An ecosystem-based approach to assess the status of the Mediterranean coralligenous habitat.

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AN ECOSYSTEM-BASED APPROACH TO ASSESS THE STATUS OF THE MEDITERRANEAN CORALLIGENOUS HABITAT

Abstract
Coralligenous outcrops are a Mediterranean sciaphilic habitat whose three-dimensionally layered communities develop on a basal biogenic concretion of calcareous red algae, along with a rich assemblage of sciaphilic sessile animals. The complexity of the evaluation of the ecological status of coralligenous is on a par with the complexity of this habitat. Biotic indices developed to implement the EU Water Framework Directive reflect the ecological status of the environment using species whose function, population or status depend on the quality of the water column. However, the state or achievement of good quality in a water body and the apparent health of some biological indicators are not always indicative of good structure and functioning of the whole ecosystem, even if they are key-species or ecosystem engineers. The new indices to be developed according to the Marine Strategy Framework Directive (MSFD) of the EU require an ecosystem approach, which takes into account the functioning of the ecosystem. Here, on the basis of a simplified conceptual model of the ecosystem, we propose an Ecosystem-Based Quality Index (EBQI) focused on the structure and functioning of coralligenous outcrops. The coralligenous EBQI is based upon (1) a set of representative functional compartments, (2) the weighting of these compartments and (3) the assessment of their quality by comparison with an assumed baseline. The implementation of the EBQI is non-destructive, relatively robust, according to the selection of the compartments and to their weighting, and is associated with confidence indices (both at the level of each compartment, and for the overall score), thus indicating possible weaknesses and biases in the data and therefore the need for further field data acquisition.

Key-words: Coralligenous; Ecosystem-based approach; Marine Strategy Framework Directive; biotic index; Mediterranean Sea.

Introduction

Depending on a number of biotic and abiotic factors, several assemblages could coexist or dominate in coralligenous habitats, over a wide depth distribution range (from 20 m down to −120 m). Even if coralligenous outcrops are not a single habitat but a combination of different habitats, we will use hereafter the term of 'ecosystem'. According to Ballesteros (2006), the coralligenous outcrop is a hard substratum of biogenic origin mainly produced by encrusting calcareous algae growing in dim light conditions. Even if such algae could also grow near the surface, shallow-water concretions are excluded from this work. Human activities can profoundly alter the environment, species composition and the functioning of the coralligenous ecosystem. Biotic indices, which reflect the quality of the environment, are extensively used in the marine realm, especially in the context of European Directives, to (i) assess the quality of a water body, (ii) to indicate the respective weighting of processes such as e.g. currents, sedimentation and climate under natural and anthropogenic forcing, and (iii) to monitor the status of species of interest, whether emblematic species, indicators of ecosystem health or indicators of pollution. However, does an index based on the health of a single species give information about the health of the entire ecosystem to which it belongs, even if it is a key-species or an ecosystem engineer? A key point in the Marine Strategy Framework Directive (MSFD, 2010/477/EU) is based on the ecosystem-wide evaluation of the 'good environmental status' in order to ensure that the marine environment is at a level that allows uses, exploitations and activities by current and future generations.

Material and methods

The method developed by Personnic *et al*. (2014) for *Posidonia oceanica* meadows has been adapted to the coralligenous ecosystem. The first step was to design a simplified conceptual model of the functioning of the ecosystem; it includes 10 functional compartments and 11 parameters (Fig. 1; Tab. 1). The DELPHI process was used to integrate the expert judgment (Dalky & Helmer, 1963). For each ecosystem compartment, a set of relevant parameters according to expert judgment was chosen and assessed through a semi-quantitative scale: very bad (0), bad (1), moderate (2), good (3), and very good (4) ecological status (S in equation 1). Compartments were balanced, according to their relative weight (W) in the ecosystem functioning according to expert judgment, from 5 (highest weight) to 1 (lowest weight). The scores of all compartments were added up, is on a par with which gave the final mark of the ecosystem status (Ecosystem Based Quality Index EBQI) at a given site. For practical purposes, the EBQI was converted to a scale from 0 (worst quality) to 10 (best quality) (equation 1).

$$EBQI = \left[\sum_{i=1}^{11}(W_i \times S_i) / \sum_{i=1}^{11}(W_i \times S_{max})\right] \times 10 \qquad \text{Equation (1)}$$

For each compartment status, a Confidence Index (CI) was proposed. The CI was evaluated through a semi-quantitative scale: (0) no quantitative field data and no suitable expert judgment; (1) no quantitative field data, but ancient expert judgment; (2) no quantitative field data but recent expert judgment; (3) field data recent, partially completed with expert judgment and (4) field data available, recent and suitable, obtained with the recommended methods. The Confidence Index of the EBQI (CI_{EBQI}), which ranges between 0 (worst) and 10 (best), was obtained by equation 2:

$$CI_{EBQI} = \left[\sum_{i=1}^{11}(W_i \times CI_i) / \sum_{i=1}^{11}(W_i \times CI_{max})\right] \times 4 \qquad \text{Equation (2)}$$

Results

A simplified conceptual model of the functioning of coralligenous ecosystem has been designed using scientific expert judgement and information collected from the literature (*in* Ballesteros, 2006 and references therein). This model encompasses the following compartments (boxes; Fig. 1):

The builders, *i.e.* MPOs (Multicellular Photosynthetic Organisms) and invertebrates (box 1; Fig. 1). The framework of coralligenous outcrops is the bioconcretion by mainly encrusting, foliaceous and articulated calcareous 'macroalgae' (MPOs) belonging to the Corallinales (red algae). This biogenic concretion is not only due to primary producers, but also to invertebrate builders (bryozoans, serpulid annelids, etc.), with more than 120 species are known to contribute to the frameworks (Hong, 1980).

The non-calcareous MPOs (box 2; Fig. 1). This compartment encompasses erect macrophytes (arborescent and shrubby; *e.g. Phyllariopsis brevipes*, *Sebdenia dichotoma*).

Benthic filter- and suspension-feeders (box 3; Fig. 1). A large number of filter- and suspension-feeders dwell in the coralligenous outcrops: bryozoans (*e.g. Pentapora fasciata*), cnidarians (e.g. *Paramuricea clavata, Eunicella cavolini*), sponges (*e.g. Agelas oroides*), etc.

Bio-eroders (box 4; Fig. 1). Numerous organisms, whether microborers, macroborers or grazers (*i.e.* raspers), erode calcareous concretions, in particular the excavating sponges (Clionaidae), cyanobacteria, molluscs, and sea urchins.

Browsers - Grazers (box 5; Fig. 1). This compartment encompasses herbivores and carnivorous organisms that browse benthic non-calcareous MPOs and invertebrates, other than builders.

Planktivorous teleosts (e.g. *Anthias anthias*), **predatory teleosts** (*e.g. Diplodus* spp.) and **cephalopods** (e.g. *Octopus vulgaris*), **high-level predators** (*e.g. Epinephelus marginatus, Dentex dentex*) (boxes 6, 7 and 8; Fig. 1) encompass all teleosts and cephalopods that could be sampled by visual censuses. Planktivorous teleosts, although exploiting the water column, and therefore another ecosystem, are taken into account here because they spend part of their life (*e.g.* at night) in coralligenous outcrops.

Benthic POM (box 9; Fig. 1). This compartment corresponds essentially to the fraction of dead MPOs, detritus imported from adjacent habitats, and all kinds of particulate matter.

Detritus feeders (box 10; Fig. 1). Detritus feeders constitute a complex compartment. Here we have chosen to quantify Holothurioidea and *Bonellia viridis* as proxies.

Other compartments, not numbered in the conceptual model (Fig. 1; plankton, POM, pelagic microbial loop, pelagic DOC, POM), will be not quantified here because of the difficulty of obtaining data in the framework of a monitoring approach.

Compartments 1 to 5, 9 and 10 were sampled in part using 30 photographic quadrats 0.5-m × 0.5-m along a 40-m long transect (Deter *et al*., 2012) and species seen during the field work. The coralligenous composition in terms of species was evaluated as 1 666 species (315 MPOs, 61 unicellular eukaryotes, 1290 metazoans including 110 fish species) according to Ballesteros (2006). Here, the builder (box 1), filter (box 3) and browser-grazer species (box 5) taken into account are the principal species to be considered for the inventory listed by UNEP-MAP-RAC/SPA (2011). For browser-grazers, we have added 5 opistobranchs (*Cratena peregrina, Flabellina affinis, F. pedata, Felimare picta, Peltodoris atromaculata*). The number of strata for builders (box 1) was evaluated by the use of the Rapid Visual Assessment (RVA) method proposed by Gatti *et al.* (2012) and modified by the INDEX-COR method (Stéphane Sartoretto pers. comm.).

The compartments of teleosts and cephalopods (boxes 6 to 8; Fig. 1) were estimated by visual censuses at a standardized daytime (10:00 to 16:00 UT) during the warm season (summer-autumn) in the same site than benthic compartments.

All teleosts and cephalopods were counted within ten linear 20-m long and 2-m wide transects. Total length (to nearest 2 cm) of individuals and the number of individuals per species were noted. These data enable calculation of teleost biomass.

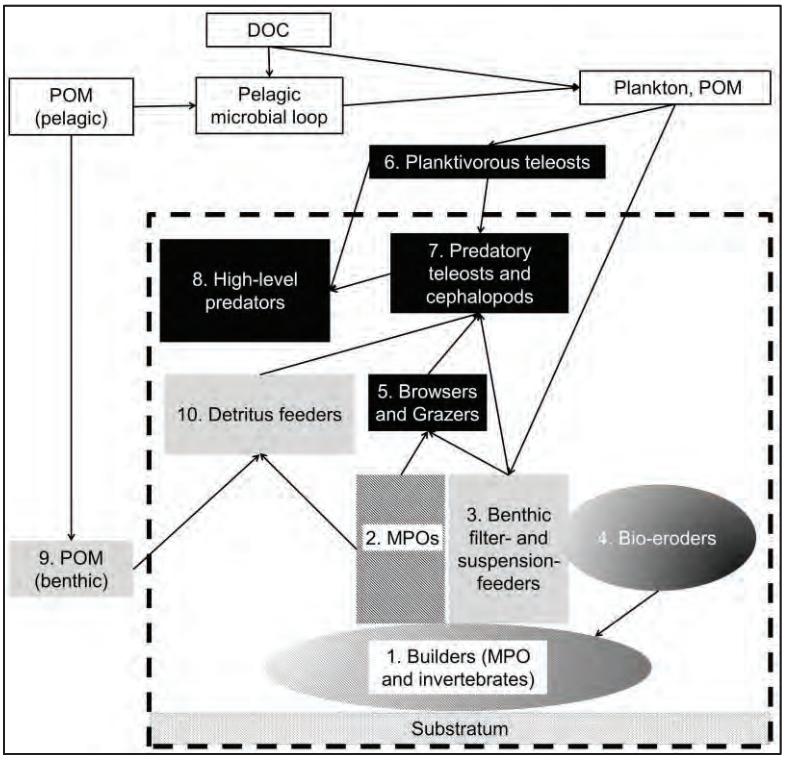

Fig. 1: Conceptual model of the functioning of a coralligenous ecosystem. For functional compartments and box numbers, see text. Primary producers (MPOs) are in hatched frame; predators and browsers - grazers are in black; pelagic particular organic matter (POM), pelagic microbial loop, plankton and dissolved organic carbon (DOM) are in white; benthic POM, detritus feeders, benthic filter-feeders are in grey; compartments that belong to several categories are in gradient color. The sensu stricto coralligenous ecosystem is included within the hatched rectangle.

The Specific Relative Diversity Index (SRDI) is the mean number of species met with per transect. Considered components of the coralligenous habitat and respective evaluation criteria are presented in Table 1.

Discussion and conclusion

The assessment of the EBQI in coralligenous outcrops usually calls for complex diving logistics because of the depth at which they thrive. We have chosen the use of photographic quadrats as sampling method because it involves spending less time for diving and provides information for several compartments. In fact, photographic quadrats are currently used in several protocols (Cecchi & Piazzi, 2010; Kipson *et al*., 2011; Deter *et al*., 2012). However, the photographic methods involves image processing, which is also time-consuming. The use of the EBQI needs to (i) to assess the status of the compartments in non-human impacted areas and (ii) to be adapted according to biogeographic features. A similar methodology has already been tested on *Posidonia oceanica* meadows, the best documented marine ecosystem of the Mediterranean coastal areas, and it has been applied to seventeen sites (Personnic *et al*., 2014), showing that (i) EBQI was not redundant with already existing indices and (ii) EBQI was robust even if some arbitrary choices are possible for the considered compartments and their weighting (expert judgment).

Tab. 1: Functional compartments of the coralligenous ecosystem, box number, weight and parameters used to evaluate the ecological quality (status from 0, very bad to 4, very good). cp: calibration in process, * species listed by UNEP-MAP-RAC/SPA (2011), $^{\Theta}$ 5 opistobranchs added (see the text).

Box number / weight	Functional compartment	Parameters	Status				
			4	**3**	**2**	**1**	**0**
1 / 5	Builders (MPOs and invertebrates)	Number of builders species (34 listed)*	≥25	15 to 24	10 to 14	6 to 9	≤5
		Cover of non-disrupter species (%) (others than invasive, eroder, tolerant species)	>75%	>50 to 75%	>25 to 50%	>0 to 25%	0%
		Number of strata (basal (0-5 cm height), intermediate (5-15 cm) and upper (>15 cm)	3 strata >50% of cover	3 strata <50% of cover	2 strata	1 stratum	0 stratum
2 / 3	Non-calcareous MPOs (facies dominated by MPOs)	Number of MPO species (34 listed)*	≥25	15 to 24	10 to 14	6 to 9	≤5
		Cover of non-disrupter species (%)	>75%	>50 to 75%	>25 to 50%	>0 to 25%	0%
		Number of strata (arborescent, shrubby, turf-forming, encrusting)	4 strata	3 strata	2 strata	1 stratum	0 stratum
	Non-calcareous MPOs (facies dominated by fauna)	Number of strata	4 strata	3 strata	2 strata	1 stratum	0 stratum
3 / 5	Filter and suspension feeders	Density (m^{-2}) or cover (%)	cp	cp	cp	cp	cp
		Number of filter species (43 listed)*	≥30	20 to 29	12 to 19	6 to 11	≤5
4 / 5	Bio-eroders	Eroding sponges (Clionaidae)	Scarce papillae	Few papillae	Moderately abundant papillae	Abondant papillae	Massive specimens
		Density of sea urchins (*Echinus melo* and *Sphaerechinus granularis*) or erosion marks	cp	cp	cp	cp	cp
5 / 3	Browsers and grazers	Density of invertebrates (m^{-2})	cp	cp	cp	cp	cp
		Number of browsers and grazers (12 listed)*$^{\Theta}$	≥10	7 to 9	4 to 6	3 - 2	≤1
6 / 2	Planktivorous teleosts 'planktivorous'	Zooplankton feeders (kg WM 100 m^{-2})	cp	cp	cp	cp	cp
		Omnivores teleosts (kg WM 100 m^{-2})	cp	cp	cp	cp	cp
7 / 2	Predatory teleosts	Teleosts (kg WM 100 m^{-2})	cp	cp	cp	cp	cp
8 / 4	Piscivorous teleosts	Teleosts (kg WM 100 m^{-2})	cp	cp	cp	cp	cp
6-8 / 3	All teleosts	Specific Relative Diversity Index (SRDI)	≥8	<8 to ≥6	<6 to ≥4	<4 to ≥3	<3
9 / 2	Benthic detritus matter (POM)	Cover (%)	0-10%	>10 to 25%	>25 to 50%	>50 to 75%	>75%
10 / 3	Detritus feeders	Density of Holothurioidea, and *Bonellia viridis*	cp	cp	cp	cp	cp

However, since coralligenous outcrops are a much more complex and less well-known ecosystem than *P. oceanica* meadows, calculation of coralligenous EBQI will require the participation of experts in several fields of marine ecology. Its implementation may require the participation of several Mediterranean research teams and could contribute to the development of new scientific networks.

Acknowledgements

This work is included in the scientific program GECO med, funded by the French Water Agency Rhône Méditerranée Corse (AERMC) and the French Agency of Marine Protected Areas (AAMP).

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