharges) are widespread along the coast and rocky coasts are among the most vulnerable habitats to pollution, increased sediment loads and deposition (Airoldi, 2003; Ballesteros, 2006). Increasing anthropogenic pressures and their consequences on water quality decline have led the European Union to engage a new strategy to conserve and recover the ecological quality of the marine environment. With the Water Framework Directive (WFD, Directive 2008/56/EC), European commission aims to achieve (or maintain at least) a "good status" in all the European waters by 2015. WFD defines the ecological status as the quality of the structure and functioning of ecosystems associated with homogenous water bodies. The

* Corresponding author at: L'œil d'andromède, 7, place Cassan, 34280 Carnon, France. Tel.: +33 4 67 66 32 48.
E-mail addresses: julie.deter@andromede-ocean.com (J. Deter), pierre.descamp@andromede-ocean.com (P. Descamp), laurent.ballesta@andromede-ocean.com (L. Ballesta), pierre.boissery@eaurmc.fr (P. Boissery), florian.holon@andromede-ocean.com (F. Holon).

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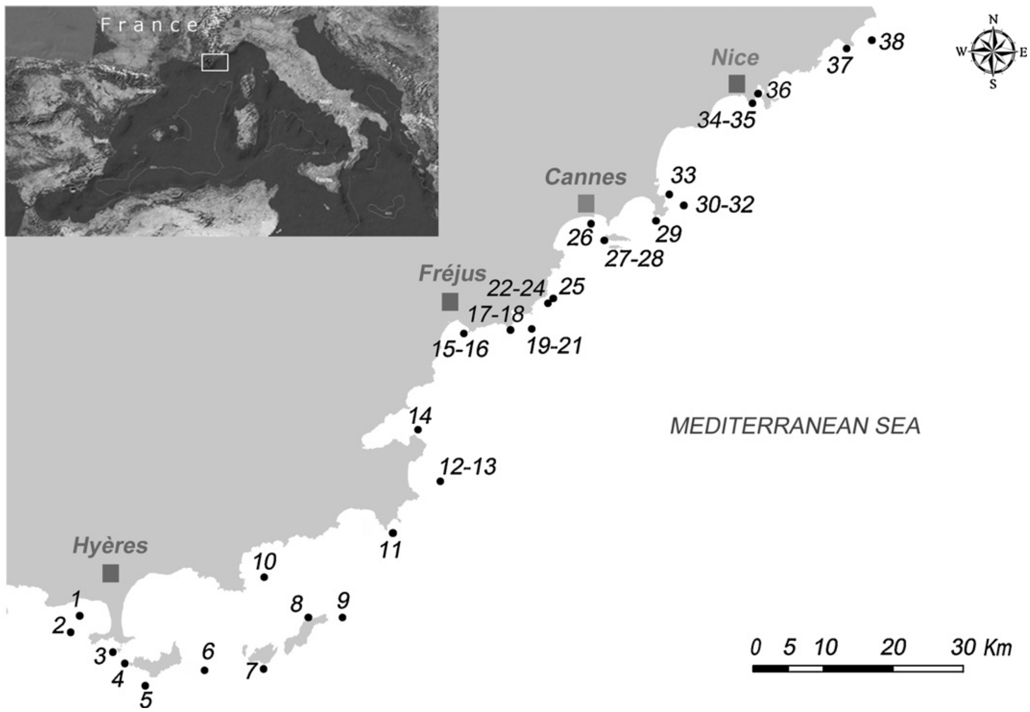

Fig. 1. Map presenting the 38 stations studied on the Mediterranean French coast (PACA region).

status of each water body is evaluated thanks to variables relative to organisms or groups of organisms sensitive to anthropogenic pressures and called biological quality elements (phytoplankton, macroalgae, angiosperms and benthic fauna) (Devlin et al., 2007). Despite the great contribution of coralligenous communities to Mediterranean biodiversity (Ballesteros, 2006) and its recognition as a natural habitat of communitarian interest, whose conservation requires the designation of Zones of Special Conservation at European level (92/43/CE Habitat Directive, habitat code 1170-14: Reefs, coralligenous assemblage), coralligenous assemblages were largely neglected for the water body quality assessment. Actually, most efforts in ecological status assessment of marine waters have been carried out in the implementation of angiosperms and soft bottom biotic indices (Borja et al., 2000; de-la-Ossa-Carretero et al., 2009; Gobert et al., 2009; Fitch and Crowe, 2010; Lopez y Royo et al., 2011). This relative lack of interest could be explained by the depth of this habitat (from 12–50 m to 40–120 m depth depending on water transparency (Ballesteros, 2006)) and a missing consensual methodology for its monitoring (UNEP-MAP-RAC/SPA, 2011). Even despite the lack of overall community analyses, several species (believed to be the most sensitive) found in coralligenous assemblages were nevertheless studied for their responses to common anthropogenic disturbances and highlighted for their potential quality indicator role. For example, gorgonians (very slow-growing threatened species), because of their particular sensitivity when faced with increasing disturbances, were proposed as potential indicators of the effects of climatic anomalies on the coralligenous community (Linares et al., 2008). Similarly, red coral was particularly well surveyed because it underwent specific harvesting as well as other anthopogenic pressures (Tsounis et al., 2006; Bruckner, 2010). Other large and/or erected species such as bryozoans (e.g. *Pentapora fascialis*) or ascidians (e.g. *Halocynthia papillosa*) are also influenced by diving frequency and waste water impacts (Sala et al., 1996; Pérez et al., 2002; Luna-Pérez et al., 2010).

Based on field data sampled around coralligenous assemblages, the aim of this study was to present a multimetric methodology for the environmental evaluation of water quality, in agreement with the principles of the WFD.

2. Materials and methods

2.1. Field work

In June 2010, 38 stations presenting coralligenous concretions were sampled (depth between −30 and −84 m) in 13 water bodies on the Eastern part of French Mediterranean coast (Fig. 1). Details concerning these stations are described in Table 1: they were chosen in order to represent different anthropogenic pressure conditions. Coralligenous assemblages, especially sessile species and species believed to be vulnerable, were described at each site. Two protocols were applied by CCUBA (Closed Circuit Underwater Breathing Apparatus) divers for the metrics measurements at each station.

Coralligenous assemblages (sessile organisms) description with photographic quadrats. Each station was sampled using 30 photographic quadrats (50 × 50 cm) along a 40 m-long transect. Pictures were taken using a digital camera (D2Xs Nikon at 12.4 megapixels with a 12–24 mm zoom-lens Nikon and used with a housing, a dome and SEACAM® flashes specially adapted to deep dives) perpendicularly fixed 50 cm over the quadrat frame, thus minimizing possible parallax errors. Pictures were analyzed using CPCe 3.6 (Kohler and Gill, 2006) for the estimation of the percentage of the total area covered by each species. This non-destructive method samples 64 random points per quadrat frame and is judged to be fast and efficient for coralligenous community analyse (Holon et al., 2010). Structure parameters like sludge and crevice percent covers were estimated by the same way. Taxa (sessile organisms) were identified to the level of species or genus. Where identification at the most detailed level of taxonomical resolution was not possible, animals were grouped in phyla. Hydrozoa and encrusting Bryozoa were not identified further and were classified as "Hydrozoa" and "Encrusting Bryozoa". Unidentifiable organisms were classified as "unknown" and were not considered in community analyses.

Erected species demography (especially gorgonians). Gorgonian demographic structure was classically obtained from density and individual height measured underwater in 2 m^2 (eight 50 × 50 cm quadrats) (Sartoretto, 2003). Thirty 50 × 50 cm quadrats were used

Table 1
Description of the 38 stations sampled in June 2010.

Code	Name	Depth (in m)	Morphology	Principal current direction	Orientation (slope direction)
1	Sabran	35	Bank	N	SW
2	Off Fourmigues	35	Rim	NW	SW
3	South Ribaud	47	Bank	NW	SW
4	Langoustier edge	33	Rim	NW	SW
5	Cape Arme	50	Bank	W	S
6	Shallow Sarranier	41	Rim	W	SE
7	Gabinière	41	Rim	W	S
8	Castelas edge	43	Bank	SW	N
9	Levant Beacon	38	Bank	SW	SE
10	Baleine	36	Rim	S	SW
11	Ancres	39	Bank	SW	S
12	Pampelone-62	62	Bank	S	NE
13	Pampelone-70	70	Bank	S	NE
14	Rabiou beacon	52	Bank	S	E
15	Lion de mer-30	30	Rim	W	S
16	Lion de mer-39	39	Rim	W	S
17	Dramont-40	40	Rim	W	SW
18	Dramont-30	30	Rim	W	SW
19	banc de vieilles-50	50	Rim	W	SW
20	banc de vieilles-60	60	Rim	W	SW
21	banc de vieilles-70	70	Rim	W	SW
22	Chrétienne-50	50	Rim	SW	S
23	Chrétienne-60	60	Rim	SW	S
24	Chrétienne-70	70	Rim	SW	S
25	Off Cap roux	37	Bank	S	N
26	Midi	33	Rim	NW	SW
27	Dragon edge-63	63	Rim	N	W
28	Dragon edge-70	70	Rim	N	W
29	Shallow st pierre	40	Rim	S	SW
30	Raventurier-44	44	Bank	S	E
31	Raventurier-54	54	Bank	S	E
32	Raventurier-65	65	Rim	S	E
33	Bacon edge	36	Rim	S	E
34	American rim-63	63	Rim	W	S
35	American rim-84	84	Rim	W	S
36	Lido	36	Bank	N	S
37	Eastern Martin cape	55	Bank	SW	SE
38	Western Martin cape	48	Bank	W	S

N = Nord, S = South, E = East, W = West

for necrosis study: necrosis percent (Perez et al., 2000), distribution of necrosis (diffused or localized) and dating of necrosis colonization (with old, recent or mix colonization). Such metrics are routinely measured for gorgonian monitoring (Harmelin and Marinopoulos, 1994; Pérez et al., 2002; Sartoretto, 2003). Quadrats used for erected species demography were randomly chosen and were different from photographic quadrats. For time constraints, only one station was sampled when stations were located close-at-hand (Table 1). Consequently, gorgonian species demography was studied at 24 stations (codes 1, 3, 6-10, 11, 14, 17, 21, 23-26, 29-31, 33-35, 37, 38).

These protocols figured among the proposed standard methods for inventorying and monitoring coralligenous populations (UNEP-MAP-RAC/SPA, 2011) and moreover fitted with the methodological guide for the evaluation of the conservation state of Natura 2000 marine natural habitats (Lepareur, 2011).

2.2. Anthropogenic pressure estimation

We calculated an anthropogenic pressure index (API) for each field station considering three body water state descriptors (coastal artificialization percent, ecological and chemical state considering respective confidence index as communicated by the French Water Agency for each water body http://www.rhone-mediterranee.eaufrance.fr/gestion/dce/telechargements-sdage.php) and local descriptors. These last ones were principally based on an anthropization index defined by Gobert et al. (2009). It included a score (from 0 (no impact) to 5 (dramatic pressure)) for eight pressures: fish farming, population development, industrial development, agriculture, tourism, fishing, commercial ports and urbanization. Considering the possible depth and distance from the coast, an accessibility factor was added on the same way. API was defined as the sum of these twelve factors affecting the seawater quality and/or biotope quality. Scores for local descriptors were estimated from freely available information: trade association, INSEE (National Institute for Statistics and Economical Studies, http://www.insee.fr), French Ministry of Ecology, Industry, Sustainable Development and Sea (http://carmen.developpement-durable.gouv.fr/25/environnement.map), DREAL (Regional Direction for Environment, development and housing, http://www.paca.developpement-durable.gouv.fr), MEDAM (Coastal development on the French Mediterranean coast, http://sigcol.unice.fr/website/MEDAM/site_medam/index.php) and aerian pictures from Google Earth (http://www.google.fr/intl/fr/earth/index.html).

2.3. Selecting and testing candidate metrics

According to WFD (2000/60/EC), monitoring should concern quality elements which are indicative of the pressures to which each water body is subject. Drivers-pressures-state-impacts-responses (DPSIR) approach provides a good communication tool between researchers, stakeholders and decision makers, but also a global mechanism for assessment and management of environmental problems with regards to sustainable development. Different metrics measuring impacts may provide pertinent

Table 2
Drivers–pressures-state-impacts analysis.

Drivers	Pressures	State	Impacts	References
Urbanization, population	Runoff waters; sewage discharges; diving pressure	Toxic contamination; degradation of water/sediment quality; habitat loss; water temperature; eutrophication; habitat destruction	Diversity; dominance; abundance; age structure; massive death; selective mortality	Sala et al. (1996), Garrabou et al. (1998), Pérez et al. (2002), Fraschetti et al. (2006), Ballesteros (2006), Luna et al. (2009) and Luna-Pérez et al. (2010)
Agriculture and fish farming	Pesticides; effluent discharges; pathogens; individuals leak	Eutrophication; degradation of water/sediment quality; toxic contamination; habitat loss; biological pollution	Diversity; dominance; abundance; age structure; massive death; reproductive dysfunction; genetic variability	Hong (1983) and Claudet and Fraschettia (2010)
Industrial development	Industrial effluents discharges	Toxic contamination; degradation of water/sediment quality; habitat loss; eutrophication; water temperature	Diversity; dominance; biomass; abundance; age structure; massive death; reproductive dysfunction	Hong (1983), Terlizzi et al. (2002) and Aguilar et al. (2009)
Fishing	Destructive methods; selective catch, overfishing	Selective mortality; habitat destruction	Diversity; dominance; abundance; age structure	Tsounis et al. (2007), Ballesteros (2006) and Aguilar et al. (2009)
Port activity	Ballast waters; boats pressure	Toxic contamination; Degradation of water/sediment quality; biological pollution; noise perturbance	Diversity; dominance; abundance; age structure; massive death; exotic species; pathogens; genetic variability; reproductive dysfunction;	United Nations Environment Programme (2007) and Baldacconi and Corriero (2009)
Dredging activity	Contaminants and sediments suspension; sediments removing	Toxic contamination; degradation of water/sediment quality; biological pollution; habitat destruction; increased turbidity	Diversity, dominance; abundance; massive death; exotic species; genetic variability	Balata et al. (2005), United Nations Environment Programme (2007), UNEP-MAP-RAC/SPA (2008)

Drivers: main socio-economic driving human activities; pressures: consequences of the human activities in the environment; state: environment changes due to pressures force; Impacts: potential alterations in the coralligenous assemblages due to the increasing of the state.

information on coralligenous habitat vitality (at the individual and population level) for a wide spectrum of disturbance (water turbidity, nutrient concentrations, sedimentary dynamics, erosion) regularly described in the Mediterranean Sea (Table 2). In the development of the index described here, metrics we are interested in fitted with this DPSIR analysis and provided pertinent information on coralligenous habitat vitality. The candidate metrics obtained from the field work are based upon either presence/absence of potentially indicator species (protected species and/or vulnerable species) or big and easily detectible species, 'relative' abundance (number, density or percent cover) or number of present taxa (Table 3). These metrics were easy to acquire, present a good cost-efficiency ratio and require a low technological investment (no laboratory work). Once normalized, each metric (dependent variable) was tested for a link with API, depth (independent variables) and morphology (co-variable) using an ANCOVA. Depth (correlated to light irradiance) and morphology were included in the models because of their potential important influence on coralligenous assemblages (Ballesteros, 2006). Metrics significantly ($P < 0.05$) linked to API and that were not redundant (Pearson's $r < 0.8$ with a multiple correlation matrix) were selected for the index elaboration. Analyses were performed using Statistica 6.1 (Statsoft, Inc.).

2.4. Combining metrics and building a Coralligenous Assemblage Index (CAI)

The choice of the metrics was based on their ecological meaning, response to "state" of environmental change (interpretable and significant link with API) and the redundancy relation between them (excluding the redundant metrics). WFD states that the classification of ecological status shall be based on ecological quality ratios (EQR = observed values/reference values), i.e. the deviation of the status of the quality element from its potential status under pristine conditions (undisturbed, reference conditions). Given that no pristine conditions could be determined in the studied area, in a first approach, we postulated the reference condition as a "theoric optimal site", corresponding to the best values of each metric noted in the field. According to WFD, each EQR was expressed as a numerical value between zero and one, with high ecological status represented by values close to one and bad ecological status by values close to zero. The chosen metrics were added and averaged. The resulting value provided an overall coralligenous habitat classification index called Coralligenous Assemblage Index (CAI). Assignment of quality status for each station was established according to the five classes scale proposed by WFD and ranging from high (<0.75–1), good (>0.60–0.75), moderate (>0.40–0.60), poor (>0.25–0.40) to bad (0–0.25). Although the methodology used did not guarantee the reality of our reference limits, ecological results obtained for this study were comparable because they were obtained considering by a similar way. Finally, the robustness of our index obtained for each station was tested with a comparison to API using a linear regression. Stations classified in "high ecological status" were sampled a second time in June 2011. Selected metrics, CAI and classification were compared (variation relative to the values measured in the first survey and *t*-tests).

3. Results

3.1. Candidate metrics measurement and selection

All the 38 stations were analyzed for photographic quadrats. Unidentified species covered 4.84% (±3.30) of the quadrats. Crevice, sludge and rubble mean percents were 15.68% (±0.81), 39.94% (±2.84) and 2.35% (±0.47) [mean (±standard deviation)]. Mean percent covers were highly variable depending on groups considered (Table 3). Among these candidate variables, three were significantly linked to API and selected to be included in the CAI: sludge percent ($P < 0.001$), percent cover of builders ($P = 0.034$) and percent cover of bryozoans ($P = 0.016$) (results presented in Table 4). Sludge percent (Correlation coefficient $r = 0.471$) increased with API when percent cover of bryozoans ($r = -0.375$) and builders ($r = -0.283$) decreased with API (Fig. 2). Sludge percent ($r = 0.353$) and the percent cover of builders ($r = -0.600$) were also influenced by depth (Table 4).

Table 3
List of the candidate metrics tested to be included in the coralligenous index with mean values and standard errors calculated from the field stations sampled. Densities are expressed in number of individuals per m^2. Gorgonian colonies were counted as big when measuring more than 50 cm and small when measuring less than 15 cm. According to Ballesteros (2006), builder species were composed on Coralline species, bryozoans, scleractinians, *Miniacina miniacea* and *Leptopsammia pruvoti* and eroder species were composed on *Cliona* spp, *Echinus melo, Sphaerechinus granularis, Polydora* spp and *Lithophaga lithophaga.*

Fiel method	Metrics (mean value [standard error])
Photographic quadrats (38 stations)	Crevice percent cover (15.68% [±0.81]) Sludge percent cover (39.94% [±2.84]) Rubble percent cover (2.35% [±0.47]) Percent cover of macroalgae (14.75% [±2.58]) Percent cover of coralline species (9.11% [±1.24]) Percent cover of ascidians (0.81% [±0.22]) Percent cover of scleractinians (0.12% [±0.05]) Percent cover of hydrozoans (2.15% [±0.38]) Percent cover of alcyonarians (0.21% [±0.09]) Percent cover of gorgonians (6.33% [±0.92]) Percent cover of porifora (13.87% [±2.11]) Percent cover of bryozoans (3.23% [±0.30]) Percent cover of bryozoans with a height > 15 cm (2.68%[±6.50]) Percent cover of builders (12.70% [±1.31]) Percent cover of builders + *Peyssonnelia* sp (24.82% [±2.42]) Percent cover of eroders (0.57% [±0.15]) Percent cover of erected species (bryozoan + gorgonian + *Axinella polypoides*) (9.64% [6.85]) Shannon weaver diversity index of gorgonians (0.53 [±0.36]) Percent cover of *Corallium rubrum* Linnaeus, 1758 (0.84% [±0.57]) Percent cover of *Paramuricea clavata* Risso, 1826 (3.41% [±0.56]) Percent cover of *Eunicella cavolini* koch, 1887 (2.02% [±0.34]) Percent cover of *Leptogorgia sarmentosa* Esper, 1789 (0.08% [0.27]) Percent cover of *Halocynthia papillosa* Linnaeus, 1767 (0.08%[0.11]) Percent cover of *Aplysina cavernicola* Vacelet, 1959 (2.29% [±0.63]) Percent cover of *Axinella damicornis* Esper, 1794 (0.37% [±0.12]) Percent cover of *Phorbas tenacior* Topsent, 1925 (0.67% [±0.19]) Percent cover of *Adeonella calveti* Canu and Bassler, 1930 (0.37% [0.71]) Percent cover of *Myriapora truncata* Pallas, 1766 (0.26% [0.27]) Percent cover of *Parazoanthus axinellae* Schmidt, 1862 (0.81% [1.87]) Percent cover of *Caulerpa racemosa* (Forsskål) Agardh, 1873 (0.25% [0.75]) Percent of *Filograna* sp or *Salmacina* sp (0.11% [0.14])
Gorgonian species demography (18 stations)	Density of *P. clavata* colonies (8.04 [±1.38]) Number (or density) of *E. cavolini* colonies (4.90 [±0.85]) Presence/absence of *L. sarmentosa* colonies Percent of gorgonians with necrosis > 10% (11.60% [±3.07]) Percent of *P. clavata* with recent (0.86% [1.64]) Percent of *E. cavolini* with recent or old necrosis (0% [0]) Maximal class of necrosis for *P. clavata* or *E. cavolini* Density of big or small *P. clavata* individuals (0.50 [0.31] or 0.31 [0.35]) Density of big or small *E. cavolinii* individuals (0.02 [0.05] or 0.39 [0.69])) Presence/absence of recruitment (colonies < 10 cm) in *P. clavata* (or *E. cavolini*) Maximal height of *P. clavata* or *E. cavolini* (115-120 cm or 65-70 cm)

These relationships were clearest for data samples at depth inferior to −45 m than superior to −45 m (graphs not showed). None of these three metrics was significantly influenced by morphology.

Among the 24 stations studied for gorgonian demography, six were not included in these data because of an insufficient number (<4 colonies) of gorgonians (stations 1, 3, 10, 24, 34, 35). Considering the 18 stations, mean density was 13.34 (±1.67) gorgonians per m^2 mostly due to red and yellow gorgonian (respective mean densities 8.04 (±1.38) and 4.90 (±0.85). Results are detailed in Table 3. The highest red and yellow gorgonian observed measured 115–120 (station 37) and 65–70 cm (station 38). No variable associated to gorgonian species demography was found to be significantly linked to API.

3.2. Coralligenous Assemblage Index (CAI) elaboration

CAI was based on the three metrics selected from statistical analyses (see above). This included sludge percent, percent cover of builders and percent cover of bryozoans. Reference values (best values = minimal or maximal values depending the sense of the correlation with API) considered the depth (more or less than −45 m) for all metrics except the last one (Table 5). All of the five levels of

Table 4
Results of ANCOVA testing for a link between anthropogenic pressure index (API), depth, morphology and candidate metrics (N = 38 stations). Only candidate metrics presenting a significant (P < 0.05) link with API are presented here.

Dependent variable (*Y*)	Explanatory factors (*X*)	Degree of freedom	Wald statistics	*P*
Sludge percent cover	API	1	13.836	<0.001
	Depth	1	8.860	<0.001
	Morphology	1	5.561	0.062
Percent cover of builders	API	1	4.317	0.038
	Depth	1	13.993	<0.001
	Morphology	1	0.203	0.652
Percent cover of bryozoans	API	1	5.492	0.019
	Depth	1	0.197	0.657
	Morphology	1	3.392	0.065

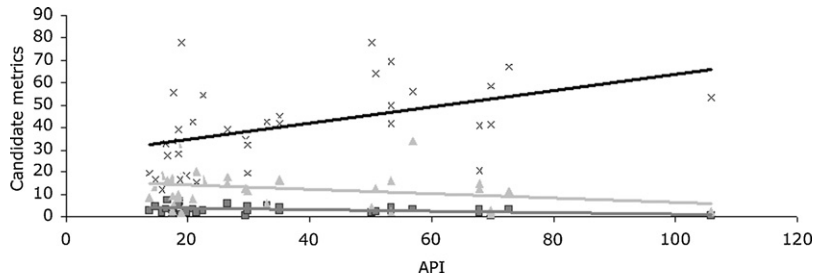

Fig. 2. Evolution of three selected metrics: sludge percent (cross and black line), percent cover of bryozoans (square and dark grey line) and percent cover of builders (triangle and light grey line) in function of API (anthropogenic pressure index) on the 38 stations studied.

Table 5
Reference conditions for each metrics.

	All depths	Stations shallower than – 45 m	Stations deeper than – 45 m
Sludge percent	–	12.093	26.920
Percent cover of builders	–	29.039	32.326
Percent cover of bryozoans	7.423	–	–

status were represented by the 38 stations sampled. The ecological statuses obtained in the application of the CAI are presented in Table 6. Most of the stations were classified between "moderate" and "good" status. Four stations were classified in "bad ecological status" (stations 13, 27, 36, 38), four in "poor ecological status" (stations 3, 29, 34, 35), and three in "high ecological status" (stations 5, 6 and 19). The quality of seawater expressed by API was negatively and significantly correlated with CAI ($r = -0.518$, Fig. 3). The highest API (105.96) was given to station 36, classified in "bad ecological status" using CAI (Table 6). This station presented high population (including tourism) and boat pressures but also an easy access and moderate fishing activities. Coastal artificialization percent was largely the highest (61%) and chemical state was judged bad by the French Water Agency. The lowest APIs were allocated to stations 7, 8 and 9 (14.67; 13.67; 15.67), classified in "moderate" and "good ecological status" according to CAI. These stations were located in moderately urbanized areas, with weak tourism and fishing activities; coastal artificialization percent was around 3%. The three stations classified in "high ecological status waters" (5, 6 and 19) presented only a little higher API values than stations 7, 8 and 9 (16.67, 18.67 and 18.47) mostly because of an easier accessibility and higher fishing activities.

A second sampling at these three stations classified in "high ecological status" did not show any significant inter-annual variation for selected metrics (t-test with paired samples, all $P > 0.05$) and all of the three stations conserved their classification as "high

Table 6
Coralligenous Assemblage Index (CAI) and anthropogenic pressure index (API) values calculated for the 38 stations studied on the French Mediterranean coast (PACA region).

Code	API	CAI	Ecological status level
1	29.82	0.501	Moderate
2	29.82	0.686	Good
3	17.67	0.340	Poor
4	19.67	0.565	Good
5	16.67	0.831	High
6	18.67	0.788	High
7	14.67	0.646	Good
8	13.67	0.525	Moderate
9	15.67	0.583	Good
10	29.47	0.406	Moderate
11	21.47	0.609	Good
12	20.91	0.509	Moderate
13	18.91	0.165	Bad
14	22.41	0.507	Moderate
15	67.88	0.574	Good
16	67.88	0.442	Moderate
17	26.47	0.632	Good
18	26.47	0.657	Good
19	18.47	0.919	High
20	18.47	0.714	Good
21	18.47	0.681	Good
22	17.47	0.528	Moderate
23	17.47	0.504	Moderate
24	17.47	0.452	Moderate
25	16.47	0.690	Good
26	56.9	0.653	Good
27	53.40	0.230	Bad
28	53.40	0.355	Poor
29	53.40	0.568	Good
30	35	0.511	Moderate
31	35	0.620	Good
32	33	0.554	Moderate
33	72.72	0.403	Moderate
34	69.79	0.282	Poor
35	69.79	0.306	Poor
36	105.96	0.238	Bad
37	50.29	0.211	Moderate
38	50.79	0.410	Bad

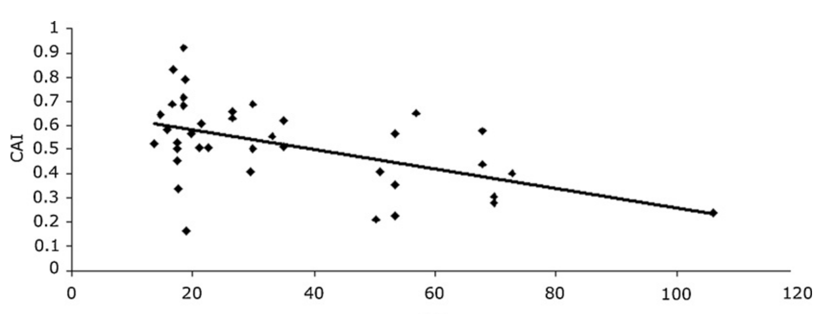

Fig. 3. Regression between the anthropogenic pressure index (API) and the classification obtained by the Coralligenous Assemblage Index (CAI). $N = 38$ sites, $R^2 = 0.268$, $P < 0.001$.

ecological status" (CAI = 0.829; 0.898; 0.790 for respectively stations 5, 6 and 19).

4. Discussion

Our study did not succeed in highlighting adequate metrics linked with anthropogenic pressures concerning gorgonian or target species variables. Because of their long life expectancy and slow dynamics, gorgonian populations are particularly vulnerable and show long-term consequences of disturbances (Garrabou and Harmelin, 2002; Linares et al., 2007). Climatic anomalies like 1999 mass mortality event were for example still visible on *P. clavata* populations (biomass and density) studied in 2003 (Linares et al., 2008). Because of this weak resilience, it is thus difficult, without population historic and long-term data, to link present observation with present anthropogenic pressures especially potentially recent enhancements; in other terms, metrics acquired during our study might be more explained by former events. Actually, punctual data are hardly exploited because life-history traits measured over large temporal scales are the most appropriate to long-lived marine species studies (Hughes and Connell, 1999). Concerning the percent cover of species targeted for their potential sensitivity, the absence of a significant link observed with API could be explained by the very small percents and weak variations recorded for these species during our study. It does not contradict previous studies (see the introduction) or reject the potential usefulness of these species as indicators of water quality but the method we used was inadequate to highlight such a role.

Three metrics were selected for the CAI design: percent cover of builders, percent cover of bryozoans and sludge percent cover. As expected, sludge percent cover increased with API when percent cover of bryozoans moderately decreased with API. Percent cover of builders weakly decreased with API mostly because of station 26. This station (the shallowest one) was strongly covered by builders although a moderate API perhaps because of its relative weak depth. Taken together, these metrics bring information concerning both of the two parameters defined for the evaluation of the conservation state of Natura 2000 marine natural habitats: structure - functionality (state of the bioconstructions, diversity of associated assemblages) with the percent cover of builders and bryozoans and threats - pressures (physical perturbations, biological perturbations and pollution) with sludge percent cover (Lepareur, 2011). Builder species intrinsically constitute the basis of coralligenous concretions and assemblages. They are influenced by various environmental factors such as light, nutrients and salinity potentially influenced in turn by human pressures (waste water for example) (Ballesteros, 2006). Similarly, bryozoans are sensitive to nutrients, sediment deposition and to mechanical pressures such as diving or fishing. Lastly, sludge, and thus, turbidity (re-suspended sediment) and sedimentation have terrestrial origins largely affected by human activities since the past few decades (land overuse, deforestation, increased erosion, alteration of sediment transport) (see Airoldi's review (2003)). Several studies showed the influence of sediment deposition on coralligenous assemblages through various suspected mechanisms (clogging of filtering apparatus, inhibition of recruitment, alteration of metabolic process, limitation of algal production, increase of burial and scouring, etc.) (Valiela, 1995; Airoldi, 2003; Balata et al., 2005). Finally, CAI, with its integrated response at three levels (physics with sludge, structure with builders and community with bryozoans) reflected the main anthropogenic factors that were found to occur in littoral zones. The quality of seawater expressed by API was significantly and negatively correlated with CAI and the resulting ecological classification using CAI was in accordance with our field knowledge.

All metrics included in the CAI were obtained from photographic quadrats. This cheap-cost method presents the advantages to provide objective and repeatable estimations thanks to a fast and non-destructive underwater work (Bianchi et al., 2004). Such a method is particularly well adapted to life cycle and temporal variation studies and/or to deep water station survey requiring scarce taxonomic precision (no method can be more accurate in taxonomy than direct collection) (Bianchi et al., 2004). Thanks to this method, this preliminary study benefited on a strong field sampling effort. All stations were sampled during a short period (three weeks), which avoided seasonality effects. Moreover, a second sampling at three stations did not show any inter-annual effect and classifications remained similar. The next field campaign planned for summer 2011 and 2012 should confirm the robustness of the CAI index with the acquisition of new data in Corsica and Languedoc-Roussillon. These new data will be analyzed using CPCe 4.1 "Coralligenous assemblages version" (CPCe 4.1. 2011).

Regarding WFD, coralligenous assemblages do not figure among the four biotic descriptors (biological quality elements) to be characterized and monitored by member states for coastal waters: phytoplankton, benthic invertebrate fauna, macroalgae and angiosperms. Pressure categories (use, discharges, alien species and development) recognized to be able to affect ecological status and the link pressure/state/impact/response is required in order to appreciate measurement program efficiency and corrective actions such as use management, cleanup, effluent discharges decrease etc. CAI will complete this obligatory dispositive. By providing a supplementary measurement but also data at higher depths than provided for required descriptors, CAI reinforces ecological status appreciation. Moreover, respecting the link state/pressure, this tool will help to appreciate corrective measures efficiency.The goal of the Marine Strategy Framework Directive (MSFD, Directive 2008/56/EC) is in line with the objectives of WFD. It aims to achieve good environmental status of the EU's marine waters by 2020 and to protect the resource base upon which marine-related economic and social activities depend. The final goal is to protect more effectively the marine environment across Europe but an important point is that each Member State "shall ensure that measures are cost-effective and technically feasible". Identified under Community legislation (Habitats Directive 92/43/CEE) as being a special habitat with biodiversity interest, coralligenous assemblages shall be monitored as a descriptor in the framework of MSFD. Pragmatic and cheap, CAI brings first relevant elements to be considered for MSFD measurement program draw up.

5. Conclusions

To our knowledge, this study brought the first results concerning an assay with the determination of a multimetric index for coastal waters based on invertebrates from hard bottom community. The Coralligenous Assemblage Index (CAI) was based on three metrics acquired using photographic quadrat analyses: sludge percent cover, bryozoa and builder species percent cover. CAI was proved to be a useful tool for the assessment of the ecological quality of coralligenous communities and ecological status of Mediterranean French coastal waters in accordance with WFD requirements and United Nations Environment Programme, Mediterranean Action Plan and Regional Activity Centre for Specially Protected Areas proposal of standard methods (UNEP-MAP-RAC/SPA, 2011). This index was demonstrated to detect likely effects of anthropogenic pressures. However, further applications and validation are needed in order to better adjust the quality scores and properly evaluate the strengths and weaknesses. The selection of metrics that were cheap and easy to acquire and analyze will guaranty an effortlessly use and understanding by coastal managers and stakeholders.

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References

Aguilar, R., Pastor, X., de la Torriente, A., Garcia, S., 2009. Main threats and proposals for the protection of the coralligenous beds in the Mediterranean sea. In: Proc. 1st Mediterranean Symposium on the Conservation of the Coralligenous and other Calcareous Bio-concretions, 15-16 January 2009 – Tabarka, Tunisia, pp. 13–15.

Airoldi, L., 2003. The effects of sedimentation on rocky coastal assemblages. Oceanogr. Mar. Biol. Annu. Rev. 41, 161–203.

Balata, D., Enrico, C., Piazzi, L., Cinelli, F., 2005. Variability of Mediterranean coralligenous assemblages subject to local variation in sediment deposition. Mar. Env. Res. 60, 403–421.

Baldacconi, R., Corriero, G., 2009. Effects of the spread of the alga *Caulerpa racemosa* var. cylindracea on the sponge assemblage from coralligenous concretions of the Apulian coast (Ionian Sea Italy). Mar. Ecol. 30, 337–347.

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

Bianchi, C.N., 2001. La biocostruzione negli ecosistemi marini e la biologia marina italiana. Biol. Mar. Medit. 8, 112–130.

Bianchi, C.N., Pronzato, R., Cattaneo-Vietti, R., Benedetti-Cecchi, L., Morri, C., Pansini, M., Chemello, R., Milazzo, M., Fraschetti, S., Terlizzi, A., Peirano, A., Salvati, E., Benzoni, F., Calcinai, B., Cerrano, C., Bavestrello, G., 2004. Mediterranean marine benthos: a manual of methods for its sampling and study. Hard Bottoms. Biol. Mar. Medit. 11, 185–215.

Borja, A., Franco, J., Perez, V.P., 2000. A marine biotic index to establish the ecological quality of soft-bottom benthos within European estuarine and coastal environments. Mar. Poll. Bull 40, 1100–1114.

Bruckner, A.W., 2010. Quantifying the decline in *Corallium rubrum* populations: Reply to Santangelo & Bramanti (2010). Mar. Ecol. Prog. Ser. 418, 299–303.

Claudet, J., Fraschettia, S., 2010. Human-driven impacts on marine habitats: a regional meta-analysis in the Mediterranean Sea. Biol. Conserv. 143, 2195–2206.

CPCe 4.1., 2011 Coral Point Count with Excel extension Coralligenous assemblages version. Developped by NCRI/L'oeil d'Andromède/Agence de l'Eau. http://www.andromede-ocean.com/index.php?page=oceanologie_reference&id_reference=78.

de-la-Ossa-Carretero, J.A., Del-Pilar-Ruso, Y., Gimenez-Casalduero, F., Sanchez-Lizaso, J.L., 2009. Testing BOPA index in sewage affected soft-bottom communities in the north-western Mediterranean. Mar. Poll. Bull 58, 332–340.

Devlin, M., Besyt, M., Haynes, D., 2007. Implementation of the Water Framework Directive in European marine waters. Mar. Poll. Bull. 55, 1–2.

Fitch, J.E., Crowe, T.P., 2010. Effective methods for assessing ecological quality in intertidal soft-sediment habitats. Mar. Poll. Bull 60, 1726–1733.

Fraschetti, S., Gambi, C., Giangrande, A., Musco, L., Terlizzi, A., Danovaro, R., 2006. Structural and functional response of meiofauna rocky assemblages to sewage pollution. Mar. Poll. Bull. 52, 540–548.

Garrabou, J., Sala, E., Arcas, A., Zabala, M., 1998. The impact of diving on rocky sublittoral communities: a case study of a bryozoan population. Conservation Biology 12, 302–312.

Garrabou, J., Harmelin, J.G., 2002. A 20-year study on life-history traits of a harvested long-lived temperate coral in the NW Mediterranean: insights into conservation and management needs. J. Anim. Ecol. 71, 966–978.

Gobert, S., Sartoretto, S., Rico-Raimondino, V., Andral, B., Chery, A., Lejeune, P., Boissery, P., 2009. Assessment of the ecological status of Mediterranean French coastal waters as required by the Water Framework Directive using the *Posidonia oceanica*. Mar. Poll. Bull 58, 1727–1733.

Harmelin, J.G., Marinopoulos, J., 1994. Population structure and partial mortality of the gorgonian *Paramuricea clavata* (Risso) in the North-Western Mediterranean (France, Port-Cros Island). Marine Life 4, 5–13.

Holon, F., Descamp, P., Boissery, P., Deter, J., 2010. Mise en place d'un protocole pour la caractérisation et le suivi du coralligène, Application sur 41 sites en région PACA entre −90 m et −35 m. Report L'Oeil d'Andromede/Agence de l'Eau.

Hong, J.S., 1983. Impact of the pollution on the benthic community. Environmental impact of the pollution on the benthic coralligenous community in the Gulf of Fos, NorthWestern Mediterranean. Bull. Korean Fish. Soc. 16, 273–290.

Hughes, T.P., Connell, J.H., 1999. Multiple stressors on coral reefs: along-term perspective. Limnol. Oceanogr 44, 932–940.

Kohler, K.E., Gill, S.M., 2006. Coral Point Count with Excel extensions (CPCe): A visual basic program for the determination of coral and substrate coverage using random point count methodology. Comput. Geosci. 32, 1259–1269.

Lepareur, F., 2011. Evaluation de l'état de conservation des habitats naturels marins à l'échelle d'un site Natura 2000—Guide méthodologique—Version 1. Février 2011. Museum National d'Histoire Naturelle (MNHN), Paris.

Linares, C., Doak, D., Coma, R., Diaz, D., Zabala, M., 2007. Life history and population viability of a long-lived marine invertebrate: the octocoral *Paramuricea clavata*. Ecology 88, 918–928.

Linares, C., Coma, R., Garrabou, J., Díaz, D., Zabala, M., 2008. Size distribution, density and disturbance in two Mediterranean gorgonians: *Paramuricea clavata* and *Eunicella singularis*. J. Appl. Ecol. 45, 688–699.

Lopez y Royo, C., Pergent, G., Alcoverro, T., Buia, M.C., Casazza, G., Martinez-Crego, B., Perez, M., Silvestre, F., Romero, J., 2011. The seagrass *Posidonia oceanica* as indicator of coastal water quality: experimental intercalibration of classification systems. Ecol. Indic. 11, 557–563.

Luna, B., Valle Pérez, C., Sánchez-Lizaso, J.L., 2009. Benthic impacts of recreational divers in a Mediterranean Marine Protected Area. ICES J. Mar. Sci. 66, 517–523.

Luna-Pérez, B., Valle, C., Vega Fernández, T., Sánchez-Lizaso, J.L., Ramos-Esplá, A.A., 2010. *Halocynthia papillosa* (Linnaeus, 1767) as an indicator of SCUBA diving impact. Ecol. Indic. 10, 1017–1024.

Perez, T., Garrabou, J., Sartoretto, S., Harmelin, J.G., Francour, P., Vacelet, J., 2000. Mortalité massive d'invertébrés marins: un événement sans précédent en Méditérranée nord-occidentale. C. R. Acad. Sci. Paris 323, 853–865.

Pérez, T., Sartoretto, S., Harmelin, J.G., 2002. La bioévaluation de la qualité littorale par les peuplements de substrats durs: spongiaires, gorgonaires et bryozoaires comme indicateurs de pollution. Rapport final. Ministère de l'Aménagement du territoire et de l'Environnement/Centre d'Océanologie de Marseille.

Sala, E., Garrabou, J., Zabala, M., 1996. Effects of diver frequentation on Mediterranean sublittoral populationsof the bryozoan *Pentapora fascialis*. Mar. Biol. 126, 451–459.

Sartoretto, S. 2003. Le Réseau de Surveillance Gorgones en région Provence-Alpes-Côte d'Azur: Deuxième campagne de mesure et recommandations. Conseil Régional PACA/Agence de l'Eau RMC/DIREN PACA/Conseil général 13/Conseil général 83/Conseil général 06/Ville de Marseille/GIS Posidonie/Centre d'Océanologie de Marseille.

Terlizzi, A., Fraschetti, S., Guidetti, P., Boero, F., 2002. The effects of sewage discharge on shallow hard substrate sessile assemblages. Mar. Poll. Bull. 44, 544–550.

Tsounis, G., Gili, J.M., Arntz, W.E., 2006. Population structure of an exploited benthic cnidarian: the case study of red coral (*Corallium rubrum* L.). Mar. Biol 149, 1059–1070.

Tsounis, G., Rossi, S., Gili, J.M., Arntz, W.E., 2007. Red coral fishery at the costa brava (NW mediterranean): case study of an overharvested precious coral. Ecosystems 10, 975–986.

UNEP-MAP-RAC/SPA, 2008. Action plan for the conservation of the coralligenous and othercalcareous bio-concretions in the Mediterranean Sea. Ed. RAC/SPA, Tunis.

UNEP-MAP-RAC/SPA, 2011. Proposal for the definition of standard methods for inventorying and monitoring coralligenous and maërl populations. Ed. RAC/SPA, Tunis.

United Nations Environment Programme, 2007. Draft decision on the adoption of the guidelines concerning pleasure craft activities and the protection of the marine environment in the Mediterranean United Nations Environment Programme, Madrid.

Valiela, I., 1995. Marine Ecological Processes. Springer Edition, New York, USA.