



Multidisciplinary rapid assessment of coastal areas as a tool for the design and management of marine protected areas



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ABSTRACT

A method is described for rapid multidisciplinary environmental assessment of coastal areas within the conceptual framework of comprehensive management of Marine Protected Areas (MPAs). The aim is to provide tools for the selection, design and management of coastal MPAs when time, budget or potential human pressures, either alone or in combination, create an urgent need for prioritisation. Maximising results and minimising cost and time is the goal, using a methodology that re-evaluates existing information on the area, allows use of physical, environmental and socio-economic indicators, and finally integrates information in a Geographic Information System capable of generating outputs in the form of thematic maps to support managers.

The final products obtained inform planners and managers about the study areas, across multiple aspects that all need to be considered in integrated coastal management. Although originally proposed for widespread use in the Mediterranean, this methodology can be flexibly adapted, with minor modifications in the selection of indicators, for its use in other regions. The results show its potential for merging and synthesising information not only as a tool in Rapid Assessment Programs but also as a tool for facing management of wide coastal areas as social-ecological ecosystems.

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Introduction

The management of coastal areas must integrate information from a multi-disciplinary perspective, including governance, human uses and activities, and ecological quality or status of habitats and their spatial distribution (Agardy 2010; Barragán Muñoz 1997; Pomeroy et al. 2004; Post et al. 1996). Related cartographic products are main tools used to support ecosystem based coastal zone management (Agardy 2010; Nobre & Ferreira 2009). Getting these maps can be challenging, however. The data collection for mapping parameters related to benthic habitats (Kenny et al. 2003; Sheehan et al. 2010), spatial distribution of human activities (Balaguer et al. 2011; Halpern et al. 2009), water quality or bio-physical indicators (see Pomeroy et al. 2004, for a review of

indicators), may need specific, sometime costly, equipment and time-demanding post processing procedures. Additionally, field work in coastal areas is highly dependent on the sea conditions. These constraints must be considered when planning time and budget for data collection prior to developing a management plan for a coastal area.

The collection of information in the field when time and budget is limited is what led to the emergence of Rapid Assessment Programs or RAPs (Alonso et al. 2011). These programs, originally designed for the conservation of the natural environment, formally came into being at the end of the 1980s with two different objectives in mind: (1) to quickly provide the minimum biological information needed to bring forward conservation proposals and actions; and (2) to improve biodiversity conservation in these areas through management measures implemented as a result of the assessments.

So far, most RAPs programs in the marine environment focus on tropical environments (DeVantier et al. 1998; Dutra et al. 2006; Kramer 2003; McKenna 2011; Wilkinson et al. 2006). There are very few examples of applications in the Mediterranean, mainly related to surveys of the biodiversity of Greek coastal lagoons (Arvanitidis

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et al. 2005), the monitoring of the Albanian coast for the loggerhead turtle and the monk seal (White et al. 2005), and the evaluation of oil spill effects in the sea during the 2006 Israeli-Lebanese conflict (Steiner 2006). In the Mediterranean, considered a biodiversity hot spot at a global level (Myers et al. 2000), Marine Protected Areas (MPAs) are an important management approach for conservation (García-Charton et al. 2008).

The percentage of Mediterranean littoral zone that has been evaluated from a comprehensive ecological perspective with conservation in mind is rather low, further complicating proper MPA design and implementation. Most of what has been already surveyed is along the northern coast, particularly the sector located in the most developed countries, and in particular the European countries with a coastline affected by the obligations of Habitats Directive 49/92 and the Natura 2000 network. Although rather complete in ecological terms, the selection of Natura 2000 sites is based exclusively on habitats, and gaps in knowledge about uses and impacts in the marine arena are still pervasive. Total MPA coverage is still minute in the Mediterranean Basin (De Juan et al. 2012) and basic knowledge of huge stretches of littoral from North Africa and the Eastern Mediterranean is still rather poor. Considering the present day situation in the context of global environmental initiatives, Objective 11 of the Nagoya Conference – which encourages the Parties of the Convention on Biological Diversity to take actions in order to declare at least 10% of their territorial waters as MPAs, is far from being reached.

Developing a RAP framework for Mediterranean coastal areas would be of interest for coastal planners and management agencies aiming to design MPAs, especially in areas where the existing information is poor and/or the resources or time available may restrict more expensive and time demanding sampling programs. Even in places where scientific information exist, efforts must be made in the development of comprehensive tools for connecting science and decision makers (Gregr & Chan 2011), especially in complex Social Ecological Systems (SES) such as those that exist in most sites where MPAs are or will be designated (Pollnac et al. 2010).

Although MPAs are best designed by thoroughly assessing community perceptions, socio-economics, politics, and institutional weaknesses and strengths, a cost-effective RAP can provide the foundation for selecting target sites around which to begin such participatory planning processes. The information obtained from multidisciplinary RAP can also help harness the ecological science for the purposes of management, by highlighting which areas within the overall target area are most critical to protect, which human activities are sources of potential conflicts and which stakeholders will be affected by new regulations.

Thus, there is an interest in developing specific assessment methodologies for coastal conservation purposes that adopt a systemic approach going far beyond the simple management of fishing resources or the protection of a particular habitat or species. Multidisciplinary coastal RAPs will facilitate ecosystem based marine management (Agardy 2010) serving as basis for implementing actions in zoning, management and regulation of coastal areas requiring protection.

In this work we propose a rapid assessment methodology for coastal marine areas, integrating information of human activities and bio-physical aspects of the area under study, selecting a set of indicators and integrating them into final products to support decision making processes. These products are designed to be discussed openly, prior to MPA declaration, in order to grant the local stakeholders a relevant role in the decision taking procedures.

To be rapid and cost effective, the method has been based on obtaining and merging existing information for the area, knowledge of local stakeholders, and an optimized design of in situ sampling. The main outputs consist of three cartographic products, giving information on: (a) human pressure; (b) marine

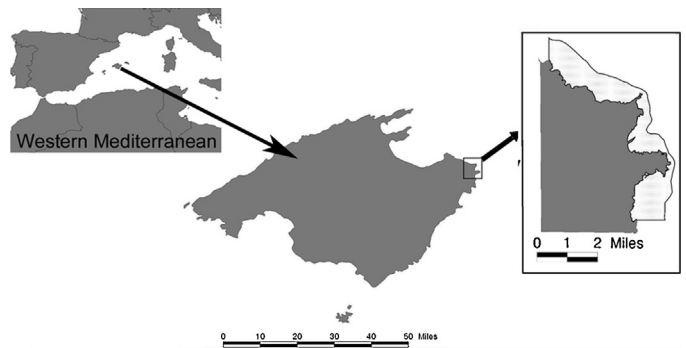


Fig. 1. Majorca Island, Balearic archipelago, NW Mediterranean. Location of study site.

environment quality; and, (c) coastal environmental quality, as well as a matrix of conflicts between different human activities.

The proposed methodology was tested in a coastal area of Mallorca Island (Balearic archipelago, NW Mediterranean) that comprises 26 linear km of coast, covering a total of 2013 ha (1445 ha of marine surface and 568 ha of land) and including a main fishing and leisure boat harbour, Cala Ratjada (Fig. 1). This study area was selected because it presents multiple human activities characteristic of the western Mediterranean coast, both on the terrestrial and the marine side as well as different levels of anthropogenic impacts.

Methods

The information needed to address the multidisciplinary approach was identified from studies oriented to the selection of candidate sites for MPAs (Roberts et al. 2003), MPA evaluation and zonation (Kelleher 1999; Pomeroy et al. 2004; Villa et al. 2002), general Integrated Coastal Zone Management (ICZM) (Barragán Muñoz 1997), integration of information obtained from local stakeholders (Vella et al. 2009), and integrated management of Mediterranean MPAs (Ojeda-Martínez et al. 2009). The general framework to rank indicators and develop cartographies has been adapted from already proposed methodologies developed for terrestrial environment (Machado 2004) and for coastal areas (Ballesteros et al. 2007).

Based on these studies we adapted a number of available environmental and socio-economic indicators. When different indicators provided information about a common subject they were grouped into indices facilitating data management and interpretation (Ebert & Welsch 2004; Hargrave 2002).

The selection of indicators and their corresponding weighting factors have been obtained by a “nominal group technique of experts” (Stewart et al. 2007) that allows the capture of most of the knowledge flow among experts. For the application of this technique, experts on coastal conservation, marine protected areas monitoring and marine biology make an initial design proposal for each index (identification of indicators and weighting factors), including a rationale for the proposal. Information is then shared among experts. After similar proposals were grouped or eliminated, an open discussion forum ends with a second proposal and ranking of solutions.

The selection of indicators for the RAP was guided by the following criteria: (a) easy to measure; (b) data gathering without the need to install oceanographic equipment; (c) adjustable to simple scales of measurement; and (d) minimising the need for data processing after sampling. Selected indicators were classified according to their spatial scale and to the origin of the information. Indicators at macroscale (>1 km), mesoscale (100–500 m) and microscale (<100 m) levels were identified. Indicators were divided into two kinds: Class 1, derived from existing information or interviews to local stakeholders; and Class 2, based on in situ sampling.

Table 1
List of indicators.

Class	Scale	Name	Variable	Id.
1	Macro	Degree of exposure index	Habitat quality for rocky fish communities	1
		*Human activity pressure indices (activity specific)	One pressure index for each human activity identified	2
		*Fisheries diversity index	Species and habitat richness	3
		Urban pressure index	Human pressure in the coast	4
		Level of administrative protection	Inclusion or non inclusion of Natura 2000 sites, MPAs, etc.	5
	Meso	*Quality diving site index	Habitat quality state	6
		*Intensity of recreational diving	Pressure by recreational scuba diving	7
		Biodiversity hotspots	Habitat and fish community richness	8
		Habitat of interest	Presence of habitats of community interest (Dir 43/92), threatened and/or legally protected	9
	Micro	Naturalness index	Coastal state of conservation.	10
		Water quality from coastal macro algae	Coastal water quality	11
		Seabird index	Degree of habitat conservation	12
		Habitat mesoscale index	Quality of habitat	13
		Habitat microscale index	Quality of habitat	14
		Invasive algae	Degree of wild state	15
		Singular species	Degree of wild state	16

* Information collected from questionnaires.

The complete list of indicators, the scales to which they belong and the variable about which it gives information about are presented in Table 1.

Human activities pressure indices (id. 2, Table 1), Fisheries diversity index (id. 3, Table 1), Habitat mesoscale index (id. 13, Table 1) and Habitat microscale index (id. 14, Table 1) are related to human activities, fisheries diversity and habitats of interest found in the study area. Therefore the methodology has to be easily adapted to the local characteristics. Here we propose the generic methodologies for data collection, indicator calculation and ranking.

Macroscale indicators were always Class 1 indicators as they relate to geographically wide areas. The method is designed to avoid having to complete in situ sampling along the entire study area, taking instead existing information and knowledge from local stakeholders and combining those with limited sampling. Mesoscale indicators were Class 1 – when they were calculated from interviews or Class 2 – when they were referred to habitat characteristics. Microscale indicators, giving information about environmental quality of particular habitats were always Class 2 indicators.

Categorisation of indicators is an advantage when different types of information have to be merged in “easy-to-use” products for managers (Hargrave 2002). Following this approach local values of indicators presented in Table 1, used for calculation of final products were standardised to simple scales 1 (very low), 2 (low), 3 (medium), 4 (high) and 5 (very high), interpretation of values are provided for each indicator within the methodology.

A scheme of the three methodological phases and specific activities is presented in Table 2.

Phase 1

Task 1.1. Compilation of existing information

Several sources of spatial data for the study area, both for the terrestrial and marine environments, were explored among the different administrations at local, national and European levels as well as online public remote sensing data sources. Previous research studies on the marine environment, especially those related to local fisheries in the area, were also compiled. Key administrative bodies and other local stakeholders were identified.

Task 1.2. Structured interviews

The local stakeholders were guided through structured interviews (Taylor & Bryan 2002) to complete predefined questionnaires.

Three types of questionnaires were designed for the study area for collecting information proposed as relevant for evaluating management effectiveness of MPAs from local stakeholders (Vella et al. 2009):

Questionnaire 1: Fisheries related information: Structured interviews to fishermen and fisheries technicians provided the identification of fishing tactics (gears) of professional and recreational fisheries, target species, fished habitats and other habitats of interest in the area, and the spatial distribution of fishing effort of each tactic. Spatial distribution of fishing effort was evaluated by stakeholders from 1 – areas supporting minimum fishing effort – to 5 – areas supporting maximum fishing effort.

Questionnaire 2: Diving related information: Structured interviews to diving centres/clubs, those responsible for marine monitoring and marine researchers provided information about: scuba diving locations and relative diving pressure at site, their relative quality in terms of seascape and the locations of biodiversity hot spots and identification of habitats of interest in the area.

Questionnaire 3: Human pressure related information: Structured interviews to stakeholders allowed identification of important human activities in the area, the relative intensity of its spatial distribution and the degree of conflicts among all activities.

Parameters in questionnaires 2 and 3 were evaluated by stakeholders from 1 to 5 five following similar ranks to those in questionnaire 1.

Task 1.3. Setting up a GIS and development of seabed cartography

A GIS (ArcView 3.2, ESRI Inc.) was set up to manage all cartographic information from tasks 1.1 and 1.2. This information was used for delimitating marine habitats of interest and designing a grid. Each cell of the grid acquired a value for each indicator (Fig. 2). The grid cell size is chosen based upon spatial information accuracy of maps obtained in task 1.1. When one of the habitat mesoscale or microscale index presented different values in one cell due to the presence of different habitats of interest, the maximum value was given to the cell.

Cells located over an area affected by the presence of a harbour were flagged as *harbour affected area* and were excluded from the evaluation of any other indicator, ensuring that cells are easily identifiable in all final products.

The cartographic information integrated into the GIS was used to generate three base maps (herein referred as study area *descriptors*) used for the later calculation of environmental indices and identification of in situ sampling sites. The three base maps are:

Table 2
Methodological phases and tasks.

Phase	Task	Activities
Phase 1	1.1 Compilation of existing information And GIS development	Compilation of cartography, previous studies, main human activities in the area, identification of local experts Setting up a GIS
	1.2 Structured interviews	Development of questionnaires for the structured interviews Conducting interviews with relevant stakeholder to collect information about: (1) Fisheries; (2) Diving sites and biodiversity hot-spots; and, (3) Human activities and conflicts
	1.3 GIS project and drawing up descriptors base maps	- Setting a GIS and the grid map for data integration - Develop cartography of study area descriptors Geomorphologic units, Homogeneous slope areas and main habitats - Identification of target habitats for evaluation
	1.4 Calculation of Class 1 indicators	Evaluate and standardise the Class 1 indicators (Table 1)
Phase 2	2.1 In situ sampling indicators that do not require underwater techniques	I Naturalness index for the terrestrial side of the coast (indicator 10 in Table 1) II Water quality and the seabird index for the marine side of the coast (indicators 11 and 12 in Table 1)
	2.2 Identification of mesoscale units and calculation of habitat mesoscale indices	For each habitat under evaluation: I Identify relevant mesoscale habitat specific indicators II Delimitation of areas where mesoscale habitat specific indicators. Present homogeneous values III Sampling the mesoscale habitat specific indicators at each unit of analysis IV Process mesoscale index
	2.3 Identification of microscale sampling locations and calculation of habitat microscale index	For each habitat under evaluation: Delimitate areas of homogeneous mesoscale habitat specific indicators values. Sample microscale habitat specific indicators at each area delimited
Phase 3	3.1 Process final products	I Thematic map of marine environment quality II Thematic map of terrestrial environmental quality III Thematic map of human pressure IV Activities conflict matrix

- *Map of geomorphologic units*: Delimitation of areas with similar geomorphologic structures. Different geomorphologic classes were adapted locally from information collected in task 1.1.
- *Homogeneous slope areas*: Delimitation of areas with homogeneous values of bathymetric slopes calculated from bathymetric data obtained from task 1.1. The grid cells are ranked from 1 (very low slopes) to five (very high slopes).
- *Map of marine habitats*: Delimitation of main habitats identifiable in the area from cartographic products collected in previous tasks.

Habitats in the study area that will be evaluated during the assessment have to be selected with the information coming from tasks 1.1 and 1.2. Specific information to evaluate the quality status of those habitats is based on a set of meso and microscale indicators, which are either selected or adapted from scientific literature.

Task 1.4. Calculation of Class 1 indicators

Degree of exposure index: Areas of the same habitat with similar slopes are delimited. Based on the effect of slopes in the species richness of fish assemblage (Hamner et al. 1988; Harmelin 1987; Kiflawi & Genin 1997; McGehee 1994) ranks for each area are proposed as follows: (1) gently sloping coves and bays that

connect without discontinuity with respect to adjacent shoreline; (2) straight, gently, sloping shoreline; (3) small caves, closed and shallow with bathymetric and habitat discontinuity with respect to the exterior; (4) islets or capes with even depths and habitat similar to those on the surrounding coast, straight shorelines with cliffs and sharp bathymetric drops; and, (5) islets or capes with sharp bathymetric drops that contrast with the surrounding coast.

Human pressure indicators: Adapted from previous studies (Pomeroy et al. 2004; Vella et al. 2009; Villa et al. 2002). Questionnaires obtained in task 1.2 provided grid maps of activity pressure in the area. The final value of pressure index for each activity was calculated by means of the spatial distribution values obtained from the questionnaires.

The fisheries diversity index informs about the species diversity and type of habitats. Values associated to fishing grounds were locally ranked from one – low diversity of target species being fished on low interest habitat – to five-high diversity of species being fished over habitats of interest. Local ranks were obtained through a nominal group technique who evaluated the fisheries operating at each fishing ground in the study area. The evaluation of fisheries data to obtain fishing ground indicators has been adapted from Mouillot et al. (2002).

The urban pressure index: Values were assigned as a function of buildings and roads density based on aerial photos and maps.

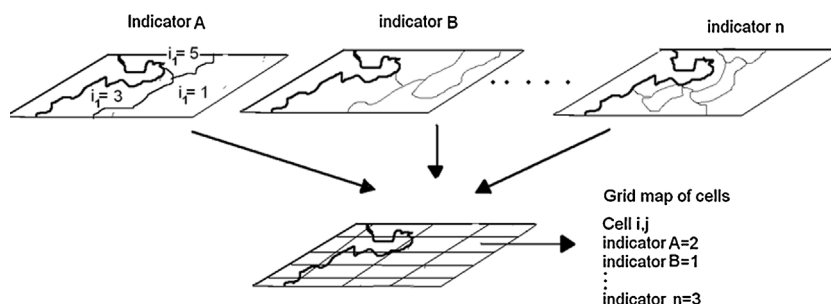


Fig. 2. GIS scheme for integration of indicators and indices.

Areas with a similar density of urban development were grouped and values were assigned to the area from one (very low pressure: absence of buildings and/or roads in the cell, to five: very high dense urban development).

The level of protection. Ranked from one, areas not protected, to five, maximum protection level for biodiversity conservation found inside the study area; equivalent to a marine or terrestrial reserve, or a marine no entry/no take zone (Pomeroy et al. 2004).

Mesoscale Class 1 indicators: *Quality diving site index*, *Biodiversity hotspots* (id. 7, Table 1) and *Habitat of interest*, allowed mapping of diving site locations that are highly prized by both divers and clubs, and already known by local divers. Pressure on these areas is measured with the *Intensity of recreational diving value*. The indicators were proposed, with slight modifications, from Vella et al. (2009). They are ranked from one to five, from standardised means of the spatial distribution values obtained from the questionnaires in task 1.2.

Phase 2

Task 2.1. Sampling of indicators that do not require underwater techniques

Aerial pictures from task 1.1 and landscape photographs taken by the working team assessed the main habitats and state of conservation for the evaluation of the naturalness index (Machado 2004).

The macroalgae indicator species was evaluated visually in the surf zone during surveys along the coast for the calculation of the water quality index. Surveys were conducted in spring – due to the seasonal growth of the algae considered for the calculation of this index – with an inflatable boat that allowed nearshore sampling (Ballesteros et al. 2007). Seabird values were obtained from the location of the colonies of threatened seabird species observed during these surveys.

Task 2.2. Identification of units of analysis for the selection of mesoscale underwater sampling sites and calculation of habitat mesoscale index

The set up of the site sampling selection procedure begins with the identification of homogeneous areas which have to be sampled at meso and microscale levels, herein referred as *units of analysis*, which are habitat specific. The identification of these areas starts with the selection of the main environmental variables that drive and control the development of that particular habitat. These environmental variables are expressed as indicators calculated from previously obtained information and ranked from one to five. Areas with homogeneous values are delimited, defining the *units of analysis* of that particular habitat. Each unit of analysis has to be sampled to obtain representative values of the mesoscale habitat specific indicators. The number of samples per unit of analysis can be adjusted to the time and budget available. This approach for sampling stratification allows maximising of resources to ensure the collection of a spatially representative sample of mesoscale indicators.

Once the selected sites have been sampled, mesoscale indicator values must be transferred to the cells in the grid map of the GIS. Other non sampled cells where that habitat is present take the value for each indicator from the closest sampled site in the same unit of analysis.

For each habitat, mesoscale indicators were grouped into the habitat specific mesoscale index designed by a nominal group technique.

Task 2.3. Identification of microscale sampling locations and calculation of habitat microscale index

Samples of microscale habitat specific indicators have to be taken at representative sites for the mesoscale index homogeneous areas inside each unit of analysis of that habitat, and eventually at hot spots identified in phase 1. If budget limitations affect microscale sampling regimes, sites must be selected to ensure data from units of analysis with the highest values of mesoscale index.

Microscale habitat specific indicators were grouped into the *habitat microscale index*, formulated specifically for each type of habitat following a *nominal group technique*.

Additionally two more indicators were always evaluated:

Invasive algae abundance index: Invasive algae present in the study area were identified in phase 1, percentage of coverage of the bottom was visually evaluated and final values were ranked from one to five (minimum and maximum coverage detected in the area).

Singular species with indicator value: Species with value in terms of conservation, and potentially present in the study area identified in phase 1, were selected for evaluation. The presence of each individual was annotated. On each transect a final value of abundance for each species identified was obtained. Abundances in the transect were ranked from one to five, corresponding to the minimum and maximum values in the area.

Phase 3

This phase consists of data analysis and generation of the final outputs, integrating the information provided by the indicators from three different perspectives: (1) an ecosystem evaluation reflected in the thematic map of marine environmental quality index and the thematic map of coastal environmental quality index; (2) the spatial distribution of human pressure, reflected in the thematic map of human pressure index; and, (3) the synergies of different uses and activities reflected in the activities conflict matrix.

Product 1: Thematic map of Marine Environmental Quality Index (MEI). The grid values are calculated from the sum of selected indicator classified in three levels according to the assigned weighing factors: indicators of the highest importance were assigned a weight factor of 2; indicators of high importance were assigned a weight factor of 1.5 and finally indicators of medium importance were assigned a weight factor of 1.

Final values obtained from each equation are ranked linearly from one (minimum value of the index in the study area) to five (maximum value of the index in the study one area).

$$\begin{aligned} \text{MEI} = & 2(\text{mesoscale index} + \text{degree of exposure index}) \\ & + 1.5(\text{fisheries diversity index} + \text{the biodiversity hot} \\ & \text{spots} + \text{singular species} + \text{microscale index}) \\ & + (\text{quality diving sites index} - \text{invasive algae} \\ & + \text{quality index derived from coastal macro algae}) \end{aligned} \quad (1)$$

Product 2: Thematic map of Coastal Environmental Quality Index (CEQI). Includes Class I indicators for the terrestrial environment giving information on environmental quality.

$$\text{CEQI} = \text{seabird index} + \text{naturalness index} - \text{urban pressure index} \quad (2)$$

Table 3
Fisheries diversity index local ranks.

Type of fisheries within each cell	Indicator value
Surface trolling line fishing area	1. Very low
Fishing areas with a concurrence of surface troll lines, trolling lines and hand lines	2. Low
Fishing for red mullet and cuttlefish (trammel nets) associated with seagrass meadows zones where hand lines fisheries converge	3. Medium
Ancient semi pelagic long line fishing grounds where surface and bottom troll lines are also used	4. High
Ancient fishing grounds for semi pelagic longline fishing and spear fishing for target species that are indicators of the reserve effect, where trolling is practiced and with fishing areas where trammel nets are used for red mullet	5. Very high

Product 3: *Thematic map of Human Pressure Index (HPI)*. Each cell takes the sum value of the activity pressure intensity processed from information obtained by questionnaires in Phase 1.

$$\begin{aligned} \text{HPI} = & \text{Anchoring Pressure index} + \text{Navigation pressure index} \\ & + \text{Professional fishing pressure index} \\ & + \text{Recreational fishing pressure index} \end{aligned} \quad (3)$$

Product 4: *Activities conflict matrix*. Assessing the present or potential conflicts among stakeholders is a key question to be considered for the management of MPAs (Vella et al. 2009). Here the evaluation is based on the matrix of conflicts, where activities and interests on the marine environment can eventually interact with each other (Barragán Muñoz 1997). Conflicts among activities were evaluated by stakeholders during questionnaires used in Phase 1.

Results

We field-tested the methodology by first identifying the relevant stakeholders, including: National Agency for Coastal Management, Balearic Government departments of fisheries and environment, local agency for cartographic data (SITIBSA), Administrative departments of Artá city, Spanish Oceanographic Institute and Mediterranean Institute for Advanced Studies, diving centres operating in the study area and the local fishermen association.

The main sources of cartographic information gathered during Phase 1 included nautical charts, remote sensing images from SPOT satellite obtained from Google Earth and aerial photographs from the coast provided by local government. The main source of information for identification of threatened species, indicator species, species of commercial interest and invasive species were found in inventories of fish communities in the Balearic archipelago (Riera et al. 1993), studies on invasive species (Boudouresque & Verlaque 2002), IUCN lists (Hilton-Taylor 2000) and local Red Lists (Mayol et al. 2011).

The main human activities identified during tasks 1.1 and 1.2 were professional and recreational fishing, swimming and tourism, navigation and anchoring, diving, harbour and urban development. The questionnaires developed for the *structured interviews* ($n = 14$) in task 1.2 allowed the distribution of human pressure from these activities to be mapped. This information also provided the spatial distribution of fishing tactics and identification of potential hotspots for biodiversity. The information related to local fisheries collected in task 1.1 and 1.2 allowed the setting up of the local ranks (Table 3) for the local fisheries diversity index.

Identified substrates and key habitat codes (Aguilar et al. 2006) in the study area were: 1 – Rocky reefs associated with submarine promontories; 2 – Rocky reefs associated with limestone islets; 3 – *P. oceanica* meadows over rocky platforms or sandy bottoms; 4 – Submarine caves; and, 5 – Sandy beds.

The *Geomorphologic units* base map descriptor were adapted from previous generic classification (Bird 2008) and included for

the experimental site: (1) cliffs; (2) flat rocky shore without scree; (3) flat rocky shore alternating with small caves; and, (4) beaches.

The *main habitats* descriptor base map obtained in task 1.3 was compared with bionomic maps from high quality sampling techniques (side scan sonar and trawled video) to evaluate the level and quality of the information provided by free access data and local fisheries distribution (Fig. 3). Based on this cartography, a grid cell size of 300 m was chosen, which represents six times the minimum mapping unit of the developed habitat map. This relation showed the best equilibrium between spatial definition required and spatial quality of available information. Class 1 indicators were calculated inside this grid. Cartography of *fisheries diversity index*, *naturalness index* and *human activity pressure index*, calculated for boat traffic navigation are presented as examples of cartographic results (Fig. 4).

The habitats selected for evaluation were those associated with rocky bottoms and *Posidonia* meadows, while sandy bottoms were excluded. This selection was based on the higher abundance of fish species that can respond to protection in these types of bottoms. Submarine caves were evaluated as part of rocky bottoms and following the same techniques.

Habitat specific indicators at mesoscale and microscale levels for each habitat selected for evaluation in the study area are presented in Table 4. Rationale for selection, techniques for sampling and ranks for these indicators are provided in Appendix A. Habitat macroscale and microscale indices obtained through the nominal group technique are provided in Appendix B.

Macroscale indicators (from Table 1) and area descriptors selected for delimitation of the units of analysis (task 1.5) for rocky bottoms were: geomorphologic units; degree of exposure index; and, depth. These variables were selected according to its effect on the richness of associated fish communities (García-Charton et al. 2000; García-Rubies 1997; Harmelin 1987; Massuti & Renones 2005), the dynamics of benthic communities (Ballesteros 1989, 1991; Wheeler 1980) and the richness of particular fish species (Harmelin 1987; McGehee 1994).

Seagrass meadows macroscale indicators considered for the delimitation of units of analysis were the degree of urban pressure index (id. 4, Table 1) and water quality derived from coastal macro algae. Both indicators are related to the introduction of organic elements and nutrients into the marine environment, which directly affects the state of health of meadows, particularly when these grow on sediments very rich in carbonates (Calleja et al. 2007; Diaz-Almela et al. 2008).

The sampling sites for application of mesoscale indicators were selected randomly in each unit of analysis. Data were gathered at sites of special interest, and additional mesoscale samplings were conducted at seabeds with high diversity associated with scree areas along with edges, promontories, islands and biodiversity hot spots identified during task 1.2. Nineteen sites were sampled in total.

The spatial distribution of the mesoscale index inside each unit of analysis allowed the establishment of several criteria for microscale site selection:

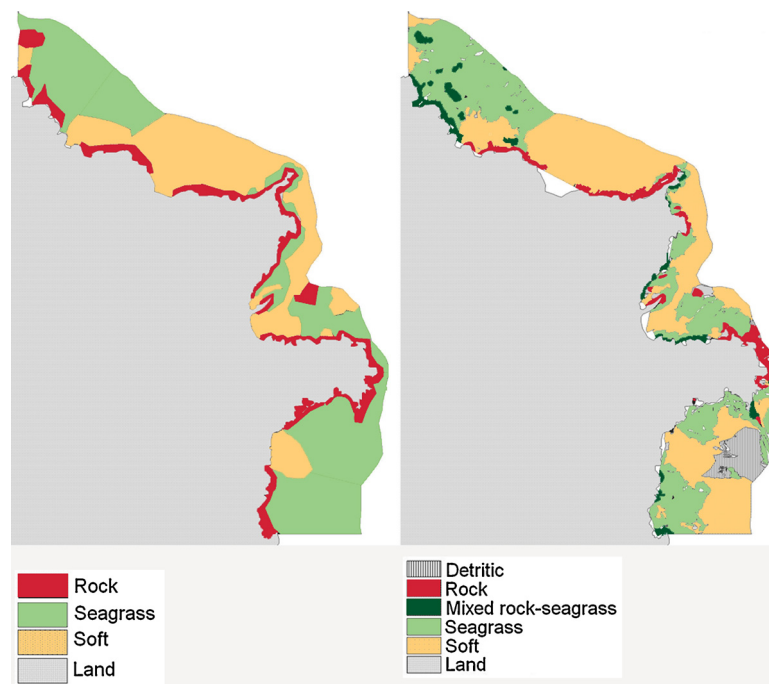


Fig. 3. Bottom types identified in the study area. Data from Class 1 mesoscale indicators (left) and data from high resolution side scan sonar and trawled video.

- (i) Areas of special interest (bottom types with high diversity associated with scree areas along with ledges, promontories, islands and submarine caves);
- (ii) For each unit of analysis: representative rocky bottoms located at depths below 15 m with high roughness and high heterogeneity and representative rocky bottoms at depths greater than 15 m with low roughness and low heterogeneity, and *Posidonia* meadows.

Pinna nobilis (Linnaeus, 1758), was selected as a threatened species, while invasive algae species were not found during the sampling at the study site.

With all the information collected final products were produced: Marine Environmental Quality Index (MEI, Eq. (1)); Coastal

Environmental Quality Index (CEQI, Eq. (2)); Huma Pressure Index (HPI Eq. (3)); and, the activities conflict matrix (Table 5). Values of stress among human activities from this table allowed the identification of potential conflicts in the area, which were: (1) professional fishing with diving and recreational fishing; (2) diving with anchoring and boating; and, (3) protection of certain areas with anchoring and urban development.

Maps of MEI and CEQI (Fig. 5 B and D) showed four hot spots in the marine side (areas 1–4, in Fig. 5A) and two hot spots in the terrestrial area (areas 8 and 9, in Fig. 5A). Area number 4 is located near a terrestrial area with the low-medium CEQI, while areas 1 and 2 present the best connectivity between marine and terrestrial well conserved sites, as CEQI in nearby areas is high to very high. Area number 1 also presents low to medium HPI while areas

Table 4
List of mesoscale and microscale habitat specific indicators.

Habitat	Scale	Name	Variable	Id.
Rocky bottoms	Meso	Habitat heterogeneity	Number of different habitat	1
		Habitat connectivity	Spatial structure and patchiness of different habitat	2
		Substrate roughness	Number and structure of holes and cavities	3
		Underwater landscape value	Habitat and fish community richness	4
		Specific richness of vulnerable species	Degree of conservation	5
	Micro	Specific richness of threatened species	Degree of conservation	6
		Fish species biomass index	State of fish communities	7
		Invasive algae	Degree of wild state	8
		Singular species	Degree of wild state	9
Posidonia meadows	Meso	Habitat heterogeneity	Number of different habitat	10
		Habitat connectivity	Spatial structure and patchiness of different habitat	11
		Substrate roughness	Number and structure of holes and cavities	12
		Underwater landscape value	Habitat and fish community richness	13
		<i>Posidonia oceanica</i> meadow cover	Percent of the coverage in sampled area	14
	Micro	<i>P. oceanica</i> meadow landscape	Habitat and fish community richness	15
		Density of shoots and rhizomes	Quality state of the meadow	16
		Demographic balance	Quality state of the meadow	17
		<i>P. oceanica</i> coverture	Quality state of the meadow	18
		Maximum depth of <i>P. oceanica</i> meadow	Water transparency	19
		Invasive algae	Degree of wild state	20
		Singular species	Degree of wild state	21

Table 5
Activities conflict matrix (1: Low; 5: Very high).

	Recreational fishing	Professional fishing	Bathing	Diving	Boating	Anchoring	Urban development	Ports	Natural heritage protection	Cultural heritage protection
Recreational fishing										
Professional fishing	4		0	0	0	0	0	0	2	0
Bathing		0	0	5	4	2	0	0	2	0
Diving				0	5	4	3	0	2	0
Boating					4	5	1	0	3	0
Anchoring						0	0	0	1	0
Urban development							0	0	4	1
Ports								0	5	0
									2	0

2, 3 and 4 present high to very high HPI values. Area number 1 presents the best combination of the three indices with the highest environmental global value.

Cartographies also allow identifying areas, 5 and 6 associated to sandy bottoms, with very low MEI. The area number 6 is located near the harbour. Finally it is also possible to identify areas (as number 7) with high HPI but low-medium values of MEI.

Discussion

Our work provides a step by step methodology to integrate indicators containing information related to different uses and activities as well as the quality of the coastal ecosystems, from a multidisciplinary approach. Final products have shown their capability to discriminate areas depending on the environmental quality of the marine and coastline and the human pressure exerted on them.

The identification of marine environmental hot spots connected with areas of high terrestrial environmental quality makes them candidates for no take zones or integral reserves in an eventual zoning of a MPA linked to the site. This information, combined with the human pressure index, suggest the best option among the candidate sites for maximum protection level, areas of public use, diving sites or other specific activities, thus making the final products a useful tool for the development of MPA management plans and zoning, that are relevant policy making criteria that precede decision making procedures conducted by managers. The use of indices facilitates the discussion of these aspects with final users and even with stakeholders having limited experience in zoning and conservation of coastal areas.

The higher weighting factors assigned to bottom substrate roughness and habitat diversity for the rocky habitat mesoscale index (see [Appendix B](#), Eq. (B.1)) reflects the fact that experts consulted during the nominal groups gave higher priority to the potential of the habitat to promote high biomass and diversity of Mediterranean littoral fish communities. Additionally the higher weighing factor of mesoscale index and degree of exposure index in the MEI final product against the microscale one (Eq. (1)), also indicates that experts considered more relevant the capabilities of habitats to recover than the actual status of the habitat, shown by the microscale indicators like species assemblages or seagrass meadow growing capacity.

The process to develop the methodology considered two premises: its adaptability in relation to the resources available for the survey and in relation to the different ecological characteristics within the study area. This explains the relevance given to Class 1 indicators, the interaction with local stakeholders to take advantage of all the existing information and the choice of techniques of nominal groups for index design instead of other multivariate analysis ([DeVantier et al. 1998](#)).

In order to be applicable in other areas the method has been designed to be flexible in relation to: (1) measuring different types of human activity; (2) including other type of habitats not considered during the study case; and, (3) applying other indicators for water quality. In this work we proposed a generic approach for obtaining information from stakeholders about human activity pressures and conflicts through the *structured interviews* and to obtain indicators for different type of habitats following a generic scheme for the identification of *units of analysis* and design mesoscale and microscale habitat specific indicators. This implies the identification of macroscale environmental variables that drive important differences in the structure and state of that type of habitat, the mesoscale variables expressing real differences in the state of conservation/quality of that habitat, and the key indicators for microscale samples. Indicators for mapping coastal water quality

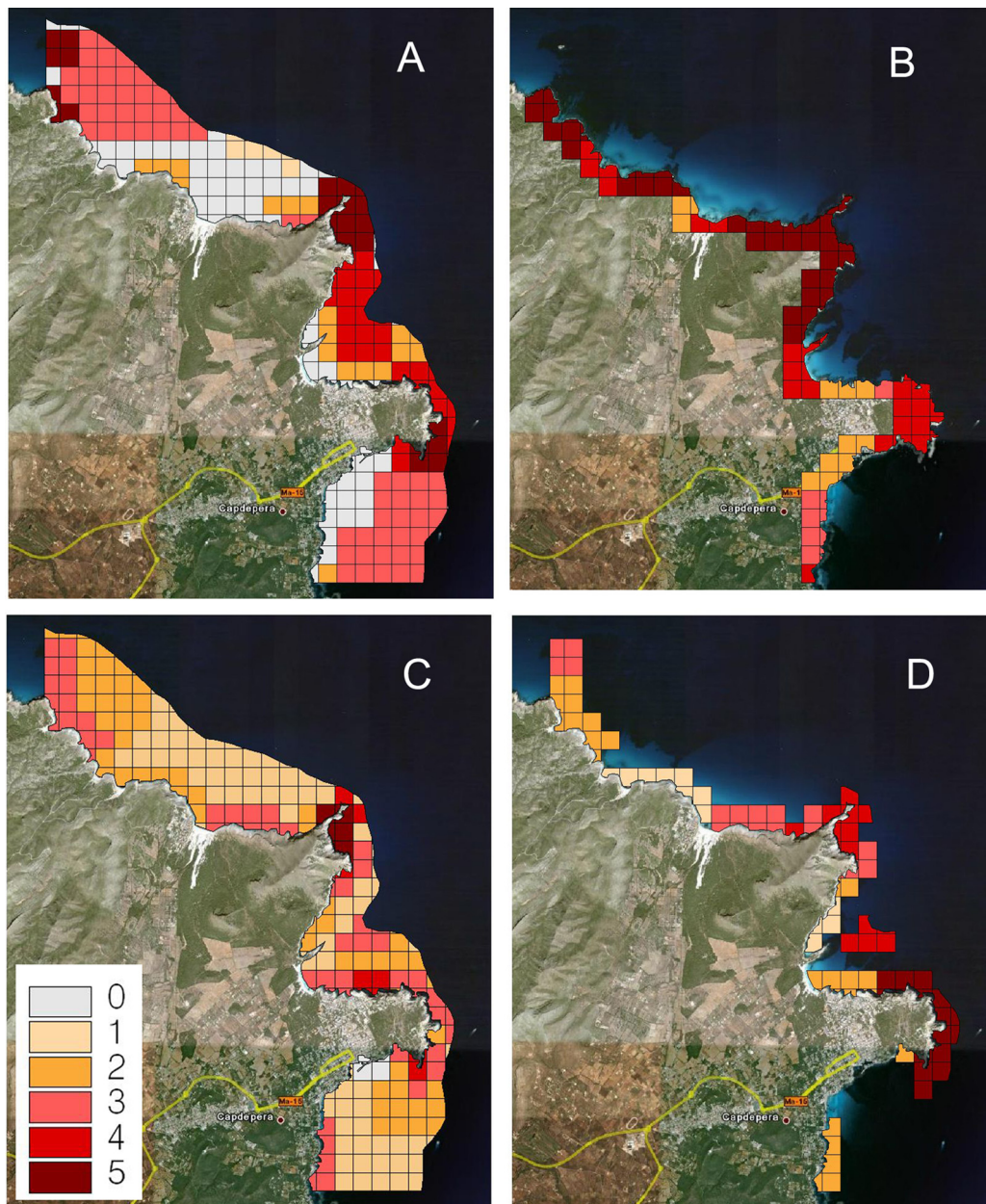


Fig. 4. Fisheries diversity index (A), Naturalness index (B), Mesoscale index, each cell present values related to main habitat inside: rocky bottom or *Posidonia oceanica* meadows (C), and Microscale index over rocky bottoms (D).

have been based on methods for Mediterranean algae species with indicator values and therefore the application to other geographical areas would require adapting these methods or following guidelines to design new indicators of water quality (Beliaeff & Pelletier 2011).

Researchers and managers responsible for assessment in other areas may have other interests or objectives for zoning an MPA that might require other indicators. New indicators could be included in the final products by assigning correspondent weighing factors. This flexibility also allows the incorporation of other types of ecosystem indices as PREI (Gobert et al. 2009) or POMI (Romero et al. 2007), proposed for *P. oceanica* in the Water Framework Directive of the European Union.

Limitations in use of expensive and time-consuming oceanographic equipment and the time required for post processing data analysis influences the selection of indicators and techniques. Once the in situ sampling procedure has started, data collected in each

task drives the decisions for data collection at the following task. Increasing the time needed between tasks due to oceanographic equipment handling and data processing would increase the time and cost needed for the development of the final products.

In the study case presented here diving based techniques have been selected to collect data at mesoscale and microscale levels to provide information on potential for habitat recovery (habitat specific mesoscale indicators, Appendix A) and habitat quality status (microscale habitat specific indicators, Appendix A). Even though these techniques require a certain level of infrastructure and expertise, underwater visual census and other diving based approaches are some of the most used techniques in marine rapid assessment for the evaluation of ecosystem quality status (Kramer & Lang 2003; McKenna 2011; McKenna et al. 2002). They offer a good balance between quality data and time required for post processing in comparison to other techniques giving information about similar variables (Stobart et al. 2007).

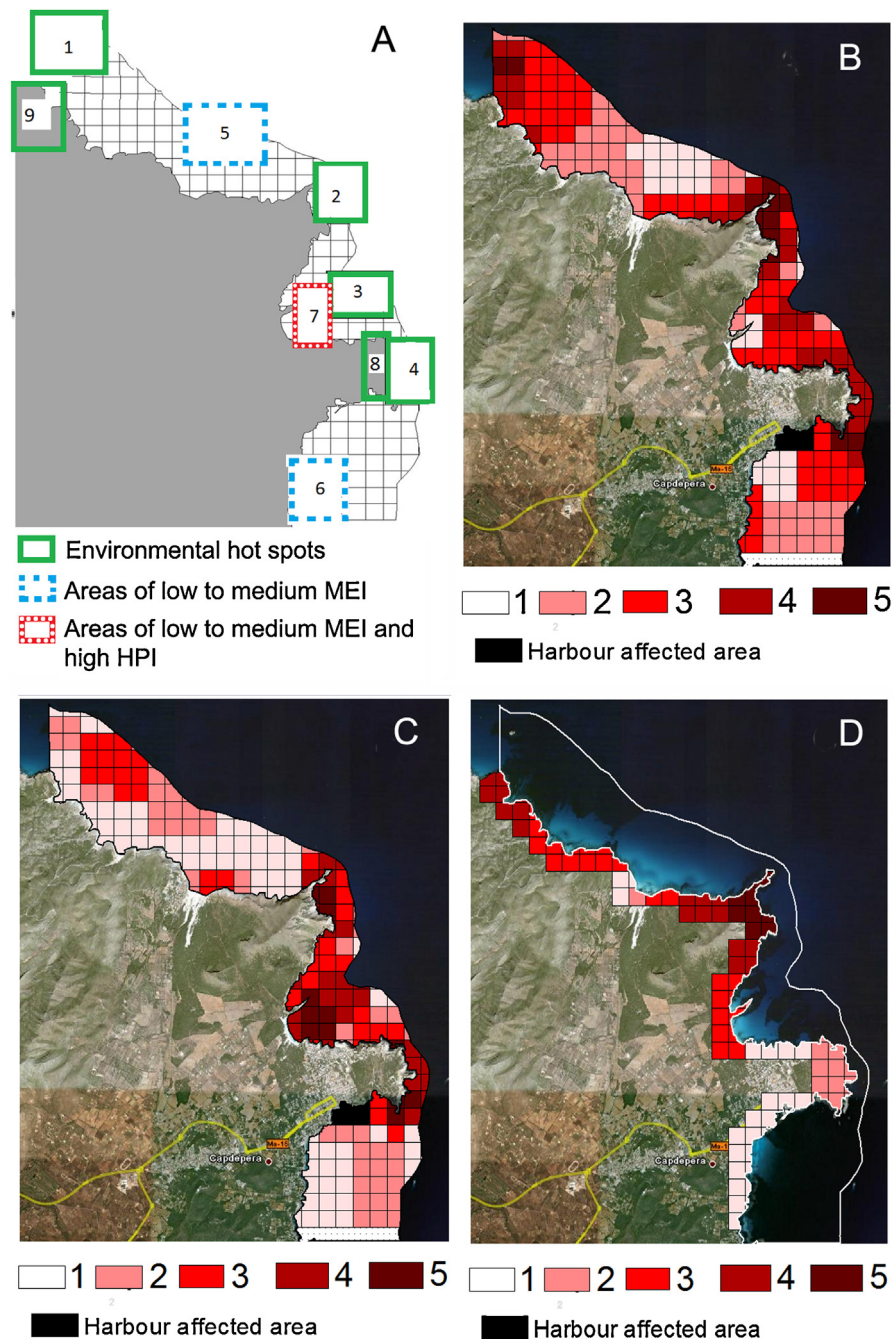


Fig. 5. Identification of areas (A), MEI: Marine Environmental Quality Index (B), HPI: Human Pressure Index (C), and CEQI: Coastal Environmental Quality Index (D).

If time and budget are not limitations the method can be enriched by the application of several other techniques, such as acoustic (Kenny et al. 2003) or combined acoustic/video for habitat mapping and classification (Rooper & Zimmermann 2007), trawled video for marine species evaluation (Assis et al. 2007; Sheehan et al. 2010) or baited underwater video (Colton & Swearer 2010; Stobart et al. 2007). These techniques would improve the quality of final products as they could provide better spatial definition and they would also allow users to scale up the area evaluated, which was limited in this study to shallow waters due to the dependence on diving sampling.

The availability of existing data in the study area from oceanographic devices deployed for monitoring or operational oceanography could also improve significantly the quality of final products. For example the existence of previous cartographies of

habitat from side scan sonar would improve the spatial definition and quality of final maps, or the access to meteorological buoys could provide better maps of coastal exposition (Ekeboom et al. 2003).

An important issue to consider for the application of existing oceanographic deployments to the RAP framework is the level and formats of the data provided. Products obtained from deployments must be available in an “end-user friendly format”; on the contrary, time for data formatting or post processing would prevent its application in the scope of the RAP.

The methodology proposed here has been designed to make the most of the resources available, but running this method with a very low number of in situ sampling may reduce the accuracy of the marine quality index. We have recommended at least one sampling site at each identified hot spot and at each unit of analysis,

but increasing the sampling effort will for sure improve the final products as the spatial definition will be higher.

The techniques used to rank the environmental and human pressure indices from 1 to 5 allowed the separation of minimum and maximum values, thus increasing the spatial differences inside the study area to facilitate the marine zoning, but the use of the same relative indices in other geographic areas may be not feasible.

In many cases the lack of information or resources available for conducting extensive surveillance restricts the possibility of developing comprehensive management plans. In other cases, even when this information exists there are limitations in the knowledge transfer from scientists to managers. RAPs provide cost effective tools for data collection, but techniques have been developed and examples of their use have been published in relation to tropical areas and particular studies, as is the ecological state of particular species or ecosystems, but not on the selection and design of MPAs so far. The methodology proposed here, and the final products obtained try to overlap these limitations and constraints, allowing the integration of anthropic activity indicators as well as the global environmental quality of the coastal ecosystems from a multidisciplinary approach.

Conclusions

The method described herein provides a way to collect and integrate information from multiple disciplines related to management of coastal areas as social ecological systems. The final results are designed to be easy to use tools for managers responsible for zoning and managing marine protected areas. The capacity to incorporate information from local stakeholders and previous studies, along with the feasibility for use in other geographical areas, makes the method a reasonable choice in a time of global budgetary constraints. This tool, with its reduction in costs and time needed to survey, the coordination of already existing but dispersed information, the extensive use of public and accessible resources, the applicability in different biogeographic regions with minor modifications and the maximisation of results, can be useful when economic or time constraints run against effective protection, even at a basic level, of the coastline under threat.

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Appendix A. Mesoscale and microscale habitat specific indicators used in the case study area Artà. Rationale for selection, sampling techniques and ranking

1 – Rocky bottom specific indicators

1.1. Mesoscale rocky habitat indicators (indicators 1–4, Table 4)

These indicators are measured visually during underwater surveys. Large areas can be covered in as far as divers can be towed by a boat or use submarine scooters. The lengths surveyed can vary from 100 to 500 m depending on the size of the area to be sampled. Indicators are specific for each type of habitat. Values of four mesoscale indicators – habitat heterogeneity, habitat connectivity, substrate roughness and underwater landscape value–were collected in the

selected in situ sampling sites of rocky bottom zones for each unit of analysis:

The *habitat heterogeneity* (Indicator 1, Table 4) expresses the number and the relative extension of sub-habitats (rocky boulders, lifts, caves and flat areas) present in the area assessed. The rank values are higher when the number of sub-habitats and evenness is higher following the same concept of [Shannon–Weaver \(1949\)](#) diversity index. The values are scaled as (1) a single type of sub-habitat, or more than one type providing that 80% of the surface area corresponds to a single type, (2) two types of sub-habitat balanced in size, (3) more than two types of sub-habitats that are not balanced in size, and (4) three or more types of sub-habitats that are balanced in size.

The *habitat connectivity* (Indicator 2, Table 4) measures the continuity of a type of habitat both in depth and in extensiveness, scaling from (1) habitats in the sampling site that are separated by marked ecotones, (2) boundaries between habitats are patchy or interlocked, and (3) very interconnected habitats without boundaries. These values measure the influence of habitat continuity on the fish species biomass exportation/retention ([Gillanders et al. 2003](#); [Palumbi 2004](#); [Forcada et al. 2009](#)) giving higher rank to habitat structure promoting species movement.

The *substrate roughness* (Indicator 3, Table 4) is a semi-quantitative measurement of the vertical relief and of the presence of dips. This index is derived from the semi-quantitative application and on a larger scale of the roughness concept ([Luckhurst & Luckhurst 1978](#)) which has demonstrated important effects on Mediterranean littoral fish assemblages ([Ordines et al. 2005](#); [Mellin et al. 2007](#)). Classification values are: (1) flat rock; (2) small boulders and/or scattered crevices or dips occupying less than 25% of the subzone's surface area, and/or small scale cavities; (3) boulders of various sizes and/or crevices or dips occupying more than 50% of the surface area; and, (4) areas mostly occupied with scree and/or cavities of a certain size.

Underwater landscape (Indicator 4, Table 4). Visual landscapes have shown to provide valuable information for the evaluation of landscape functions in terrestrial environments ([Tveit et al., 2006](#)). In this methodology indicator values for rocky habitat have been obtained by a nominal group of experts in MPA monitoring: (1) homogeneity of the seabed in terms of habitat type and bathymetry; (2) heterogeneous seabed with slight bathymetric variation; (3) heterogeneous seabed with a steep bathymetric gradient; and, (4) significant topographic and bathymetric heterogeneity, diversity of benthic communities and outstanding elements.

1.2. Microscale rocky habitat indicators (indicators 5–7, Table 4)

In rocky habitats, microscale indicators were collected in transects of 5 minute-long tracks where 2.5 m at each side of the centre of the track were sampled following a *visual fast count method* ([Kimmel 1985](#)). These are carried out at low speed, swimming at a distance of about 1 m above the bottom.

Indicators are based on the evaluation of biomass and diversity of fish species as well as of the presence or absence of indicator species (algae, molluscs, crustaceans). Similar indicators are standard in RAP methods used in marine tropical environments ([McKenna et al. 2002](#); Atlantic and Gulf Rapid Reef Assessment AGRRA <http://coral.aoml.noaa.gov/agra/>).

In each transect, the fish species vulnerable to professional or recreational fishing (angling and spear fishing) belonging to spatial categories 3, 5 and 6 according to ([Harmelin 1987](#)) were counted and size estimated in 2 cm classes. For species from category 1 only presence/absence data were recorded. The indicators to be calculated for each transect are:

Specific richness of vulnerable species (S) (Indicator 5, Table 4). The species to consider as vulnerable are those littoral species over

rocky substrates that are included in the spatial categories 1, 3, 5 and 6 from the list of the target species in local fisheries (Harmelin 1987). The ranking is performed on data obtained in field work by splitting its distribution in four classes considering the maximum values obtained in marine protected areas in the Balearic Islands (Coll et al. 2012).

Specific richness of threatened species (Sa) (Indicator 6, Table 4). The values are calculated as in previous indicator. The list of threatened species must be obtained for the area of study from local Red Lists, previous research or interviews.

Fish species biomass index (Bv) (Indicator 7, Table 4). Calculated from biometry, correlating fish size with weight (Morey et al. 2003) the values are ranked from 1 to 5 as in minimum and maximum values where adjusted from marine protected areas in the western Mediterranean (Coll et al. 2012; García-Charton et al. 2004).

2.2. Microscale Posidonia meadow indicators (indicators 10–15, Table 4)

For selected sites of *P. oceanica* meadows, the sampling consisted of duplicated 20 m transects marked with a tape, measured and fixed to the bottom with stakes. The indicators *P. oceanica* cover, shoot density and demographic balance (Ids 29–32 32, Table 1) were measured. Annual net population growth rate and demographic balance (μ) were calculated following methods of (Duarte et al. 1994) to provide information on the biological state of the meadows. The maximum depth of the meadow was calculated as it determines the quantity of light available at the bottom and therefore the lower limit to which the meadow can extend (Duarte et al. 1994) and the structure of the meadow, particularly the shoot density (Marba et al. 2002).

Appendix B. Habitat macroscale and microscale indices obtained through the nominal group technique for habitats selected in the study area.

The rocky bottom mesoscale index (RBmeso).

$$RBmeso = 2 \times \text{substrate roughness} + 2 \times \text{habitat heterogeneity} + 1.5 \times \text{underwater landscape value} + \text{habitat connectivity.} \quad (B.1)$$

Rocky bottom microscale index (RBmicro).

$$RBmicro = 1.5 \times \text{Biomass of threatened species value} + \text{Specific richness of threatened species value} \quad (B.2)$$

P. oceanica mesoscale index (Pmeso).

$$Pmeso = (\text{Habitat heterogeneity value} + \text{habitat connectivity value}) + \text{meadow cover value} + 2 \times \text{meadow landscape value.} \quad (B.3)$$

P. oceanica meadow microscale index (Pmicro).

$$Pmicro = \left(\frac{(P. \text{ oceanica } \text{coverture value} + \text{density of shoots} + \text{max. depth of meadow}/3) + \text{demographic balance}}{2} \right) \quad (B.4)$$

2. Posidonia meadows specific indicators.

2.1 Mesoscale Posidonia meadow indicators (indicators 10–15, Table 4)

For seagrass meadows four mesoscale indicators were selected, the habitat heterogeneity and connectivity, the meadow cover and the meadow landscape. The habitat heterogeneity and connectivity (indicators 10–11, Table 4) following the same techniques as for rocky bottoms. During the transects two more indicators were collected.

Meadow cover (Indicator 14, Table 4). It expresses the percentage of the sampled area covered by *P. oceanica*, in contrast to the percentage covered by other types of habitats (sandy bottoms, rocky without seagrass). The scale of values was: 1 = less than 20% of the sampled area covered with seagrass meadows; 2 = from 20 to 40%; 3 = from 40 to 60%; 4 = from 60 to 80%; 5 = more than 80% covered with seagrass meadows.

Meadow landscape (Indicator 15, Table 4). Propose following same methods used for indicator 23. This indicator enables a first comparison of the different meadows and is useful when it comes to determining the location of microscale sampling. Classification values are 1–3 (low, medium, high) and evaluate the general aspect of the area in terms of density of the *P. oceanica*, species associated and presence of small and rich patchy habitats. Low: *P. oceanica* meadows patchy distributed in sand or flat rocky areas with a poor fish communities associated. Medium: continuous *P. oceanica* meadow with richer fish and indicator species communities associated. High: very wide *P. oceanica* meadows with high canopy and shoot density alternated with patches of rough rocky areas and presence of rich associated fish and invertebrate communities.

Estimated values for Pmicro were ranked from 1 to 5 considering 1 as very low (significantly receding), 2 as low (in recession), 3 as normal or stable, 4 as high (in expansion) and 5 as very high (significantly expanding).

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