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Videoconference, 10-11 June 2021

**Agenda item 3: Monitoring Guidelines/Protocols for IMAP common indicators 1 and 2 on Benthic Habitats**

**Update of Monitoring Protocols on Benthic Habitats**



### Note by the Secretariat

Decision IG.23/6 on the 2017 Mediterranean Quality Status Report (COP 20, Tirana, Albania, 17-20 December 2017) recommended, as general directions towards a successful 2023 Mediterranean Quality Status Report (2023 MED QSR), the harmonization and standardization of monitoring and assessment methods of agreed common indicators.

The monitoring protocols on habitats, species and non-indigenous species were reviewed by the Meetings of the Ecosystem Approach Correspondence Group on Monitoring (CORMON), Biodiversity and Fisheries (Marseille, France, 12-13 February 2019<sup>1</sup> and Rome, Italy, 21 May 2019<sup>2</sup>), the 14<sup>th</sup> meeting of the SPA/BD thematic Focal points (Portoroz, Slovenia, 18-21 June 2019)<sup>3</sup> and the 7<sup>th</sup> Meeting of the Ecosystem Approach Coordination Group (Athens, Greece, 9 September 2019)<sup>4</sup>.

These monitoring guidelines/protocols provide detailed methodologies and protocols for monitoring benthic habitats, that can be helpful to national managers and decision makers (e.g., environmental authority representatives, researchers, Marine Protected Area (MPA)'s representatives) for implementing a monitoring programme on Common indicators 1 and 2, on yearly basis, in at least two monitoring areas, one in a low pressure area (e.g. Marine Protected Area/Specially Protected Area of Mediterranean Importance (SPAMI)), or in sites of high conservation relevance (e.g., Natura 2000 sites), and one in a high pressure area due to human activity.

The developed monitoring guidelines/protocols provide information on the monitoring of the agreed biodiversity-related IMAP Common Indicators towards the GES achievement, and address the same common purposes to all monitoring guidelines developed to date:

- (i) Harmonization and standardization of monitoring and assessment methods;
- (ii) Assuring the quality of long time series of data to monitor the trends in the status of the marine environment;
- (iii) Improvement of availability of synchronized datasets for marine environmental state assessment, including data stored in other databases where some of the Mediterranean countries regularly contribute;
- (iv) Improvement of data accessibility and their continuous upgrading, with the view to improving knowledge on the Mediterranean marine environment, to accommodate data submissions for all the IMAP Common Indicators.

The Contracting Parties to the Barcelona Convention reviewed and endorsed the monitoring guidelines/protocols of marine species (marine mammals, sea turtles and sea birds), non-indigenous species and dark habitats. Minor adjustment needs of monitoring parameters on benthic habitats, i.e. marine vegetation and coralligenous and other calcareous bioconstructions, were highlighted. Consequently, they requested the Secretariat to bring them to the attention of respective CORMONs on 2020 and 2021.

The present document is an update of the monitoring protocols on benthic habitats (marine vegetation and coralligenous and other calcareous bioconstructions), that take into consideration the comments highlighted by the Contracting Parties during the 7<sup>th</sup> Meeting of the Ecosystem Approach Coordination Group and the Integrated CORMON meeting (1-3 December 2020). It outlines the monitoring guidelines of the agreed common indicators 1 and 2 related to marine habitats, namely Common Indicator 1: Habitat distributional range, to consider habitat extent as a relevant attribute and Common Indicator 2: Condition of the habitat's typical species and communities.

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<sup>1</sup> UNEP/MED WG.458/4 Guidance on monitoring concerning the biodiversity and non-indigenous species common indicators Monitoring protocols of the Ecosystem Approach Common Indicators 3, 4, 5 and 6

<sup>2</sup> UNEP/MED WG.474/3 Monitoring protocols of the Ecosystem Approach Common Indicators 1 and 2 related to marine benthic habitats

<sup>3</sup> UNEP/MED WG.461/21 Implementation of the first phase (2016-2019) of the Integrated Monitoring and Assessment Programme (IMAP - Biodiversity and non-indigenous species) in the framework of the EcAp Roadmap

<sup>4</sup> UNEP/MED WG.482/20 Monitoring Protocols for IMAP Common Indicators related to Biodiversity and Non-Indigenous species

The document is organized along two (2) monitoring guidelines/protocols:

1. Guidelines/protocols for monitoring marine vegetation;
2. Guidelines/protocols for monitoring coralligenous and other calcareous bioconstructions in the upper- circalittoral Mediterranean zone.
- 3.

In order to highlight the proposed changes and facilitate the review by the meeting, these are reported in track mode for added text and in strikethrough for deletion.

The current update, edited in track mode, is submitted to the present meeting for review and comments prior to be examined by the SPA/BD Focal Points Meeting, in June 2021.

## 1. Guidelines for monitoring marine vegetation in the Mediterranean

### Introduction

1. Seagrass meadows are widely recognized as key habitats in tropical and temperate shallow coastal waters of the world (UNEP-MAP-Blue Plan, 2009). They form some of the most productive ecosystems on earth (McRoy and McMillan, 1977), shaping coastal seascapes and providing essential ecological and economic services (Green and Short, 2003; Vassallo et al., 2013). They support high biodiverse associated communities, primary production and nutrient cycling, sediment stabilization and protection of the littoral, and globally significant ~~sequestration of carbon~~ carbon sequestration (Waycott et al., 2009 and references therein). A ~~major~~ significant economic value of over 17 000 \$ per ha and ~~per~~ annum has been quantified for seagrass meadows worldwide (Costanza et al., 1997).

2. Seagrass, like all ~~Magnoliophyta~~ Magnoliophytes, are marine flowering plants of terrestrial origin ~~which that~~ returned to the marine environment approx. 120 to 100 million ~~of~~ years. The global species diversity of seagrass is low ~~when~~ compared to any other marine Phylum or Division, with less than sixty species throughout the world. However, they form extensive meadows that extend for thousands of ~~kilometres~~ kilometers of coastline between the surfaces ~~down~~ to about 50 m depth (according to water transparency) in ~~very clear~~ apparent marine ~~waters and or~~ transitional waters (e.g., estuaries and lagoons). In the Mediterranean region five seagrass species occur: *Cymodocea nodosa*, *Halophila stipulacea* (an invasive Lessepsian species), *Posidonia oceanica*, *Zostera marina*, and *Zostera noltei*. The endemic *Posidonia oceanica* is doubtless the dominant and the most important seagrass species (Green and Short, 2003), and the only one able to build a “matte”, a monumental construction resulting from horizontal and vertical growth of rhizomes with entangled roots and entrapped sediment (Boudouresque et al., 2006).

3. Physical damages and stressful conditions resulting from intense human pressures, environmental alterations, climate warming, and reduction of water and sediment quality are causing structural degradation of seagrass meadows worldwide (Orth et al., 2006). Biological impact caused by the spread of non-indigenous species (NIS) on seagrass beds must also be considered (Montefalcone et al., 2007). An alarming ~~and accelerating~~ decline of seagrass meadows ~~has been was~~ reported in the Mediterranean Sea and mainly in the north-western side of the basin, where many meadows have ~~already~~ been lost during the last decades (Boudouresque et al., 2009; Waycott et al., 2009; Pergent et al., 2012; Marbà et al., 2014; Burgos et al., 2017). However, a deceleration in the rate of loss and some signs of local recovery have also been observed, which are indicative of a recent trend reversal in seagrass extent and density, thanks to effective/adequate management actions (de los Santos et al., 2019).

4. Concerns about these declines have prompted efforts to protect ~~legally these habitats~~ these habitats legally in several countries. Control and reduction of the full suite of anthropogenic impacts via legislation and enforcement at local and regional scales have been carried out in many countries. *Posidonia oceanica* meadows are defined as priority natural habitats on Annex I of the EC Directive 92/43/EEC on the Conservation of Natural Habitats and of Wild Fauna and Flora (EEC, 1992), which lists those natural habitat types whose conservation requires the designation of special areas of conservation (SACs), identified as ~~s~~ Sites of ~~c~~ Community ~~i~~ Interest (SCIs). Also, the establishment of marine protected areas (MPAs) locally enforces the level of protection on these priority habitats.

5. Due to their wide distribution, their sedentary habit~~u~~, and their susceptibility to changing environmental conditions, seagrass are habitually used as biological indicators of water quality in accordance with the Water Framework Directive (WFD, 2000/60/EC) and of environmental quality in accordance with the Marine Strategy Framework Directive (MSFD, 2008/56/EC) (Montefalcone, 2009). Due to its recognized ecological importance, *Posidonia oceanica* is considered as the main biological quality element in monitoring programs developed to evaluate the status of marine coastal environment. Standardized monitoring protocols for evaluating and classifying the conservation

status of seagrass meadows already exist, which are summarised in the “Guidelines for standardisation of mapping and monitoring methods of marine Magnoliophyta in the Mediterranean” (UNEP/MAP-RAC/SPA, 2015). These monitoring guidelines have been the base for the updating and harmonization process undertaken in this document.

6. Detailed spatial information on habitat distribution is a prerequisite knowledge for the sustainable use of marine coastal areas. The first step in the prior assessment of the status of any benthic habitat is thus the definition of its geographical distribution and bathymetrical ranges. Seagrass distribution maps are a fundamental prerequisite to any conservation action on these habitats. The available information on the exact geographical distribution of seagrass meadows is still fragmentary on a regional level (UNEP/MAP-RAC/SPA, 2015). ~~And a few extent extents~~ of the coastline ~~has~~ been mapped, as only 5 States out of the 21 have a mapped inventory covering at least half of their coasts (UNEP/MAP-Blue Plan, 2009). Within the framework of the Action Plan for the Conservation of Marine Vegetation in the Mediterranean, adopted in 1999 by the Contracting Parties to the Barcelona Convention (UNEP/MAP-RAC/SPA, 1999) and during the implementation evaluation of this Action Plan in 2005 (UNEP/MAP-RAC/SPA, 2005), emerged that very few countries were able to set up adequate and standardized monitoring and mapping programs. As a ~~consequence, and consequence and~~ following an explicit request by managers on the need ~~of for~~ practical guides aimed at harmonizing existing methods for seagrass monitoring and ~~for~~ subsequent comparison of results obtained by different countries, the Contracting Parties asked the Regional Activity Centre for Specially Protected Areas (RAC/SPA) to improve the existing inventory tools and to propose a standardization of the mapping and monitoring techniques for these habitats. Thus, the “Guidelines for standardisation of mapping and monitoring methods of marine Magnoliophyta in the Mediterranean” (UNEP/MAP-RAC/SPA, 2015) have been produced, as the result of a ~~number of several~~ scientific round tables ~~addressed explicitly specifically addressed~~ on this topic.

7. For mapping seagrass habitats, the previous Guidelines (UNEP/MAP-RAC/SPA, 2015) highlighted the following main findings:

- Several national and international mapping programs have already been carried out;
- ~~A S~~standardization and a clear consensus in the mapping methodology have been reached;
- All the methods proposed are usable in all the Mediterranean regions, but some of them are more suitable for a given species (e.g., large-sized species) or particular assemblages (e.g., dense meadows);
- Implementation of procedures could be difficult in some regions due to the absence of training, competence and/or specific financing.

8. For monitoring the condition of seagrass habitats, the previous Guidelines (UNEP/MAP-RAC/SPA, 2015) highlighted the following main findings:

- Several national and international monitoring programs have been successfully implemented in the Mediterranean (e.g., SeagrassNet, Posidonia national monitoring networks);
- Notwithstanding ~~that~~ most of the Mediterranean monitoring systems are mainly dedicated to *Posidonia oceanica*, there are some programs (e.g., SeagrassNet) that can be used for almost all seagrass species;
- Although the existing monitoring methods are similar, the descriptors used to provide information on the state of the system are quite diverse and cover a vast array of ecological complexity levels (i.e., from the plant to the seascape);
- Some descriptors are used by all the Mediterranean scientific communities (e.g., seagrass shoot density, lower limit depth), but the measuring techniques are often very different, and still require a larger effort to reach precise standardization;
- The different monitoring methods available in the Mediterranean countries seem all feasible when appropriate training is undertaken.

9. Based on recommendations from the previous CPs group meeting, SPA/RAC has been requested to develop an updated version of the “Guidelines for monitoring marine vegetation in Mediterranean” (UNEP/MAP-RAC/SPA, 2015), in the context of the IMAP common indicators and ~~in order to~~ ease the task of the MPA managers when implementing their monitoring programs. A reviewing process on the scientific literature, ~~taking into account~~ considering the latest techniques and the recent ~~works carried out~~ findings by the scientific community at the international level, has been carried out.

## Monitoring methods

### a) COMMON INDICATOR 1: Habitat distributional range and extent

#### Approach

10. The CI1 is aimed at providing information about the geographical area in which seagrass meadows occur in the Mediterranean and the total extent of surfaces covered by meadows. The approach proposed for mapping seagrass meadows in the Mediterranean follow the overall procedure established for mapping marine habitats in ~~the~~ north-west Europe within the framework of the European projects MESH (Mapping European Seabed Habitats; MESH, 2007) -and EUSeaMap (Vasquez et al., 2021a, b) project, ended in 2008. The mapping procedure includes different actions (Fig. 1), that can be synthesised into three main steps:

- 1) Initial planning
- 2) Ground surveys
- 3) Processing and data interpretation

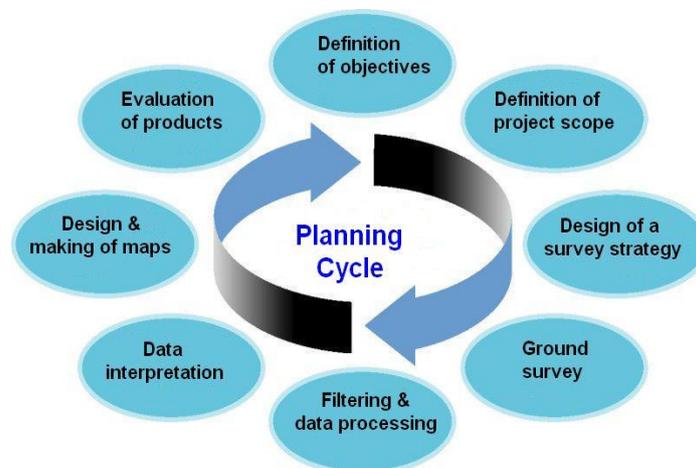


Figure 1: Planning cycle for a habitats' mapping programme (according to the MESH project, ~~2008~~).

11. Initial planning includes ~~the definition~~ defining of the objectives ~~in order to~~ select the minimum surface to be mapped and the necessary resolution. During this initial phase, tools to be used in the following phases must be defined and the effort (human, material, and financial costs) necessary to produce the mapping evaluated. A successful mapping approach requires the definition of a clear and feasible survey strategy.

12. Ground survey is the practical phase for data collection. It is often the costliest phase as it generally requires field activities. A prior inventory of the existing data for the area being mapped is recommended, to reduce the amount of work or to have ~~a~~ better targeting of the work to be done.

13. Processing and data interpretation are doubtlessly the most complex phase, as it requires knowledge and experience, so that the data gathered can be usable and reliable. The products obtained must be evaluated to ensure their coherence and the validity of the results obtained.

### Resolution

14. Selecting an appropriate scale is a critical stage in the planning phase (Mc Kenzie et al., 2001). Even though there is no technical impossibility in using a high precision over large surface areas (or inversely), there is generally an inverse relationship between the precision-accuracy used and the surface area to be mapped (Mc Kenzie et al., 2001; Fig. 2).

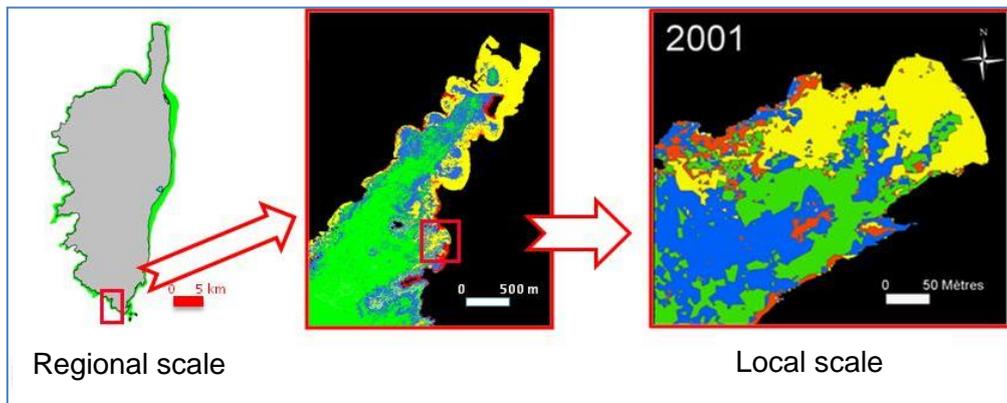


Figure 2: Resolution of a map from regional study to local study (from UNEP/MAP-RAC/SPA, 2015).

15. When large surface areas have to be mapped and global investigations carried out, an average precision and a lower detail level can be accepted, which means that the habitat distribution and the definition of its extension limits are often only indicative. Measures of the total habitat extent may be subjected to high variability, as the final value is influenced by the methods used to obtain maps and by the resolution during both data acquisition and final cartographic restitution. This type of approach is used for national or sub-regional studies and the minimum mapped surface area is 25 m<sup>2</sup> (Pergent et al., 1995a). Recently, some global maps showing the distribution of *Posidonia oceanica* meadows in the Mediterranean have been produced (Giakoumi et al., 2013; Telesca et al., 2015) (Fig. 3). These maps, however, are still incomplete being the available information highly heterogeneous due to the high variability in the mapping and monitoring efforts across the Mediterranean basin. This is especially true for the southern and the eastern coasts of the Mediterranean, where data are scarce, often patchy and can be difficultly found in literature. In data-poor regions, availability of high-quality mapping information on benthic habitat distribution is practically inexistent, due to limited resources. However, these low-resolution global maps can be very useful for an overall knowledge of the bottom areas covered by the plant, and to evaluate where surveys must be enforced in the future to collect missing data. Also, those maps are important to highlight specific areas subjected to a declining trend, where monitoring and management actions must be implemented to reverse the observed trend and to ensure proper conservation.

16. On the contrary, when smaller areas have to be mapped, a much higher precision and resolution level is required and is easily achievable thanks to the high-resolution mapping techniques available to date. However, obtaining detailed maps is time consuming and costly, thus practically impossible when time or resources are limited (Giakoumi et al., 2013). The minimum surface area can be lower or equal to 1 m<sup>2</sup> in local scale studies (Pergent et al., 1995a). These detailed maps provide an accurate localisation of the habitat distribution and a precise definition of its extension limits and total habitat extent, all features necessary for future control and monitoring purposes over a defined period-of-time. These high-resolution scales are also used to select remarkable-great sites where monitoring actions must be concentrated. As highlighted by the MESH-EU projects (2008), most of the environment management and marine spatial planning activities require a range of habitat maps between these two extremes.

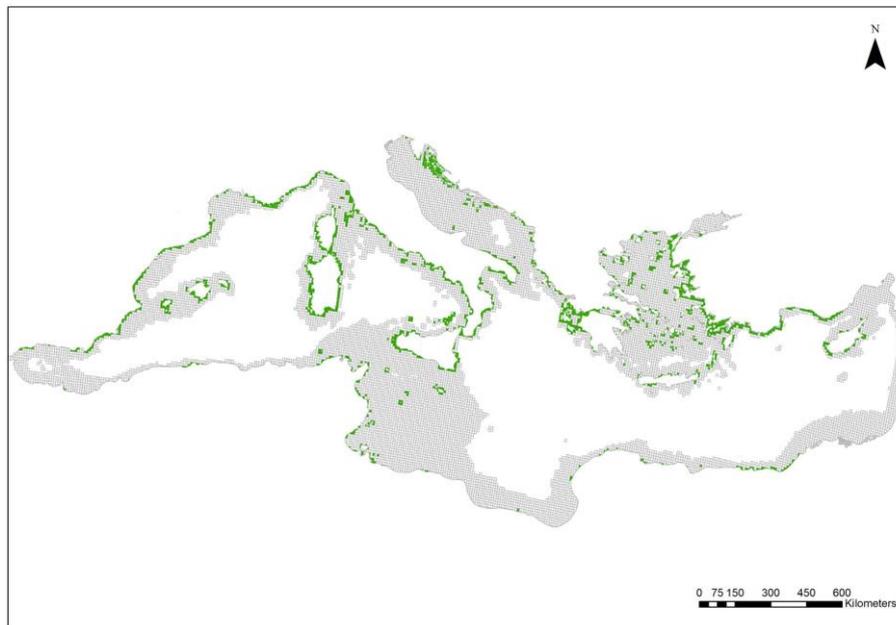


Figure 3: Distribution of *Posidonia oceanica* meadows in the Mediterranean Sea (green areas) (from Giakoumi et al., 2013).

### Methods

17. Maps of seagrass distribution and extent can be obtained by using indirect instrumental mapping techniques and/or direct field visual surveys (Tab. 1). In the last 50 years the technology in benthic habitat mapping ~~has~~ increased a lot, and several instrumental mapping techniques have been successfully applied to seagrass meadows (see synthesis in Pergent et al., 1995a; McKenzie et al., 2001; Dekker et al., 2006; Hossain et al., 2015; [Rende et al., 2020](#); [Rowan and Kalacska, 2021](#)). To map shallow meadows (from 0 to about 10-15 m depth, depending on water transparency and weather conditions), it is possible to use optical sensors (e.g., satellite telemetry, multi or hyper spectral imaging, aerial photography, ~~unmanned~~ ~~uncrewed~~ [aerial vehicles](#)). For meadows in deeper waters (down to 10-15 m depth), the acoustic techniques (e.g., side scan sonar, multi-beam echosounder) are recommended. Sampling methods involving blind grabs, dredges and box corers or direct field visual surveys by scuba diving observations (using transects or permanent square frames), Remotely Operated Vehicles (ROVs), and underwater video recordings allow to ground-truthing the remote sensing data, and provide very high-resolution maps of meadows over small spatial scales (Montefalcone et al., 2006). All these techniques are, however, time consuming, expensive, and provide only sporadic information. The simultaneous use of two or more methods makes it possible to optimize the results being the information obtained complementary. Four parameters can be mapped from remote sensing data: presence/absence, percentage cover, species, and biomass. The selection of the most relevant parameter in the scientific literature depended on the area mapped, the availability of ground truth data, and the specific target of each study (Topouzelis et al., 2018).

18. The use of remote sensing allows characterising extensive coastal areas ~~for assessment~~ ~~of to assess~~ the spatial patterns of seagrass meadows. ~~It, and~~ simultaneously can be used to reveal temporal patterns due to the high frequency of the observation. Remote sensing covers a variety of technologies from satellite telemetry, aerial photography, ~~and~~ [unmanned aerial vehicles \(UAVs\)](#), and ~~vessel acoustic~~ [acoustic vessel](#) systems. The power of remote sensing techniques has been highlighted by Mumby et al. (2004), who ~~highlighted~~ ~~showed~~ that 20 s of airborne acquisition time would equal ~~6-six~~ days of field surveys. However, all indirect mapping techniques are intrinsically affected by uncertainties due to manual ~~or~~ ~~authomatic~~ ~~automatic~~ [supervised](#) classification of spectral or acoustic signatures of seagrass meadows on the images and sonograms, respectively. Errors in images or sonograms interpretation may arise when two habitat types are not easily distinguished by the

observer (e.g., shallow seagrass meadows or dense patch of canopy-forming macroalgae). Interpretation-Understanding of remote sensing data requires extensive field calibration and the ground-truthing process remains essential (Pergent et al., 2017). As the interpretation ~~of images/sonograms~~ is also time-requiring, several image processing techniques were proposed ~~in order to~~ rapidly automate the interpretation of images and sonograms and make this interpretation more reliable (Montefalcone et al., 2013 and references therein; Rowan and Kalacska, 2021). These methods allow ~~a~~ good discrimination between soft sediments and seagrass meadows, between continuous and patchy seagrass, between a dense seagrass meadow and one exhibiting only limited bottom cover. The hHuman eye, however, always remains the final judge.

19. ~~\_\_\_\_\_~~ Satellite telemetry is a valuable tool providing high-resolution regional- to global-scale observations and repeat time-series sampling a cost-effective way to easily acquiring large scale and high resolution on seagrass distribution ~~information~~ in shallow waters. However, satellite imagery has some disadvantages, such as their reliance on weather conditions, high cost per scene, the revisit period, and the scale of many ecological processes (Ventura et al., 2018). Landsat images have been used successfully for regional mapping of seagrass distribution in many Mediterranean countries. The wide-vast area coverage of satellite imaging might reveal large-scale patterns; however, mapping seagrass meadows from space on a large scale cannot provide the same levels of accuracy and detail of a direct field visual survey. Thanks to emerging technologies, such as long-range transmitters, increasingly miniaturized components for positioning, and enhanced imaging sensors, the collection of images by unmanned aerial vehicles (UAVs), also known as “drones”, coupled with the structure-from-motion (SfM) photogrammetry, offers a rapid and inexpensive tool to produce high-resolution orthomosaic (Ventura et al., 2018). Coupling a high-resolution digital camera with side scan sonar for acquiring underwater videos in a continuous way has recently proved to be a non-destructive and cost-effective method for ground-truthing satellite images in seagrass habitats mapping (Pergent et al., 2017).

19-20. Airborne LIDAR bathymetry (ALB) or airborne light (lazer) detection and ranging (LIDAR) is a remote sensing technique for the bathymetry with an airborne scanning pulsed laser beam (Guenther, 1985). The technique is well suited to nearshore mapping because it provides the three-dimensional data needed to create an accurate digital terrain model (DTM) with 15-cm vertical accuracy (Irish et al., 2000). The LIDAR technology can measure depths up to three times Secchi depths, corresponding to about 60 m in very clear water (Guenther et al., 2000).

20-21. ~~\_\_\_\_\_~~ Once the surveying is completed, data collected needs to be organised ~~so that it can~~ be used in the future by everyone and can be appropriately archived and easily consulted. The rResulting dataset can be integrated with similar data from other sources, providing a clear definition of all metadata (MESH-project, 2007).

21-22. ~~\_\_\_\_\_~~ Despite the increasing number of studies on seagrass mapping with remote sensing instruments, datasets are not often available ~~in-on digital the~~ geographic information system (GIS) platforms. As a final remark, only recently some modelling-modeling approaches have been developed to ~~obtain-estimationestimate~~ of the potential distribution of seagrass meadows in the Mediterranean. The probability of presence of ~~the-a seagrass~~ species in a given area has been modelled using: i) a binomial generalised linear model as a function of the bathymetry and water transparency, dissolved organic matter, sea surface temperature and salinity, mainly obtained from satellite data (Zucchetta et al., 2016); ii) morphodynamics features, i.e.i.e., wave, climate and seafloor morphology, to predict the seaward and landward boundaries of *Posidonia oceanica* meadows (Vacchi et al., 2012, 2014).

Table 1: Synthesis of the main survey tools used for defining the Common Indicator 1\_Habitat distributional range and extent for seagrass meadows. When available, the depth range, the surface area mapped, the spatial resolution, the efficiency (expressed as area mapped in km<sup>2</sup> per hour), and the main advantages ~~or~~ and the limits of each tool are indicated, with some bibliographic references.

Survey tool	Depth range	Surface area	Resolution	Efficiency	Advantages	Limits	References
Satellite images	From 0 to 10-15 m	From few km <sup>2</sup> to large areas (over <del>100-400</del> km <sup>2</sup> )	From 0.5 m	Over 100 km <sup>2</sup> /hour	<ul style="list-style-type: none"> <li>• A global and large-scale coverage of virtually all coastal areas</li> <li>• Availability of free digital images, usable without authorization, from the web (e.g., Google Earth)</li> <li>• High geometric resolution</li> </ul>	<ul style="list-style-type: none"> <li>• Limited to shallow waters characterization</li> <li>• Good weather conditions required (no clouds and no wind)</li> <li>• Possible errors in image interpretation among distinct habitats</li> <li>• Possible errors in image interpretation due to bathymetric variations</li> <li>• <u>Not adequate for medium to small coastal dynamics</u></li> </ul>	Kenny et al. (2003)
Multispectral and/or hyperspectral images	From 0 to 25 m, with an optimum up to 15 m	From 50 km <sup>2</sup> to 5000 km <sup>2</sup>	From 1 m		<ul style="list-style-type: none"> <li>• High resolution <u>that allow</u> <del>ing</del> <u>distinguishing</u> seagrass species</li> <li>• Possibility to collect data even during bad weather conditions</li> </ul>	<ul style="list-style-type: none"> <li>• Complex acquisition and processing procedures requiring the presence of specialists</li> <li>• Necessary to validate the observations with field data</li> <li>• Difficulty in habitat identification in the case of very patchy populations</li> </ul>	Mumby and Edwards (2002); Mumby et al. (2004); Dekker et al. (2006); Gagnon et al. (2008)

Survey tool	Depth range	Surface area	Resolution	Efficiency	Advantages	Limits	References
Aerial images	From 0 to 10-15 m	Adapted to small areas (10 km <sup>2</sup> ), but it can be used for areas over 100 km <sup>2</sup>	From 0.3 m	Over 10 km <sup>2</sup> /hour	<ul style="list-style-type: none"> <li>• Very high resolution</li> <li>• Manual, direct and easy interpretation of the images</li> <li>• Availability of libraries with chronological series of images (often free)</li> <li>• <u>Good identification of boundaries between populations</u></li> <li>• <u>Fine-scale ecological studies</u></li> </ul>	<ul style="list-style-type: none"> <li>• Same limits as for satellite images</li> <li>• Difficulty in geometrical corrections and strong deformations if verticality is not respected or if image covers a small area (low altitude view)</li> <li>• <u>Difficulty in obtaining authorizations for imaging in some countries</u></li> <li>• <u>Expensive data acquisition</u></li> </ul>	Frederiksen et al. (2004); Kenny et al. (2003); Diaz et al. (2004)
<u>Drone images (UAVs)</u>	<u>From 0 to 10-15 m</u>	<u>Small areas (10 km<sup>2</sup>)</u>	<u>From 0.1 m</u>	<u>Less than 1km<sup>2</sup>/hour</u>	<ul style="list-style-type: none"> <li>• <u>Very high resolution</u></li> <li>• <u>Manual, direct, and easy interpretation of the images</u></li> <li>• <u>Availability of automated approaches for data classification</u></li> <li>• <u>Good identification of boundaries between populations</u></li> <li>• <u>Low-cost</u></li> </ul>	<ul style="list-style-type: none"> <li>• <u>Limited to shallow waters characterization</u></li> <li>• <u>Require permissions to fly over specific areas</u></li> <li>• <u>Optical refractive distortion effects created by the water surface</u></li> </ul>	<u>Ventura et al. (2017, 2018); Rende et al. (2020)</u>
Side scan sonar	Below 8 m	From large to medium areas (50-100 km <sup>2</sup> )	From 0.1 m	0.8 to 3.5 km <sup>2</sup> /hour	<ul style="list-style-type: none"> <li>• Very high resolution</li> <li>• Realistic representation of the seafloor</li> <li>• Good identification of boundaries between populations</li> <li>• Good identification between meadows of different density</li> <li>• Quick execution</li> </ul>	<ul style="list-style-type: none"> <li>• Small patches (smaller than 1 m<sup>2</sup>) or low-density meadows cannot be distinguished</li> <li>• Loss of definition at image edge, requiring adjustments between adjacent profiles</li> <li>• Possible errors in image interpretation due to large signal amplitude variations (levels of grey)</li> </ul>	Paillard et al. (1993); Kenny et al. (2003); Clabaut et al. (2006)

Survey tool	Depth range	Surface area	Resolution	Efficiency	Advantages	Limits	References
<u>Single-beam acoustic sonar</u>	<u>Below 10 m</u>		<u>From 0.5 m</u>	<u>1.5km<sup>2</sup>/hour</u>	<ul style="list-style-type: none"> <li>• <u>Good geo-referencing</u></li> <li>• <u>Quick execution</u></li> </ul>	<ul style="list-style-type: none"> <li>• <u>Low discrimination between habitats</u></li> <li>• <u>Lower reliability compared to satellite techniques</u></li> </ul>	<u>Kenny et al. (2003); Riegl and Purkis (2005)</u>
Multi-beam acoustic sonar	Below 2-8 m	From large (50-100 km <sup>2</sup> ) to small areas (a few hundred square meters)	From 50 cm	0.2 km <sup>2</sup> /hour	<ul style="list-style-type: none"> <li>• Possibility to obtain 3D image of a meadow</li> <li>• Data on biomass per surface area unit can be obtained</li> <li>• Huge amount of data collected</li> </ul>	<ul style="list-style-type: none"> <li>• Efficient computer systems for processing and archiving data are needed</li> <li>• Possible errors in image interpretation</li> </ul>	Kenny et al. (2003); Komatsu et al. (2003)
Transect or permanent square frames (quadrates)	Depths easily accessible by scuba diving (0-40 m, according to local rules on scientific diving)	Small areas, usually between 25 m <sup>2</sup> to 100 m <sup>2</sup> for permanent square	From 0.1 m	0.01 km <sup>2</sup> /hour	<ul style="list-style-type: none"> <li>• Very high resolution and detail in the information collected</li> <li>• Possibility to identify small structures (patches) and to localize population boundaries</li> <li>• Ground-truthing of the remote sensing data</li> <li>• Possibility to do simultaneous monitoring</li> </ul>	<ul style="list-style-type: none"> <li>• Many working hours</li> <li>• Small areas mapped</li> <li>• Necessity of numerous observers to cover larger areas</li> </ul>	Pergent et al. (1995a); Montefalcone et al. (2006)
Video camera (ROV or towed camera)	Whole bathymetric range of seagrass distribution	Small areas, usually under 1 km <sup>2</sup>	From 0.1 m	0.2 km <sup>2</sup> /hour	<ul style="list-style-type: none"> <li>• Very high resolution</li> <li>• Easy to use</li> <li>• Possibility to record seafloor images for later interpretation</li> </ul>	<ul style="list-style-type: none"> <li>• Long time to gain and process data</li> <li>• Positioning errors due to gap between the vessel position and the camera when towed</li> </ul>	Kenny et al. (2003); Diaz et al. (2004)

Survey tool	Depth range	Surface area	Resolution	Efficiency	Advantages	Limits	References
Laser-telemetry	Depths easily accessible by scuba diving (0-40 m, according to local rules on scientific diving)	Small areas, under 1 km <sup>2</sup>	Some centimetres	0.01 km <sup>2</sup> /hour	<ul style="list-style-type: none"> <li>• Very accurate localization of population boundaries or remarkable structures</li> <li>• Possibility to do simultaneous monitoring</li> </ul>	<ul style="list-style-type: none"> <li>• Range limited to 100 m in relation to the base, and thus no possibility to work over large areas</li> <li>• Necessity of markers on the seafloor for positioning the base when monitoring over time is requested</li> <li>• Possible acoustic signal perturbation due to large variations in temperature or salinity</li> <li>• Specific training on the equipment is requested</li> </ul>	Descamp et al. (2005)
GIB (GPS intelligent buoy)	Depths easily accessible by scuba diving (0-40 m, according to local rules on scientific diving)	Small areas, under 1 km <sup>2</sup>	Some centimetres		<ul style="list-style-type: none"> <li>• Same characteristics as for laser-telemetry, but with a greater range (1.5 km)</li> </ul>	<ul style="list-style-type: none"> <li>• Quite difficult technique</li> <li>• Need of many related equipments, and of a team of divers</li> </ul>	Descamp et al. (2005)

1) *Optical data*

~~22-23.~~ Satellite images are gained from satellites in orbit around the earth. Data is obtained continuously and today it is possible to buy data (sometimes subscribe for free) data that can reach a very high resolution (Tab. 2). It is also possible to ask for ~~a~~ specific programming of the satellite (programmed to pass over an identified sector with specific-particular requirements), but this will require much higher costs.

~~23-24.~~ The rough data must undergo a prior geometrical correction to compensate for errors due to the methods the images are obtained (e.g., errors of parallax, inclination of the satellite) before it can be used. Images already geo-referenced should-can also be obtained even if their cost is much higher than the rough data. The use of satellite images for mapping seagrass meadows requires knowledge of satellite image analysis software (e.g., ENVI, ErdasGeomatica), mastery in the use of the water column correction algorithm (Lyzenga, 1978), and mastery with pixel-based remote sensing supervised image-classifiers, for example, the OBIA ~~systems~~-(Object-Based Image Analysis)-classification algorithm.

Table 2: Types of satellites and resolution of the sensors used for mapping seagrass meadows. ~~n.a. = data not available.~~

Satellite	Resolution	References
LandSat 8	30 m	Dattola et al. (2018)
Sentinel 2A - 2B	10 m	Traganos and Reinartz (2018)
<del>PLANETS</del> <u>SPOT 5</u>	<del>3 m</del> <u>2.5 m</u>	<u>Traganos et al. (2017)</u> <u>Pasqualini et al. (2005)</u>
<u>SPOT 5</u>	<u>2.5 m</u>	<u>Pasqualini et al. (2005)</u>
IKONOS (HR)	1.0 m	Fornes et al. (2006)
QuickBird	0.7 m	Lyons et al. (2007)
Geoeyes	0.5 m	Amran (2017)

~~24-25.~~ In view of Given the changes ~~of in~~ the light spectrum depending on the depth, satellite telemetry can be used for mapping shallow meadows (see Tab. 1). In clear waters the maximum depths reached can be:

- With the blue channel up to approx. 20-25 m depth
- With the green channel up to 15-20 m
- With the red channel up to 5-7 m
- Channel close to the infra-red approx. from tens of centimetres up to 20 m.

~~25-26.~~ Although the spatial resolution of satellite imagery has significantly improved in the last decade, the data collected is still not sufficient for medium to small coastal dynamics. ~~In particular, resolution~~The rResolution of the LandSat-~~8~~ satellite is not adequate to have-reach high resolution mappings of seagrass meadows. However, the image LandSat-~~8~~ OLI represents a valid useful tool to estimate the presence/absence of broad seagrass meadows; moreover, LandSat has a historical series of images useful to perform a multitemporal study. For these reasons, it has been suggested to consider the Sentinel-~~2A and 2B~~ satellites of the Copernicus programme. The Sentinel-~~2A and 2B~~ satellites have a 13-band multispectral sensor (between visible and near infrared), the spatial resolution varies between 10, ~~20~~ and 60 m and the satellite revisiting time in the same area is 5 days (whilest is 18 days for LandSat). Specifically, for mapping *Posidonia oceanica* meadows, various application tests demonstrated the good applicability of the Sentinel-~~2~~ image, at 10 m resolution, for an effective evaluation of the meadows' extent (Dattola et al., 2018; Traganos and Reinartz, 2018). The use of Sentinel-~~2A and 2B~~ images, at the Mediterranean scale, can allow measuring the extent of the *P. oceanica* meadows habitat and verify any possible variations over time. The Sentinel-~~2A and 2B~~ images are also useful for the analysis of pressure and impact drivers.

~~26.~~ Multispectral or hyperspectral imaging is based on images collected simultaneously and composed of numerous close and contiguous spectral bands (generally 100 or more). There is a wide variety of airborne sensors (e.g., CASI<sup>1</sup>, Deaedralus Airborne Thematic Mapper; Godet et al., 2009), which provide data in real time, ~~and~~ also during unfavourable lighting conditions (Tab. 1). It is possible to create libraries with specific spectral responses to measure values compared to distinct component species and appraise the vegetation cover (Ciraolo et al., 2006; Dekker et al., 2006). ~~It is possible to create libraries with specific spectral responses, so that measured values can be compared to distinct component species and appraise the vegetation cover (Ciraolo et al., 2006; Dekker et al., 2006).~~

~~27.~~

28. Aerial images obtained through various means (e.g., airplanes, ~~drones~~, ULM) may have different technical characteristics (e.g., shooting altitude, verticality, optical quality). Even though it is more expensive, shooting films from a plane ~~that is~~ equipped with an altitude and verticality control system and using large size negatives (24 × 24) allows for high quality results (i.e., increase in the geometrical resolution). For example, on a photo at the scale 1/25000 the surface area covered is 5.7 km × 5.7 km (Denis et al., 2003). In view of ~~Given~~ the progress made in the last few decades in terms of shooting (e.g., the quality of the film, filters, lens) and ~~in the~~ following processing (e.g., digitalization, geo-referencing), aerial photographs represents today one of the most preferred surveying methods for mapping shallow seagrass meadows (Mc Kenzie et al., 2001). ~~Imagery acquired by unmanned aerial vehicles (UAVs), usually referred to as “drones”, coupled with structure from motion photogrammetry, has recently been extensively tested and validated for the mapping of the upper limits of seagrass meadows, as they offer a rapid and cost effective tool to produce very high resolution orthomosaics and maps of coastal habitats (Ventura et al., 2018).~~

29. Recent applications of very fine resolution Unmanned Aerial Vehicles (UAVs), usually referred to as “drones”, have showed effectiveness for mapping and for detecting changes in small patches and seascape features of seagrass meadows, at the scale and resolution that would not be possible with satellite or aerial photography (James et al., 2020). The application of UAVs for mapping and monitoring of seagrass habitats is limited by the optical characteristic of the water (e.g., turbidity) and environmental conditions (e.g., solar elevation angle, cloud cover, wind speed) during image acquisition (Rende et al., 2020 and references therein), and is therefore limited to shallow waters characterization. Imagery acquired by unmanned aerial vehicles (UAVs), usually referred to as “drones”, coupled with structure-from-motion (SfM) photogrammetry, has recently been extensively tested and validated for the mapping of the upper limits of seagrass meadows, as they offer a rapid and cost-effective tool to produce very high-resolution orthomosaics and maps of ~~coastal~~ coastal habitats (Ventura et al., 2018).

~~27.~~ Only recently the importance to integrate different methodological techniques (i.e., multispectral satellite, drone, multibeam echosounder, underwater towed video camera, autonomous surface vehicle) in a multi-scale approach for mapping seagrass meadows has been highlighted, as it allows for the acquisition of data with very high resolution and accuracy (Rende et al., 2020). An immediate advantage is related to the collection of large-scale remote sense data (with optic and acoustic methods), combined with images from underwater photogrammetry cameras for ground-truth, which ensures very high accuracy in both shallow and deep waters. At present, an integrated approach is the best option for seagrass mapping, as it offers a greater modularity in function of the spatial scales and allows optimizing costs, always maintaining the primary objective of high-resolution seafloor and habitat mapping, from the coastline to deeper water.

## 2) Acoustic data

~~28-30.~~ Sonar provides images of the seafloor through the emission and reception of ultrasounds. Among the main acoustic mapping techniques, Kenny et al. (2003) distinguishes ~~distinguishes~~: (1) wide acoustic beam systems like the Sside sScan sSonar (SSS), (2)

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<sup>1</sup>CASI: Compact Airborne Spectrographic Imager

single-beam ~~sounder~~echosounder (3), multiple narrow beam bathymetric systems, and (4) multi-beam ~~sounder~~echosounder.

~~29-31.~~ Side scan Sonar (SSS) tow-fish (transducer), with its fixed recorder, emits acoustic signals. The obtained images, or sonograms, visualize the distribution and the boundaries of the different entities over a surface area of 100 to 200 m along the pathway (Clabaut et al., 2006; Tab. 1). The resolution of the final map partly depends on the means of positioning used by the vessel (e.g., radio localisation or satellite positioning). The existence of a sonogram atlas (Clabaut et al., 2006) could ~~be helpful in interpreting~~ help interpreting the data ~~and to differentiate in differentiating among habitats or substrate typologies~~. Although this method has strong limitations in shallow waters (Tab. 1), a side scan sonar array able to efficiently map seagrass beds residing in 1 m or less of water has been recently developed (Greene et al., 2018).

~~30-32.~~ Single-beam echosounder is based on the simultaneous emission of two frequencies separated by several octaves (38 kHz and 200 kHz) to obtain the seafloor characterisation ~~and the bathymetric profile~~. The sounder's acoustic response is different depending on whether the sound wave is reflected by an area covered or not covered by vegetation.

~~31-33.~~ Multi-beam echosounder may precisely and rapidly provide: (i) topographical images of the seafloor (bathymetry), (ii) sonar images representing the local reflectivity of the seafloor as a consequence of its nature (backscatter). The instrument simultaneously measures the depth in several directions, determined by the system's receiver beams. These beams ~~form a beam~~ are perpendicular to the axis of the ship. The seafloor can thus be explored over a wide band (5 to 7 times the depth) with a high degree of resolution. A high-resolution 3D structure of the seafloor is also obtained (the digital elevation model, DEM), where meadows can be visualized and the biomass can be evaluated (Komatsu et al., 2003). Other derived products can be slope, aspect, curvature, and terrain ruggedness maps. Multi-beam echosounders surveys are also limited in very shallow waters, and especially at depths lower than 5 m where vessel navigation might be difficult and dangerous and the swath coverage is very limited (generally, it is 3-4 times the depth of the seabed; Rende et al., 2020).

### 3) *Samplings and visual surveys*

~~32-34.~~ Field samples and direct underwater observations provide discrete punctual data (sampling of distinct points regularly spread out in a study area). They are vital for ground-truthing the instrumental surveys, and for the validation of continuous information (i.e., having a complete coverage of surface areas) obtained through interpolation methods from data collected on limited portions of the study area or along the pathway. Field surveys must be sufficiently numerous and distributed appropriately to obtain the necessary precision, and also in view of the heterogeneity of the habitats. In the case of meadows of *Cymodocea nodosa*, *Posidonia oceanica*, *Zostera marina* or *Zostera noltei*, destructive sampling (using dredger buckets, core samplers, trawls, dredgers) are forbidden in view given of the protected character of these species (UNEP/MAP, 2009) and direct underwater samples (e.g., shoot samples) should be limited as much as possible.

~~33.~~ Observations from the surface can also be made by observers on a vessel using, for instance, a bathyscope, or underwater by using imagery-visual techniques such as photography and video recording. Video-photography plays a valuable role in seagrass research, as a non-destructive technique and especially in fine and meso-scale studies. Photographic equipment and cameras video cameras can also be mounted on a vertical-platform structure (sleigh) or within the remotely operated vehicle (ROV). The camera on a-the vertical-structure platform is submerged at the back of the vessel and is towed by the vessel that advances very slowly (under 1 knot), allowing for the collection of long video transects; on the contrary whilst the ROVs have their own-propulsion system and are remotely controlled from the surface and allow recording comparatively shorter video transects. Recent development in underwater photogrammetry and 2D photo mosaicing (i.e., merging several images of the same scene into a single and larger composite image photo mosaic by aligning and stitching photographs together) provided an ultrafine scaling methodology for micro-chartography and for monitoring activities in the short term to assess current regression/progression of individual

meadows, such as using permanent squares or for monitoring the meadow boundaries (Rende et al., 2015). To acquire overlapping pictures, ensuring about 75% of shared coverage between two consecutive photos, the vessel needs to maintain a speed of about 1 knot/h.

34.35. The use of towed video cameras (or ROVs) during surveys makes it possible to see the images on the screen in real time, to identify specific features of the habitat and to evaluate any changes in the habitat or any other characteristic element of the seafloor. ~~and~~ This preliminary video survey may ~~be also~~ be useful to locate sampling stations. Recorded images are then reviewed to obtain a cartographical restitution on a GIS platform for each of the areas surveyed. To facilitate and ~~to~~ improve the results obtained with the camera, joint acquisition modules integrating the depth, ~~and~~ images of the seafloor ~~and~~ with geographical positioning have been developed (UNEP/MAP-RAC/SPA, 2015).

35.36. *In situ* direct underwater observations by scuba diving represent the most reliable, although time-consuming, surveying technique. Surveys can be done along lines (transects), or over small surface areas (permanent square frames, i.e., quadrates) positioned on the seafloor and located to follow the ~~limits of the habitat~~ habitat limits. The transect consists of a marked line wrapped on a rib and laid on the bottom from fixed points and in a precise direction, typically perpendicular or parallel ~~with respect~~ to the coastline (Bianchi et al., 2004). Any changes in the habitat and in the substrate typology, within a belt at both sides of the line (considering a surface area of about 1-2 m per side), are recorded on underwater slates (Fig. 4). The information registered allows precise and detailed mapping of the sector studied (Tab. 1).

36.37. Marking the limits of a meadow also allows obtaining a distribution map. Laser-telemetry is a ~~useful~~ valuable technique for highly precise mapping surveying over small surface areas (Descamp et al., 2005). The GIB system (GPS Intelligent Buoys) consists of 4 surface buoys equipped with differential GPS receivers and submerged hydrophones. Each of the hydrophones receives the acoustic impulses emitted periodically by a synchronized pinger installed on-board the underwater platform and recorded ~~eds~~ their ~~times of arrival~~ arrival times. Knowing the moment of emission of these signals and the sound propagation speed in the water, the distances between the pinger and the 4 buoys is directly calculated. The buoys communicate via radio with a central station (typically on-board a support vessel) where the position of the underwater target is computed and displayed. The depth is also indicated by the pressure sensor (Alcocer et al., 2006). To optimize meadows mapping operations, the pinger can ~~be also~~ be fixed on a submarine scooter driven by a diver. The maximum distance of the pinger in relationship to the ~~entre~~ center of the polygon formed by the 4 buoys can be approx. 1500 m (UNEP/MAP-RAC/SPA, 2015).

37.38. Free-diving monitoring with a differential GPS can also be envisaged to locate the upper limits of the meadows. The diver precisely follows ~~precisely~~ the contours of the limits and the ~~D~~GPS continuously records the diver's geographical ~~data~~ position. The mapping data is integrated on a GIS platform using the route followed. The acquisition speed is 2-3 km/hour, the sensor precision can be sub metric (UNEP/MAP-RAC/SPA, 2015). *In situ* direct underwater observations by scuba diving along a depth transect perpendicular ~~on~~ to the coastline (© Monica Montefalcone).

### **Data interpretation**

38.39. The recent MESH-EU projects (2008) on habitat mapping (MESH, 2007; Vasquez et al., 2021a, b) identified four ~~important~~ essential stages ~~for the production of~~ to produce a habitat map:

- Processing, analysis and classification of the biological data, through a process of interpretation of acoustic and optical images, ~~when available~~;
- Selecting the most appropriate physical layers (e.g., substrate, bathymetry, hydrodynamics);
- Integration of biological data and physical layers, and use of statistical modelling to predict seagrass distribution and interpolate information;
- The map produced must then be evaluated for its accuracy, i.e., its capacity to represent reality, and ~~therefore~~ its reliability.

40. During the processing, analysis and classification stage, pixels in the image (obtained from both optical and acoustic methods) are given a thematic label as belonging to groups that have either been defined by the user or generated by algorithm models to automate the classification process (Rowan and Kalacska, 2021). Object-Based Image Analysis (OBIA) differs from traditional pixel-based classification methods (maximum likelihood classifiers) because these latter techniques group similar, neighboring pixels into distinct image objects within designated parameters. A typical OBIA workflow involves firstly image segmentation (sequence of processes that are executed in a defined order including segmentation parameters that create meaningful objects made up of multiple neighbouring pixels sharing similar spectral values) and secondly classification of the segmented data through a multiresolution segmentation algorithm that generates objects with similar information by using only the most important features identified (Rende et al., 2020). OBIA methodology allows classifying also underwater cover classes in a rapid, accurate and cost-effective way, and represents to date an effective tool to obtain robust thematic maps of benthic communities. An automatic classification approach can also be applied onto underwater photogrammetry (Marre et al., 2020). Images must be georeferenced and before performing the 3D processing, an image enhancement technique should be performed to minimize the effect of the water column on the underwater images. After the image enhancement step, a Structure-from-Motion (SfM) 3D reconstruction is performed using any commercial software available (Rende et al., 2020). Finally, a Multiview Stereo (MVS) algorithm can be used to produce a dense 3D point cloud from the refined intrinsic orientation and ground-referenced camera exterior orientation.

To label and classify benthic habitats on resulting maps, a standardised classification system must be used to ensure the uniformity and the readability of maps.

~~39.41. During the processing analysis and classification stage, t~~The two recently updated lists of benthic marine habitat types should be consulted, which are: 1) the European Nature Information System (EUNIS) proposed for the European seas (available at <http://eunis.eea.europa.eu>; Evans et al., 2016); and 2) the Barcelona Convention classification of marine benthic habitat types adopted for the Mediterranean region<sup>4</sup> by the Contracting Parties should be consulted (available at [https://www.rac-spa.org/sites/default/files/doc\\_fsd/habitats\\_list\\_en.pdf](https://www.rac-spa.org/sites/default/files/doc_fsd/habitats_list_en.pdf); SPA/RAC-UN Environment/MAP, 2019a, b; Montefalcone et al., 2021UNEP/MAP SPA/RAC, 2019) to recognize any specific habitat type (i.e., seagrass species). As seagrass assemblages are often small in sizesmall, they can only be identified with high (metric) precision mapping. The updated lists identifyies the specific “seagrass meadow” habitats that are also listed in the annex of the Habitats Directive (Directive 92/43/EEC), and which must be taken into consideration within the framework of the NATURA 2000 programs. A complete-The first original description of these habitat types for the Mediterranean has been revised in 2015 (UNEP/MAP-RAC/SPA, 2015b), but a newly updated interpretation manual of all the updated reference habitat types for the Mediterranean region is under elaboration, which also provides s and the criteria for their identification are available in Bellan-Santini et al. (2002). Habitats dominated by seagrass species that must be represented on maps listed in the updated Barcelona Convention classification system are the following (SPA/RAC-UN Environment/MAP, 2019a, bUNEP/MAP SPA/RAC, 2019):

## LITTORAL

### MA3.5 Littoral coarse sediment

#### MA3.52 Medi delittoral coarse sediment

##### MA3.521 Association with indigenous marine angiosperms

##### MA3.522 Association with *Halophila stipulacea*

<sup>4</sup>The updated list of benthic marine habitat types for the Mediterranean region is in a draft stage. It was endorsed by the Meeting of Experts on the finalization of the Classification of benthic marine habitat types for the Mediterranean region and the Reference List of Marine and Coastal Habitat Types in the Mediterranean (Roma, Italy 22-23 January 2019). The draft updated list will be examined by the 14th Meeting of SPA/BD Focal Points (Portoroz, Slovenia, 18-21 June 2019) and submitted to the MAP Focal Points meeting and to the 21st Ordinary Meeting of the Contracting Parties, for adoption.

MA4.5 Littoral mixed sediment

MA4.52 ~~Meidi~~littoral mixed sediment

MA4.521 Association with indigenous marine angiosperms

MA4.522 Association with *Halophila stipulacea*

MA5.5 Littoral sand

MA5.52 ~~Meidi~~littoral sands

MA5.521 Association with indigenous marine angiosperms

MA5.522 Association with *Halophila stipulacea*

MA6.5 Littoral mud

MA6.52 ~~Meidi~~littoral mud

MA6.52a Habitats of transitional waters (~~e.g.~~ estuaries and lagoons)

MA6.521a Association with halophytes (~~*Salicornia* spp.~~) or marine angiosperms (~~e.g. *Zostera noltei*~~)

**INFRALITTORAL**

MB1.5 Infralittoral rock

MB1.54 Habitats of transitional waters (~~e.g.~~ estuaries and lagoons)

MB1.541 Association with marine angiosperms or other halophytes~~sa~~

MB2.5 Infralittoral biogenic habitat

MB2.54 *Posidonia oceanica* meadows

MB2.541 *Posidonia oceanica* meadow on rock

MB2.542 *Posidonia oceanica* meadow on matte

MB2.543 *Posidonia oceanica* meadow on sand, coarse or mixed sediment

MB2.544 Dead matte of *Posidonia oceanica*

MB2.545 Natural monuments/Ecomorphoses of *Posidonia oceanica* (fringing reef, barrier reef, stripped meadow, atolls)

MB2.546 Association of *Posidonia oceanica* with *Cymodocea nodosa* or *Caulerpa* spp.

MB2.547 Association of *Cymodocea nodosa* or *Caulerpa* spp. with dead matte of *Posidonia oceanica*

MB5.5 Infralittoral sand

MB5.52 Well sorted fine sand

MB5.521 Association with indigenous marine angiosperms

MB5.522 Association with *Halophila stipulacea*

MB5.53 Fine sand in sheltered waters

MB5.531 Association with indigenous marine angiosperms

MB5.532 Association with *Halophila stipulacea*

MB5.54 Habitats of transitional waters (e.g. estuaries and lagoons)

MB5.541 Association with marine angiosperms or other halophytes

MB6.5 Infralittoral mud sediment

MB6.51 Habitats of transitional waters (e.g. estuaries and lagoons)

MB6.511 Association with marine angiosperms or other halophytes

42. The selection of physical layers to be shown on maps and to be used for following predictive statistical analyses may be an interesting approach within the general framework of mapping seagrass habitats, and it would reduce the processing time, but it is still of little use for the Mediterranean meadows as only few of the classical physical parameters (e.g., substrate type, depth, salinity) are able to clearly predict the distribution of species (Fig. 5).

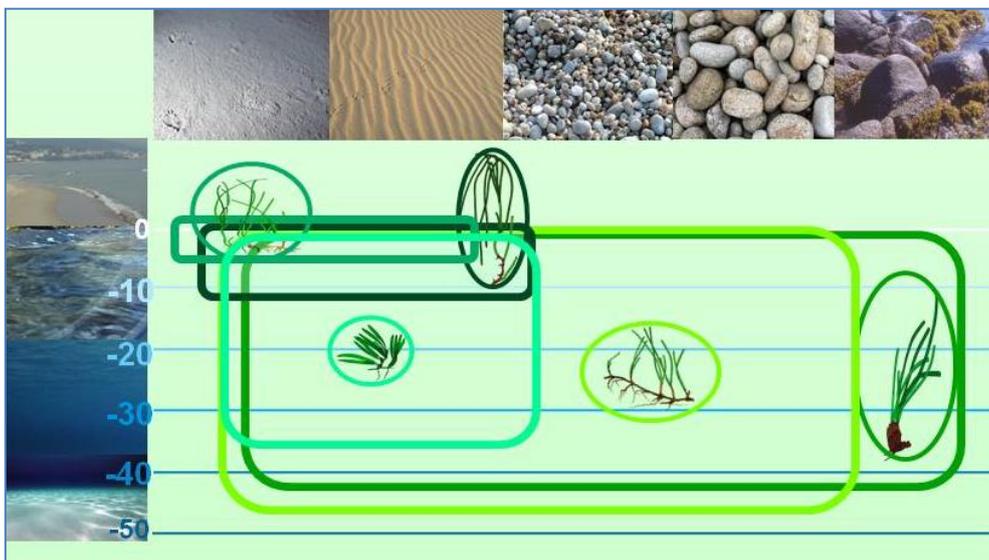


Figure 5: Distribution of seagrass species depending on the nature of the substrate and the depth in the Mediterranean (from UNEP/MAP-RAC/SPA, 2015a).

40. The data integration and modelling stage will differ depending on the survey tools and acquisition strategy used. Due to its acquisition rapidity, aerial techniques usually allow to-for a complete coverage completely-of the littoral and shallow infralittoral zones and this greatly dramatically reduces interpolation of data. On the contrary, surveys from vessels are often limited because of time and costs involved, and only rarely allow to-obtaining a complete coverage of the area. Coverage under 100% automatically means that it is impossible to obtain-get high resolution maps and therefore interpolation procedures have-to-must be used, so that from partial surveys a lower resolution map can be obtained (MESH-project, 20078; Fig. 6). Spatial interpolation is a geostatistical procedure for estimating data values at unsampled sites between actual data collection locations. Elaborating the final meadow distribution map on a GIS platform allows using different spatial interpolation tools and algorithms (e.g., Inverse Distance Weighted, Kriging) provided by the software. Even though this is rarely mentioned, it is important to provide information on the number and the percentage of data acquired on the field and the percentage of interpolations.

41-43. An “overlapping” survey strategy combining a partial coverage of a large surface area and a more detailed coverage of smaller zones of particular interest could be an interesting compromise. Sometimes it might be enough to have a precise and detailed map only of the extension boundaries limits (upper and lower limits) of the meadow, and the presence-description between these two limits could be reduced to occasional field investigations leaving the interpolation to play its part (Pasqualini et al., 1998).

42.44. The processing and digital analysis of data (optical or acoustic) on GIS allows ~~to~~ creating charts where each tonality of grey is associated ~~to~~ with a specific texture representing a type of population/habitat, also ~~on the basis of~~ based on *in situ* observations and sampling for ground-truthing. A final map is thus created, where it is possible to identify the bare substrate, hard substrates and seagrass meadows. Specific processing (e.g., analysis of the roughness, filtering, and thresholding) makes additional information accessible, such as the seagrass cover or the presence of anthropogenic signs (Pasqualini et al., 1999).

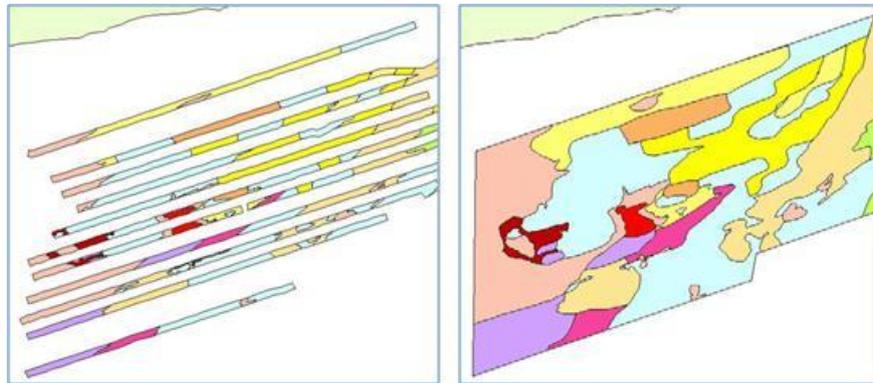


Figure 6: Example of partial coverage survey (left) and the output of the final map produced through interpolation (right). The area surveyed is about 20 km wide (from UNEP/MAP-RAC/SPA, 2015a).

43.45. To facilitate a comparison among maps, standardized symbols and colours should be used for the graphic representation of the main seagrass assemblages (Meinesz and Laurent, 1978; Fig. 7). According to the newly updated classification of marine benthic habitat types for the Mediterranean region adopted by the Contracting Parties of the Barcelona Convention (available at [https://www.rac-spa.org/sites/default/files/doc\\_fsd/habitats\\_list\\_en.pdf](https://www.rac-spa.org/sites/default/files/doc_fsd/habitats_list_en.pdf); SPA/RAC-UN Environment/MAP, 2019a, b; Montefalcone et al., 2021), all the habitats dominated by seagrass can be represented on maps using specific symbols and/or colours that can be labelled in the legend using their relative codes (e.g., code MB2.54: *Posidonia oceanica* meadow; code MB5.531: Association with indigenous marine angiosperms on fine sand in sheltered waters). When the cartographical detail is good enough, it is possible also to indicate also represent the discontinuous meadows that are characterised by a cover below 50%, or the two main species that constitute a mixed meadow (the colour of the patches allows identification of the species concerned). To represent some typical forms of *Posidonia oceanica* meadows (e.g., striped, atolls) no specific symbols are available being these forms (bands and circular structures, respectively) easily identifiable on the map.

46. On the resulting maps the seagrass habitat distributional range and its total extent (expressed in square meters or hectares) can be defined. These maps can be also also be compared with previous historical available data from the literature to evaluate any changes experienced by meadow over time a period of time (Mc Kenzie et al., 2001). Using the overlay vector methods on GIS, a diachronic analysis can be done, where temporal changes are measured in terms of percentage gained or lost of in the meadow extension, through the creation of concordance and discordance maps (Barsanti et al., 2007).

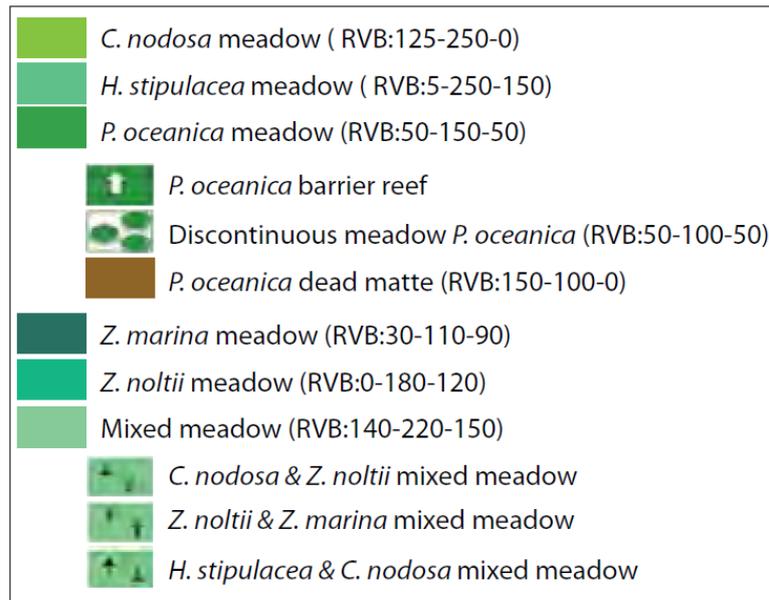


Figure 7: Examples of symbols and colours used for the graphic representation of the main seagrass assemblages. RVB: values in red, green, and blue for each type of meadow (from UNEP/MAP-RAC/SPA, 2015a).

44.47. The reliability of the map produced should also be evaluated. Several evaluation scales of-for reliability have already been proposed and may be useful-helpful for seagrass meadows. Pasqualini (1997) proposed s a reliability scale in-relation-to-about the image processing of the aerial photos, which can also be applied to satellite images, or another scale in relation to the processing of sonograms (UNEP/MAP-RAC/SPA, 2015a). Reliability lower than or equal to 50% means that the author should try to improve the reliability of the data (for example increasing the number of segments during image processing) or maybe that the restitution scale needs to be adapted.

45.48. Denis et al. (2003) proposed d a reliability index of-for the cartographic data based on the map scale (scale of 5), the positioning system (scale of 5) and the acquisition method (scale of 10) (UNEP/MAP-RAC/SPA, 2015a). The reliability index ranges from 0 to 20 and can vary from one point to another of-on the map, depending on the bathymetry of-and the survey technique used.

46.49. Leriche et al. (2001) proposed a reliability index rated from 0 to 50, which weighs three parameters: (i) the initial scale of the map (source map) and the working scale (target map), (ii) the method of data acquisition (e.g., dredges, grabs, aerial photography, side scan sonar, scuba diving), and (iii) the method of data georeferencing.

**b) COMMON INDICATOR 2: Condition of the habitat's typical species and communities**

*Approach*

47-50. Seagrasses are used as biological indicators of the water quality according to the European Water Framework Directive (WFD, 2000/60/EC), and as indicators of the environmental quality (i.e., condition of the habitat) according to the Marine Strategy Framework Directive MSFD (MSFD, 2008/56/EC) and the IMAP ~~EcAp~~ CI2-related to EO1 "biodiversity". The CI2 is aimed at providing information about the condition (i.e., ecological status) of seagrass meadows.

48-51. Monitoring the ecological status of seagrass meadows is today mandatory and is even an obligation for numerous Mediterranean countries ~~due to the fact that since~~:

- Four out of the five species present in the Mediterranean (~~*Cymodocea-*~~ *nodosa*, ~~*Posidonia-*~~ *oceanica*, ~~*Zostera-*~~ *marina*, and *Z. noltei*) are listed in the Annex II (list of endangered or threatened species) of the Protocol concerning Specially Protected Areas and Biological Diversity (SPA/BD protocol, Decision of the 16<sup>th</sup> Ordinary meeting of the Contracting Parties, Marrakech, 3-5 November 2009; UNEP/MAP, 2009);
- Three species (*C. nodosa*, *P. oceanica*, and *Z. marina*) are listed in the Annex I (strictly protected flora species) of the Bern Convention concerning the Mediterranean geographical region;
- Seagrass meadows are defined as priority natural habitats by the European Directive No. 92/43 (EEC, 1992).

49-52. This regulatory "recognition" also means that efficient management measures and conservation practices are required to ensure that these priority habitats, their constituent species, and their associated communities are and remain in a satisfactory ecological status. The good state of health of seagrasses will then reflect the Good Environmental Status (GES) pursued by the Contracting Parties to the Barcelona Convention under the Ecosystem Approach (EcAp) and under the Marine Strategy Framework Directive (MSFD).

50-53. ~~A~~ Defined and standardized procedures for monitoring the status of seagrass meadows, comparable to those provided for their mapping, should follow these three main steps:

1. Initial planning;
2. Setting-up the monitoring system;
3. Monitoring over time and analysis.

51-54. The initial planning is required to define the objective(s), determine the duration, identify the sites to be monitored, choose the descriptors to be evaluated with their acquisition modalities (i.e., the sampling strategy), and evaluate the human, technical and financial needs to ensure implementation and sustainability. This initial phase is therefore very important.

52-55. The setting-up phase is the concrete operational phase, when the monitoring program is set-up (e.g., positioning fixed markers) and realised. This phase may turn out to be the most expensive, including costs for going out to sea during field activities, equipment for sampling, and human resources, especially under difficult weather conditions. Field activities ~~must thus should~~ be planned during a favourable season, also because some of the parameters chosen for monitoring purposes must be collected during the same period due to the seasonality in seagrass growth. This phase might be quite long, especially if numerous sites have to be monitored.

53-56. Monitoring over time and data analysis phase seems to be easy being the data acquisition a routinary operation, with no major difficulties if the previous two phases had been carried out correctly. Data analysis needs clear scientific competence. Duration of the monitoring, ~~in order to~~ be useful, must be medium time/medium time at least. This phase often constitutes the key element of the monitoring system as it makes ~~it~~ possible to:

- Interpret the acquired data;
- Demonstrate its validity and interest;
- Check that the monitoring objectives have been attained.

~~54.57.~~ The objectives of the Monitoring of seagrass meadows is ~~an~~ linked ~~cover~~ with the conservation ~~targets of seagrass meadows~~ and ~~also with~~ their use as ~~an~~ ecological indicators of the quality of ~~the~~ marine environment. The main aims of seagrass monitoring are generally:

- Preserve and conserve the heritage of marine ~~the~~ priority habitats, with the aim of ensuring that ~~the seagrass~~ meadows are in a satisfactory ecological status (GES) and ~~also to~~ identify as early as possible any degradation of these priority habitats or any changes in their distributional range and extent. Assessment of the ecological status of meadows allows ~~to~~ measuring the effectiveness of local or regional environmental policies in terms of management of the coastal environment;
- Build and implement a regional integrated monitoring system of the quality of the environment, as requested by the ~~Integrated Monitoring and Assessment Programme and related Assessment Criteria (IMAP)~~ during the implementation of the EcAp in the framework of the Mediterranean Action Plan. The main goal of IMAP is to gather reliable quantitative and updated data on the status of marine and coastal Mediterranean environments;
- Evaluate effects of any coastal activity and construction likely to impact seagrass meadows during environmental impact assessment (EIA) procedures. This particular ~~type-kind~~ of monitoring aims to establish the condition of the habitat at the time “zero” (i.e., before the beginning of activities), then ~~monitor~~ the state of health of the meadow ~~is monitored~~ during the development of the works phase or at the end of the phase, to check for any impacts on the environment evaluated as changes in the meadow state of health. The EIA procedure is not intended as a typical monitoring activity, although it provides the state of the system at the “zero” time, which can be very useful in the time series obtained during a monitoring programme. Unfortunately, most of the EIA studies are qualitative and are often performed by environmental consultants without specialized personnel, using unspecific guidelines and without following any standardised procedure, which prevent their use in effective monitoring programs.

~~55.58.~~ The objective(s) ~~chosen of the monitoring system~~ will influence the choices in the following steps (e.g., duration, sites to be monitored, descriptors, sampling methods; Tab. 3). In general, and irrespective of the objective advocated, it is judicious to focus initially on a small number of sites that are easily accessible and that can be regularly monitored after short intervals of time (Pergent and Pergent-Martini, 1995; Boudouresque et al., 2000). The sites chosen must be: i) representative of the portion of the coastal area investigated (e.g., nature of the substrate), ii) cover most of the possible range of environmental situations, and iii) include sensitive zones, stable zones, or reference zones. Then, with the experience gained by the surveyors and the means (funds) available, this network could be extended to a larger number of sites.

~~56.59.~~ To ensure the sustainability of the monitoring system, the following final remarks must be taken into account:

- Identify the partners, competences and means available;
- Planning the partnership modalities (who is doing what? when? and how?);
- Ensure training for the stakeholders so that they can set up standardized procedures to guarantee the validity of the results, and so that comparisons can be made for a given site and among sites;
- Individuate a regional or national coordinator depending on the number of sites concerned for monitoring and their geographical distribution;

- Evaluate the minimum budget necessary for running the monitoring network (e.g., costs for permanent operators, temporary contracts, equipment, data acquisition, processing, and analysis).

Table 3: Monitoring criteria depending on the objectives.

Monitoring objective	Sites to be monitored	Descriptors	Monitoring duration and interval
Heritage conservation	Sites with low anthropogenic pressures or reference sites (i.e., MPAs, Sites of Community Interest) to get information on the natural evolution of the environment	<ul style="list-style-type: none"> <li>• Extent of the meadow and depths of <del>their-its</del> <u>upper and lower</u> limits</li> <li>• Descriptors of the state of health of meadow (e.g., cover, shoot density)</li> </ul>	<ul style="list-style-type: none"> <li>• Medium and long term (min. 10 years)</li> <li>• Data acquisition at least annually for non-persistent species and <u>every</u> 2-3 years for perennial species</li> </ul>
Monitoring environmental quality	Identify the main anthropogenic pressures likely to affect the quality of the environment and initiate monitoring in at least 3 sites, 2 reference/control sites and 1 impacted site, all representative of the coastal area	<ul style="list-style-type: none"> <li>• <del>Physical D</del> descriptors of the quality of the environment (e.g., <u>water turbidity, depth of lower limit, enhancement in nutrients, nitrogen content of leaves and rhizomes</u>, chemical contamination, trace metals in plant)</li> <li>• <u>Descriptors of the state of health of meadow (e.g., cover, shoot density, lower limit depth)</u></li> </ul>	<ul style="list-style-type: none"> <li>• Medium term (5 to 8 years)</li> <li>• Data acquisition is variable depending on the species concerned (<u>every</u> 1-3 years)</li> </ul>
Environmental impact assessment ( <u>EIA</u> )	The site subject to coastal development or interventions. The selection of 2 reference/control sites might be also useful <u>for comparison</u>	<ul style="list-style-type: none"> <li>• Specific descriptors to be defined depending on the possible <del>consequences-effects</del> <u>of human activities on seagrass</u></li> </ul>	<ul style="list-style-type: none"> <li>• Short term (generally 1-2 years)</li> <li>• Initiate before the impact (“zero” time), it can be continued during, or just after the conclusion. A further control can be made one year after the conclusion</li> </ul>

### Methods

~~57-60.~~ Descriptors basically provide information on the state of health of a meadow. A great number of descriptors has been proposed to assess the ecological status of seagrass meadow (e.g., Pergent-Martini et al., 2005; Foden and Brazier, 2007; Montefalcone, 2009; Orfanidis et al., 2010). Some of the most common descriptors (Tab. 4) use a standardized sampling method, especially for *P. oceanica* (Pergent-Martini et al., 2005), but there are still many disparities among data acquisition methods despite efforts to propose a common approach (Short and Coles, 2001; Buia et al., 2004; Lopez y Royo et al., 2010a). For each descriptor listed in Table 4, some bibliographic references are provided, where a detailed descriptions of the sampling tools and methodologies can be found.

61. The many available descriptors available for monitoring seagrass habitat (see Table 4) work at each of the different ecological complexity levels of seagrass-(Montefalcone, 2009), which are from the highest to the lowest: the seascape (i.e., the whole habitat), the ecosystem, the associated

community (e.g., leaf epiphytes), the population (i.e., the meadow), the ~~individual species~~ (i.e., the plant), the ~~physiological or cellular or physiological/biochemical level, and the associated community (especially leaf epiphytes)~~. At each ecological level, a pool of different descriptors and indices can be selected. The selection of the most appropriate descriptor/index should be made considering the ~~specificity~~ specificity of the monitoring program and of its objectives, the means (also funds) available, and the duration of the activities. The best choice would be to combine two or more descriptors/indices to capture the various responses of the system to environmental conditions and to accurately define the health status of seagrass (Oprandi et al., 2019). Some ecological indices (see next section) ~~have been developed to working~~ at the highest ecological levels have been recently developed. At ~~i.e.~~ the seascape level ~~there are~~, for instance, the Conservation Index (Moreno et al., 2001), ~~the Substitution Index and the Phase Shift Index~~, (Montefalcone et al., 2007), ~~and the P Patchiness Index~~ (Montefalcone et al., 2007); ~~or~~ at the ecosystem level ~~(there is the EBQI~~ (Personnic et al., 2014), ~~while~~ ~~Some recent other~~ ecological indices integrate different ecological levels, such as ~~(e.g., for instance the PREI~~ (Gobert et al., 2009), the BiPo (Lopez y Royo et al., 2009), ~~and the POMI~~ (Romero et al., 2007).

58. \_\_\_\_\_

59-62. Descriptors listed in Table 4 can be obtained using different methodologies and sampling approaches: i) on maps resulting from remote sensing surveys or visual inspections (e.g., meadow extent and depths of the limits); ii) *in situ* observations and measures by scuba diving (e.g., lower limit type, cover, rhizome baring, and shoot density); iii) direct sampling of plants (e.g., phenological descriptors). All methods requiring the direct sampling of plants for subsequent laboratory analyses are destructive, and thus the impact of the sampling procedure must be ~~taken into account~~ considered during the initial planning phase (Buia et al., 2004). Not-destructive procedures should be always preferred, especially in the case of protected species (e.g., *Posidonia oceanica*) and when the monitoring is carried out ~~within~~ inside MPAs. However, when the monitoring objective is the assessment of environmental quality, descriptors capable to link the influence of pressures with the health status of the plants are necessary, which usually require the collection of shoots (e.g., descriptors working at the physiological/biochemical level). An effective monitoring should be done at intervals over ~~a period of time~~ a fixed period, even if it ~~could~~ would mean a reduced number of sites and a reduced number of descriptors being monitored. Number of adopted descriptors should be ~~adequate enough~~ adequate to avoid errors of interpretation, but sufficiently reduced to ensure permanent monitoring. Simultaneous application of various descriptors working at different ecological complexity levels is the best choice to understand most of the possible responses of the system to environmental alterations (Montefalcone, 2009; Oprandi et al., 2019). The nature of the descriptors is less important than its reproducibility, reliability and the precision of the method used for its acquisition.

63. In situ observations and samples must be done over defined and, possibly, standardized surface areas, and the number of replicates must be adequate for the descriptor involved and high enough to catch the heterogeneity of the habitat. The analyses at the ~~individual species~~ (the plant), ~~cellular or physiological/biochemical level or cellular~~, and most of the analyses ~~associated~~ at the community level (i.e., the associated organisms of leaves and rhizomes) require collection of shoots. For *Posidonia oceanica*, the mean number of sampled ~~and measured~~ shoots ranges between a minimum of ~~10-9~~ to a maximum of ~~18-21~~ shoots collected at each sampling station (Pergent-Martini et al., 2005). At each station, an equal number of shoots should be collected in three distinct areas tens of meters apart (e.g., 3 to 6 shoots per area, for a total of 9 to 18 shoots per station).

Among all the descriptors listed in Table 4, the shoot density is the most adopted, standardized and not-destructive descriptor in the *P. oceanica* monitoring programs (Pergent-Martini et al., 2005) (Fig. 8), because it provides important information about vitality and dynamic of the meadow and proved effective in revealing environmental alterations (Montefalcone, 2009). Meadow seascape is often patchy (at large spatial scale), but the meadow distribution within patches (medium to small spatial scales) can also be highly heterogeneous (Bacci et al., 2015). The size of the quadrat and the criteria used for randomly placing it on the bottom are crucial to standardize the method to measure

shoot density. For measuring *P. oceanica* shoot density, two standardized sizes of the quadrat are usually adopted: surface area is settled at 40 cm × 40 cm and 20 cm × 20 cm. The use of a larger surface area (1600 cm<sup>2</sup>) incorporate the small-scale meadow heterogeneity, increasing the variability between replicates and thus decreasing the sensibility of statistical test to detect differences between stations. The use of the 20 cm × 20 cm quadrat (400 cm<sup>2</sup>) can reduce this small-scale variability increasing the probability to detect clear spatial patterns. The overall time required for data acquisition increases according to the quadrat size: counting shoots in a 40 cm × 40 cm quadrat is at least four times more time-consuming than in a 20 cm × 20 cm one (Bacci et al., 2015). Smaller quadrats are also easier to use and counting errors are less likely to happen. On the other hand, smaller quadrats require a larger number of replicates to catch the natural shoot density variability.

64. Many studies showed that the use of the 20 cm × 20 cm quadrat is more effective than the use of the 40 cm × 40 cm or larger quadrats, as it allows reaching a better accuracy level given the same sampling effort (Charbonnel et al., 2000; Bacci et al., 2015). To speed the count of shoot density in very dense *P. oceanica* meadows (as usually occur in correspondence of the upper limit), as well as in very sparse meadows (in correspondence of the lower limits), the use of the smaller quadrat 20 cm × 20 cm is recommended. Similarly, the 20 cm × 20 cm quadrat is generally used to measure shoot density of other smaller seagrass species (e.g., *Cymodocea nodosa*, *Zostera noltei*), with a minimum of 3-3 independent replicated counts counts should be done per-in each station of the three distinct areas tens of meters apart, totalising 9 counts per station that are enough to catch the natural within patches variability. The 3 replicated quadrats in each area must be randomly located within homogeneous seagrass patches with maximum coverage. On the contrary, in the case of a patchy meadow, quadrats must be positioned randomly using a stratified sampling procedure on the vegetated patches, and the number of replicates can be increased with 6 replicated quadrats in each area, totalising 18 measurements per sampling station.

65. Measuring the depth and defining the typology of both the upper and the lower limits of the meadow (Fig. 8), as well as monitoring over time their bathymetrical position with permanent marks (i.e., *balises*) are other commonly adopted procedures to assess the evolution of the meadow in term of stability, improvement or regression that is linked to water transparency, water movement, sedimentary balance, and human activities along the coastline.

66. An adequate number of sampling stations must be localised randomly within the meadow according to its extent, and usually in correspondence of the meadow upper limit, the meadow lower limit and at intermediate depth. As stated before, at each depth (i.e., station) 3 sampling areas must be selected, tens of meters apart. To assess the overall ecological condition of the meadow and to reduce the number of sampled shoots, samples of shoots can be performed collected only at the intermediate meadow-depth of the meadow, which is usually located at about 15 m depth, where the meadow is expected to find the optimal conditions for its development (Buia et al., 2004). When the aim of the monitoring program includes biochemical measurements, a sampling station in the deepest portion of the meadow should also be included, since many sources of pressure are usually displaced to deep areas (e.g., wastewater treatment plants, fish farms). Due to the seasonality of most of the descriptors (especially for those linked with leaves growth), and sampling activities should be carried out during the late spring or early summer season (Gobert et al., 2009).

60-67. Among all the descriptors listed in Table 4, the shoot density can be viewed as the most adopted, standardized and not destructive descriptor in the *P. oceanica* monitoring programs (Pergent Martini et al., 2005) (Fig. 8), because it provides important information about vitality and dynamic of the meadow and proves effective in revealing environmental alterations (Montefalcone, 2009). Following the requirements of the WFD and the MSFD in the European countries, the ecological quality of the environment must be defined according to classification scales. For *P. oceanica* shoot density the existing absolute scale proposed for its classification (Pergent-Martini

et al., 2005) has been adapted with the creation of five classes of ecological quality (bad, poor, moderate, good, and high; Annex 1) and can be used at the Mediterranean wide spatial scale, although it has been elaborated using data from *P. oceanica* meadows of France and Corsica. This scale provides a tool to classify the ecological status of the meadow that can be used in the frame of the IMAP under the EcAp. Evaluating depth and typology of both the upper and the lower limits of the meadow and monitoring over time their positions with permanent marks (i.e., *balises*) are commonly adopted procedures to assess the evolution of the meadow in term of stability, improvement or regression that is linked to water transparency, hydrodynamic regimes, sedimentary balance and human activities along the coastline (Fig. 8). The absolute classification scale of for the lower limit depth (Annex 1) is another valid tool to assess the meadow ecological status. Although all the existing absolute scales proposed for *P. oceanica* represent important standardized tools to classify the ecological status of meadows in the frame of the IMAP- procedure under the EcAp, and allow for the comparisons among regions, they could require some adaptations according to the specific geographical area and the morphodynamics setting of the site. It is more than likely that the threshold values fixed between classes are not valid at the whole Mediterranean scale: regional and even more local sub-regional scales should be defined (Montefalcone et al., 2007), providing the same methodologies and intercalibration procedures. For instance, in many *P. oceanica* meadows in of the Ligurian Sea (NW Mediterranean), along the Spanish coast (NW Mediterranean), and of the North Aegean Sea (NE Mediterranean) (Marbà et al., 2014; Oprandi et al., 2019; Gerakaris et al., (2021), the lower limit rarely reaches depths greater than 20-25 m, due to natural constrains (e.g., substrate typology, seafloor topography). Adopting the absolute scale proposed for the lower limit depth, all these meadows would be classified from moderate to bad ecological status, even in the case of low human pressure. Also the nitrogen (N) content in leaves is highly variable within meadows and shows a high natural variability among meadows in the Mediterranean. Each country/region is thus suggested to define proper local regional scales for the classification of each descriptor, which should also be compared with the absolute scales for the Mediterranean Sea to point out geographical patterns (Annex 1)



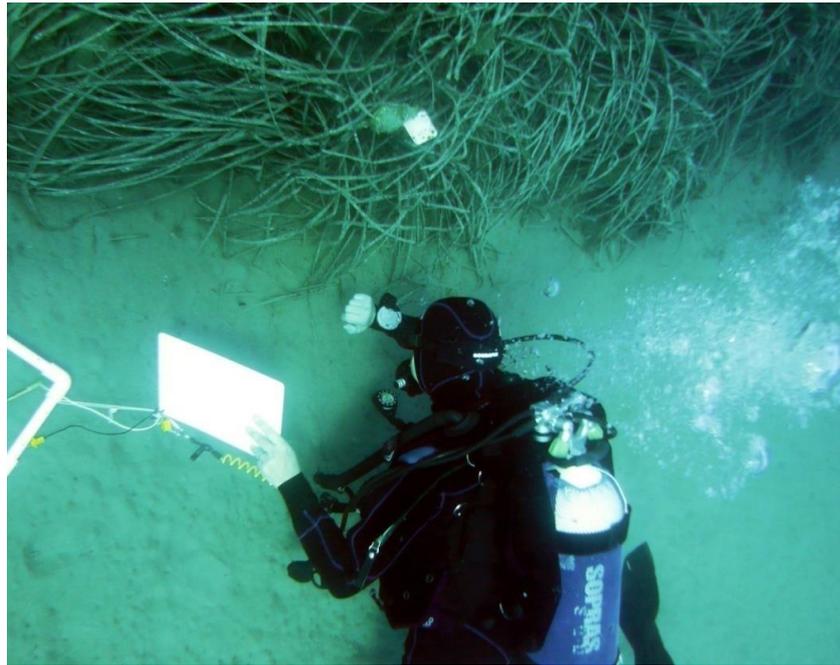


Figure 8: *In situ* measurement of *Posidonia oceanica* shoot density using ~~the a standard square frame~~ quadrat of 40 cm × 40 cm (upper imagepanel, © Monica Montefalcone) and monitoring over time of the meadow lower limit position with permanent marks (lower imagepanel), © Annalisa Azzola).

Table 4: Synthesis of main descriptors used in seagrass monitoring for defining the Common Indicator 2\_Condition of the habitat. When available, the measuring/sampling method, the expected response in ~~the~~ case of increased human pressure and the main factors likely to affect the response of the descriptor, the destructive nature of the method (Destr-), the target species, the advantages and limits, and some bibliographic references are provided. The target species are: Cn = *Cymodocea nodosa*, Hs = *Halophila stipulacea*, Po = *Posidonia oceanica*, Zm = *Zostera marina*, Zn = *Zostera noltei*. The ecological complexity level at which each descriptor works is also indicated (i.e., seascape, population, individualspecies, physiologicalcell, community).

Descriptor	Method	Expected response/factors	Destr	Target species	Advantages	Limits	References
<i>Population-Seascape (meadow) level</i>							
Meadow extent (i.e. surface area)	Mapping (Cf. Part “a” of this document) and/or <u>identification-definition</u> of the <u>meadow boundaries</u> <u>position-of</u> <u>limits</u>	<ul style="list-style-type: none"> <li>Reduction of the total meadow extent</li> <li>Coastal development, turbidity, mechanical impacts</li> </ul>	No	All	<ul style="list-style-type: none"> <li>Informative of many aspects of the meadow</li> <li>Usable everywhere in view of the many techniques available</li> <li>Cover the whole depth range of meadow distribution</li> </ul>	<ul style="list-style-type: none"> <li>For slow growing species (Po) needs of pre-positioning markers to evaluate change in meadow extent, and long response time (several years)</li> <li>Sampling must be done during the season of maximum distribution for species with marked seasonal growth (generally in summer)</li> </ul>	Foden and Brazier (2007)
<i>Population (meadow) level</i>							
Bathymetric position of <u>the</u> meadow upper limit (in m) and its morphology	A detailed mapping of <u>the</u> seagrass <u>extension</u> <u>upper</u> limit landward (Cf. Part “a” of this document) or placing fixed markers (e.g., permanent blocks, acoustic system)	<ul style="list-style-type: none"> <li>Shift of the upper limit at greatest depths</li> <li>-Coastal development <u>and</u> <u>direct destruction</u></li> </ul>	No	All	<ul style="list-style-type: none"> <li>Easily measured (also by scuba diving)</li> <li>Morphology of this limit may reflect environmental conditions</li> </ul>	<ul style="list-style-type: none"> <li>For Cn, Hs and Zn, strong seasonal variability, <u>requiring</u> periodical monitoring or observations <u>at-during</u> the same season <u>for-on</u> all sites</li> <li>• Fixed markers (<u>balises</u>) might disappear if <u>the</u></li> </ul>	Pergent et al. (1995); Montefalcone (2009)

Descriptor	Method	Expected response/factors	Destr	Target species	Advantages	Limits	References
Bathymetric position of <del>the</del> meadow lower limit (in m)	A detailed mapping of <del>the</del> seagrass <del>extension</del> <del>lower</del> limit seaward (Cf. Part “a” of this document) or placing fixed markers (e.g., permanent blocks, acoustic system)	<ul style="list-style-type: none"> <li>• Shift of the lower limit landward at shallower depths</li> <li>• <del>Water T</del>turbidity</li> </ul>	No	All	<ul style="list-style-type: none"> <li>• Easily measured (also by scuba diving)</li> <li>• <del>Absolute c</del>Classification scale available for Po</li> </ul>	<ul style="list-style-type: none"> <li>• site is strongly frequented</li> <li>• For Cn, Hs and Zn, strong seasonal variability, <del>requiring</del> periodical monitoring or observations <del>at-during</del> the same season <del>for</del> all sites</li> <li>• Beyond 30 m depth, <del>underwater acquisition surveys is-are</del> difficult and costly (limited diving time, need for experienced divers, numerous dives requested)</li> <li>• Fixed markers (<i>balises</i>) might disappear (e.g., by trawling)</li> <li>• For slow growing species (Po) long time required to see any progress (several years)</li> </ul>	Pergent et al. (2008); Annex 1

Meadow lower limit <del>typemorphology</del>	<i>In situ</i> <u>visual</u> observations	<ul style="list-style-type: none"> <li>Change in morphology</li> <li><u>Water Turbidity</u>, mechanical <u>impacts damages</u> (e.g., trawling)</li> </ul>	No	Po	<ul style="list-style-type: none"> <li>Well known descriptor</li> <li>Several <del>types</del> <u>morphologies</u> described</li> <li><del>€</del><u>Absolute</u> classification scale for Po</li> </ul>	<ul style="list-style-type: none"> <li>Good knowledge of Po meadows necessary to identify some of the <u>morphologies</u></li> <li><u>Beyond 30 m depth, underwater surveys are difficult and costly (limited diving time, need for experienced divers, numerous dives requested)</u><del>Difficult and costly the assessment at great depths (&gt;30 m)</del></li> </ul>	Boudouresque and Meinesz (1982); Pergent et al. (1995); Montefalcone (2009); Annex 1
<u>Descriptor</u>	<u>Method</u>	<u>Expected response/factors</u>	<u>Destr</u>	<u>Target species</u>	<u>Advantages</u>	<u>Limits</u>	<u>References</u>
Presence of inter-matte channels and dead matte areas	High <u>resolution and</u> <del>ly</del> detailed mapping of the area (Cf. Part “a” of this document, permanent square frames) and/or <i>in situ</i> observations	<ul style="list-style-type: none"> <li>Increase in the extent</li> <li>Mechanical <u>impacts damages</u> (e.g., anchoring, fishing gear)</li> </ul>	No	Po	<ul style="list-style-type: none"> <li>Surface areas <u>can be easily measured</u> <del>can be measured</del> on maps</li> </ul>	<ul style="list-style-type: none"> <li>Dead matte areas are natural components intrinsic <del>to</del> <u>in</u> some <u>typologies of types of</u> meadows (e.g., striped meadows) and do not reflect systematically human influence</li> </ul>	Boudouresque et al. (2006)
Density (shoots · m <sup>-2</sup> )	No. of shoots counted <u>underwater</u> within a square frame ( <u>a quadrate of fixed dimension</u> ) by divers. The square size depends on the <u>seagrass species and on the meadow density</u> . For <i>P. oceanica</i> <u>the most adopted sizes are</u> 40 cm	<ul style="list-style-type: none"> <li>Reduction</li> <li><u>Water Turbidity</u>, mechanical <u>impacts damages</u> (e.g., anchoring)</li> </ul>	No	All	<ul style="list-style-type: none"> <li><u>Easily measured</u></li> <li>Low-cost</li> <li>Can be measured at all depths <u>that can be safely reached by scuba diving</u></li> <li><u>Absolute</u> <del>€</del>classification scale available for Po</li> </ul>	<ul style="list-style-type: none"> <li>Strong variability with depth</li> <li>Long acquisition time for densities over 800 shoots <u>per square meter</u></li> <li>Many replicates necessary to evaluate meadow heterogeneity</li> <li><u>Considerable risk of error if: a) the</u> surveyor</li> </ul>	Duarte and Kirkman (2001); Pergent-Martini et al. (2005); Pergent et al. (2008); <u>Bacci et al. (2015)</u> ; Annex 1

	× 40 cm <u>and 20 cm × 20 cm</u>					is inexperienced; b) high density; c) small sized species. In this latter case <i>in situ</i> counting can be replaced by sampling over a given area and the counting can be done in the <u>laboratory</u> –(but <u>becoming a</u> destructive technique)	
<u>Descriptor</u>	<u>Method</u>	<u>Expected response/factors</u>	<u>Destr</u>	<u>Target species</u>	<u>Advantages</u>	<u>Limits</u>	<u>References</u>
Cover (in %)	Average percentage of the surface area occupied (in vertical projection) by meadow in relation to the surface area observed. Various methods to <u>visual measure-estimate</u> the cover <i>in situ</i> by divers or in <u>laboratory</u> :- (from photos or video, <u>visual estimation</u> ). Variable observation surface area (0.16 to 625 m <sup>2</sup> ), visualised by <u>a quadrat</u> or <u>a transparent plate</u>	<ul style="list-style-type: none"> <li>• Reduction</li> <li>• <u>Water Turbidity, mechanical damages</u></li> </ul>	No	All	<ul style="list-style-type: none"> <li>• Rapid</li> <li>• On photos, possibility of comparison over time and less errors due to subjectivity</li> <li>• All depths</li> <li>• Estimated also from aerial images or sonograms at large <u>spatial</u> scale</li> </ul>	<ul style="list-style-type: none"> <li>• Strong seasonal and bathymetric variability</li> <li>• Comparison of data obtained using different methods and different observation surface areas is not always reliable due to the fractal nature of cover</li> <li>• Sampling strategy and design must include proper spatial variability</li> <li>• <del>High subjectivity of <i>in situ</i> estimations</del></li> <li>• <del>—</del></li> <li>• <del>—</del></li> <li>•</li> </ul>	Buia et al. (2004); Pergent-Martini et al. (2005); Boudouresque et al. (2006); Romero et al. (2007); Montefalcone (2009)

Percentage of plagiotropic rhizomes	Counting of plagiotropic rhizomes <del>in a given on a</del> <u>defined</u> surface area (e.g., <del>40-20</del> cm × <del>40-20</del> cm, which can be visualised by a quadrate)	<ul style="list-style-type: none"> <li>• Increase</li> <li>• Mechanical <del>impacts-damages</del> (e.g., anchoring, fishing gear)</li> </ul>	No	Cn, Po	<ul style="list-style-type: none"> <li>• Easy, rapid, and low-cost</li> <li>• <del>Absolute c</del> <u>Absolute</u> classification scale available for Po</li> </ul>	<ul style="list-style-type: none"> <li>• Mainly used at shallow depths (0-20 m)</li> </ul>	Boudouresque et al. (2006); Annex 1
<u>Individual-Species (plant) level</u>							
Leaves surface area (cm <sup>2</sup> · shoot), and other phenological measures	Counting and measuring the length and width of <u>the</u> different types of leaves in each shoot ( <del>40</del> <u>9 to 18-20</u> shoots <u>according to the sampling design</u> )	<ul style="list-style-type: none"> <li>• Reduction of leaves surface area (Po) for overgrazing and human impacts</li> <li>• Increase in the length of leaves (Po, Cn) for nutrients enhancement</li> </ul>	Yes	All	<ul style="list-style-type: none"> <li>• Easy, <del>rapid</del> and low-cost</li> <li>• Possibility to measure the length of adult leaves (<u>the</u> most external leaves) <i>in situ</i> to avoid sampling</li> <li>• <del>Classification-Absolute</del> <u>classification</u> scale available for Po</li> </ul>	<ul style="list-style-type: none"> <li>• Strong seasonal variability</li> <li>• Strong individual variability and necessity to measure (and sample) an adequate number of shoots</li> <li>• <u>Destructive</u> sampling</li> </ul>	Giraud (1977, 1979); Lopez y Royo et al. (2010b); Orfanidis et al. (2010); Annex 1
<u>Descriptor</u>	<u>Method</u>	<u>Expected response/factors</u>	<u>Destr</u>	<u>Target species</u>	<u>Advantages</u>	<u>Limits</u>	<u>References</u>
Necrosis on leaves (in %)	Percentage of leaves with necrosis, through observation in <u>laboratory-</u>	<ul style="list-style-type: none"> <li>• Increase</li> <li>• Increased contaminants concentration</li> </ul>	Yes	Po	<ul style="list-style-type: none"> <li>• Easy, rapid, and low-cost</li> </ul>	<ul style="list-style-type: none"> <li>• Necrosis is very rare in some sectors of the Mediterranean (e.g., Corsica littoral)</li> <li>• Destructive sampling</li> </ul>	Romero et al. (2007)
State of the apex	Percentage of leaves with broken apex	<ul style="list-style-type: none"> <li>• Increase</li> <li>• Overgrazing, mechanical impacts (e.g., anchoring)</li> </ul>	No	Po	<ul style="list-style-type: none"> <li>• Easy, rapid, and low-cost</li> <li>• Specific marks <del>of-left by</del> the bit of some animals are easily recognizable</li> </ul>	<ul style="list-style-type: none"> <li>• Not informative <del>onf</del> the grazing pressure in the case of strong <u>hydrodynamismwater movement</u> and on old leaves</li> </ul>	Boudouresque and Meinesz (1982)
Foliar production	For Po possibility, thanks to lepidochronology, to	<ul style="list-style-type: none"> <li>• Reduction</li> <li>• Nutrients deficit, increase in</li> </ul>	Yes <u>(Po)</u>	All	<ul style="list-style-type: none"> <li>• For Po lepidochronology allows assessments at all depths</li> </ul>	<ul style="list-style-type: none"> <li>• Long time <u>to analyse-to</u> <del>acquire</del></li> </ul>	Pergent (1990); Gaeckle et al.

(in mg dry weight · shoot <sup>-1</sup> · yr <sup>-1</sup> )	reconstruct number of leaves produced in one year, at present or in the past. For other species, measuring leaves through markings or by using the relationship bases length/leaves growth (Zm)	interspecific competition	No (Zm)		<ul style="list-style-type: none"> <li>• <del>Absolute</del> Classification scale available</li> <li>• For Zm the relationship bases length/leaves growth allows <i>in situ</i> non destructive measuring</li> </ul>	<ul style="list-style-type: none"> <li>• Monthly monitoring, or at least <del>for every</del> 4 seasons, is necessary</li> <li>• Destructive sampling for Po</li> </ul>	(2006); Pergent et al. (2008)
Rhizome production (in mg dry weight · shoot <sup>-1</sup> yr <sup>-1</sup> ) or elongation (in mm yr <sup>-1</sup> )	For Po possibility, thanks to lepidochronology, to reconstruct rate of growth or biomass per year	<ul style="list-style-type: none"> <li>• Increase</li> <li>• Accumulation of sediments due to coastal development</li> </ul>	Yes	Po	<ul style="list-style-type: none"> <li>• Independent from season</li> <li>• <del>Classification</del> <u>Absolute classification</u> scale available for Po</li> </ul>	<ul style="list-style-type: none"> <li>• <u>Increase in the Interpretation sometimes difficult as rhizome production increase</u> can <del>be</del> also <u>be</u> observed in reference sites in the absence of human impacts</li> <li>• Destructive sampling</li> </ul>	Pergent et al. (2008); Annex 1
<u>Descriptor</u>	<u>Method</u>	<u>Expected response/factors</u>	<u>Destr</u>	<u>Target species</u>	<u>Advantages</u>	<u>Limits</u>	<u>References</u>
<u>Burial or baring of the rhizomes (in mm)</u>	<u>Measuring the degree of burial or baring of rhizomes <i>in situ</i>, or the percentage of buried or bared shoots on a given surface area</u>	<ul style="list-style-type: none"> <li>• <u>Increase in burial for increased sedimentation (e.g., coastal development, dredging)</u></li> <li>• <u>Increase in baring for deficit in the sediment load</u></li> </ul>	<u>No</u>	<u>All</u>	<ul style="list-style-type: none"> <li>• <u>Easily measured <i>in situ</i></u></li> <li>• <u>Not destructive and low-cost</u></li> <li>• <u>Independent from the season</u></li> </ul>		<u>Boudoresque et al. (2006)</u>
<u>Burial or baring of the rhizomes</u>	<u>Measuring the degree of burial or baring of rhizomes <i>in situ</i>, or the</u>	<ul style="list-style-type: none"> <li>• <u>Increase in burial for increased sedimentation (e.g.,</u></li> </ul>	<u>No</u>	<u>All</u>	<ul style="list-style-type: none"> <li>• <u>Eas measure <i>in situ</i></u></li> <li>• <u>Not destructive and low-cost</u></li> </ul>		<u>Boudoresque et al. (2006)</u>

(in mm)	percentage of buried or bared shoots on a given surface area	<ul style="list-style-type: none"> <li>coastal development, dredging)</li> <li>Increase in baring for deficit in the sediment load</li> </ul>			<ul style="list-style-type: none"> <li>Independent from season</li> </ul>		
<i>Cellular or physiological/biochemical level</i>							
<u>Nitrogen and phosphorus content (in % dry weight) in plant tissues</u> <b>Descriptor</b>	<u>Dosage through mass spectrometry and plasma torch in different plant tissues (both leaves and rhizomes) after acid mineralisation (e.g., in rhizome for Po)</u> <b>Method</b>	<ul style="list-style-type: none"> <li>Increase</li> <li>Nutriments enhancement</li> </ul> <b>Expected response/factors</b>	<b>Yes</b> <b>estr.</b>	<b>All</b> <b>Target species</b>	<ul style="list-style-type: none"> <li>Short response time to environmental changes</li> <li>Absolute classification scale for Po</li> </ul> <b>Advantages</b>	<ul style="list-style-type: none"> <li>Very expensive</li> <li>Analytical equipment and specific competence necessary</li> <li>Destructive sampling</li> </ul> <b>Limits</b>	Romero et al. (2007); Annex 1 <b>References</b>
<u>Carbohydrate content (in % dry weight) in plant tissues and sediments</u>	<u>Dosage through spectrophotometry after alcohol extraction in different plant tissues (e.g., in rhizome for Po)</u>	<ul style="list-style-type: none"> <li>Reduction</li> <li>Human impacts</li> </ul>	<b>Yes</b>	<b>All</b>	<ul style="list-style-type: none"> <li>Short response time to environmental changes</li> <li>Absolute classification scale for Po</li> </ul>	<ul style="list-style-type: none"> <li>Very expensive</li> <li>Analytical equipment and specific competence necessary</li> <li>Destructive sampling</li> </ul>	Alcoverro et al. (1999, 2001); Romero et al. (2007); Annex 1
<i>Physiological (cell)</i>							
<u>Trace metal content (in <math>\mu\text{g} \cdot \text{g}^{-1}</math>)</u> <u>Nitrogen and phosphorus content in plant (in % dry weight)</u>	<u>Dosage through spectrometry in different plant tissues (both leaves and rhizomes) after acid mineralisation</u> <u>Dosage through mass spectrometry and plasma torch in different plant tissues after acid</u>	<ul style="list-style-type: none"> <li>Increase</li> <li>Increased concentration of metallic contaminants</li> <li>Nutriments enhancement</li> </ul>	<b>Yes</b> <b>Yes</b>	<b>All</b> <b>All</b>	<ul style="list-style-type: none"> <li>Short response time to environmental changes</li> <li>Absolute classification scale for Po</li> <li>Short response time to environmental changes</li> <li>Classification scale for Po</li> </ul>	<ul style="list-style-type: none"> <li>Very expensive</li> <li>Analytical equipment and specific competence necessary</li> <li>Destructive sampling</li> <li>Very expensive</li> <li>Analytical equipment and specific competence necessary</li> <li>Destructive sampling</li> </ul>	Salivas-Decaux (2009); Annex 1 Romero et al. (2007); Annex 1

<u>Descriptor</u>	<u>Method</u>	<u>Expected response/factors</u>	<u>Destr</u>	<u>Target species</u>	<u>Advantages</u>	<u>Limits</u>	<u>References</u>
<p><u>mineralisation (e.g., rhizomes for Po)</u></p> <p><u>Nitrogen isotopic relationship (<math>d^{15}N</math> in ‰)</u>  <u>Carbohydrate content (in % dry weight) in plant and sediments</u></p>	<p><u>Dosage through mass spectrometer in different plant tissues after acid mineralisation (e.g., in rhizomes for Po)</u>  <u>Dosage through spectrophotometry after alcohol extraction in different plant tissues (e.g., rhizomes for Po)</u></p>	<ul style="list-style-type: none"> <li>• <u>Increase for nutriment enhancement from farms and urban effluents</u></li> <li>• <u>Reduction for nutriment enhancement from fertilizers</u></li> <li>• <u>Human impacts</u></li> </ul>	Yes/Yes	Po/All	<ul style="list-style-type: none"> <li>• <u>Short response time to environmental changes</u></li> <li>• <u>Short response time to environmental changes</u></li> <li>• <u>Classification scale for Po</u></li> </ul>	<ul style="list-style-type: none"> <li>• <u>Very expensive</u></li> <li>• <u>Analytical equipment and specific competence necessary</u></li> <li>• <u>Destructive sampling</u></li> <li>• <u>Very expensive</u></li> <li>• <u>Analytical equipment and specific competence necessary</u></li> <li>• <u>Destructive sampling</u></li> </ul>	<p>Romero et al. (2007); Aleover et al. (1999, 2001); Romero et al. (2007); Annex 1</p>
<p><u>Trace metal content (in <math>\mu g \cdot g^{-1}</math>)</u></p>	<p><u>Dosage through spectrometry in different plant tissues after acid mineralisation</u></p>	<ul style="list-style-type: none"> <li>• <u>Increase</u></li> <li>• <u>Increased concentration of metallic contaminants</u></li> </ul>	Yes	All	<ul style="list-style-type: none"> <li>• <u>Short response time to environmental changes</u></li> <li>• <u>Classification scale for Po</u></li> </ul>	<ul style="list-style-type: none"> <li>• <u>Very expensive</u></li> <li>• <u>Analytical equipment and specific competence necessary</u></li> <li>• <u>Destructive sampling</u></li> </ul>	<p>Salivas-Decaux (2009); Annex 1</p>
<p><u>Sulphur isotopic relationship (<math>d^{34}S</math> in ‰)</u>  <u>Nitrogen isotopic relationship (<math>d^{15}N</math> in ‰)</u></p>	<p><u>Dosage through mass spectrometer in different plant tissues (e.g., rhizomes of Po)</u>  <u>Dosage through mass spectrometer in different plant tissues after acid mineralisation (e.g., rhizomes for Po)</u></p>	<ul style="list-style-type: none"> <li>• <u>Reduction</u></li> <li>• <u>Human impacts</u></li> <li>• <u>Increase for nutriment enhancement from farms and urban effluents</u></li> <li>• <u>Reduction for nutriment enhancement from fertilizers</u></li> </ul>	Yes/Yes	Po/Po	<ul style="list-style-type: none"> <li>• <u>Short response time to environmental changes</u></li> <li>• <u>Short response time to environmental changes</u></li> </ul>	<ul style="list-style-type: none"> <li>• <u>Very expensive</u></li> <li>• <u>Analytical equipment and specific competence necessary</u></li> <li>• <u>Destructive sampling</u></li> <li>• <u>Very expensive</u></li> <li>• <u>Analytical equipment and specific competence necessary</u></li> <li>• <u>Destructive sampling</u></li> </ul>	<p>Romero et al. (2007); Romero et al. (2007)</p>
<u>Community De</u>	<u>Method</u>	<u>Expected</u>	<u>Destr</u>	<u>Target</u>	<u>Advantages</u>	<u>Limits</u>	<u>References</u>

<p>Epiphytes biomass (in mg dry weight · shoots<sup>-1</sup> or % dry weight · shoots<sup>-1</sup>) and epiphytes cover (in %) on the leaves Sulphur isotopic relationship (δ<sup>34</sup>S in ‰)</p>	<p>Measure of biomass (µg · shoots<sup>-1</sup>) after scraping, drying and weighing; estimate the epiphytes cover on leaves under a binocular; indirect estimation of biomass from epiphytes cover Dosage through mass spectrometer in different plant tissues (e.g., rhizomes of Po)</p>	<ul style="list-style-type: none"> <li>• Increase</li> <li>• Nutriments enhancement from rivers, high touristic frequentation</li> <li>• Human impacts</li> </ul>	<p>Yes</p>	<p>All Po</p>	<ul style="list-style-type: none"> <li>• Easily to-measured</li> <li>• Low-cost (biomass and cover)</li> <li>• Absolute classification scale available for Po</li> <li>• Early-warning indicator</li> <li>• Short response time to environmental changes</li> </ul>	<ul style="list-style-type: none"> <li>• Time-consuming</li> <li>• Strong seasonal and spatial variability</li> <li>• Specific analytical equipment (nitrogen content) necessary</li> <li>• Destructive sampling</li> <li>• Very expensive</li> <li>• Analytical equipment and specific competence necessary</li> </ul>	<p>Morri (1991); Pergent-Martini et al. (2005); Romero et al. (2007); Fernandez-Torquemada et al. (2008); Giovannetti et al. (2008, 2015) Romero et al. (2007)</p>
<p><i>Community</i></p>							
<p>Epiphytes biomass (in mg dry weight · shoots<sup>-1</sup> or % dry weight · shoots<sup>-1</sup>) and epiphytes cover (in %) of leaves</p>	<p>Measure of biomass (µg · shoots<sup>-1</sup>) after scraping, drying and weighing Measure of nitrogen content (in % dry weight). Measure using simple CHN analyser Estimate the epiphytes cover on leaves under a binocular Indirect estimation of biomass from epiphytes cover</p>	<ul style="list-style-type: none"> <li>• Increase</li> <li>• Nutriments enhancement from rivers, high touristic frequentation</li> </ul>	<p>Yes</p>	<p>All</p>	<ul style="list-style-type: none"> <li>• Easy measure</li> <li>• Low cost (biomass and cover)</li> <li>• Classification scale available for Po</li> <li>• Early warning indicator</li> </ul>	<ul style="list-style-type: none"> <li>• Time consuming</li> <li>• Strong seasonal and spatial variability</li> <li>• Specific analytical equipment (nitrogen content) necessary</li> <li>• Destructive sampling</li> </ul>	<p>Morri (1991); Pergent-Martini et al. (2005); Romero et al. (2007); Fernandez-Torquemada et al. (2008); Giovannetti et al. (2008, 2015)</p>

~~61-68.~~ The setting-up phase is the concrete operational phase of the monitoring program that starts with ~~the~~ data acquisition. The observations and samplings during the acquisition phase or data validation of the cartographical ~~surveys, could surveys may~~ also constitute an output of ~~a the~~ monitoring system (Kenny et al., 2003), and cartography could also represent a monitoring tool (Tab. 4; Boudouresque et al., 2006).

~~62-69.~~ At the regional spatial scale, two main monitoring systems have been developed: 1) the seagrass monitoring system (SeagrassNet), which ~~was has been~~ established at ~~the a~~ worldwide scale at the beginning of the year 2000 and covers all the seagrass species (Short et al., 2002); and 2) the “Posidonia” monitoring network started at the beginning of the 1980s in the Mediterranean (Boudouresque et al., 2006), which is specific to *Posidonia oceanica* but can be adapted to other Mediterranean species and ~~to for~~ the genus *Posidonia* worldwide. The “Posidonia” monitoring network is still used today, with a certain degree of variability from one country to another and even more from a region to another, in at least nine Mediterranean countries and ~~in~~ over 350 sites (Buia et al., 2004; Boudouresque et al., 2006; Romero et al., 2007; Fernandez-Torquemada et al., 2008; Lopez y Royo et al., 2010a). After the work carried out within the framework of the Interreg IIIB MEDOCC programme “Coherence, development, harmonization and validation of evaluation methods of the quality of the littoral environment by monitoring the *Posidonia oceanica* meadows”, and the “MedPosidonia” programme set up by RAC/SPA, an updated and standardized approach for the *P. oceanica* monitoring network has been tested and validated (UNEP/MAP-RAC/SPA, 2009). The main differences between the ~~former~~ two monitoring systems are:

- Within the framework of SeagrassNet, monitoring is done along three permanent transects, laid parallel to the coastline and positioned respectively (i) in the most superficial part of the meadow, (ii) in the deepest part, and (iii) at an intermediate depth between these two positions. The descriptors chosen (Short et al., 2002; Tab. 5) are measured at fixed points along each transect and every three months.
- Within the framework of the “Posidonia” monitoring network, measurements are taken (i) in correspondence of fixed markers placed along the lower limit of the meadow, (ii) at the upper limit, and (iii) at the intermediate and fixed depth of 15 m. The descriptors (Tab. 5) are measured every three years only if, after visual surveys, no visible changes in the geographical position of the limits are observed.

~~63-70.~~ SeagrassNet allows ~~to comparing~~ the data obtained in the Mediterranean with the data obtained in other regions of the world, having ~~a world-wide~~ coverage ~~on f~~ over 80 sites distributed in 26 countries ([available at www.seagrassnet.org](http://www.seagrassnet.org)). However, this monitoring system is not suitable for large-size species (such as *Posidonia* genus) and for meadows where ~~the~~ lower limit is located beyond 25 m depth. This monitoring system has been set up only for one site in the Mediterranean (Pergent et al., 2007). The “Posidonia” monitoring network, in view of the multiplicity of descriptors identified (Tab. 5), allows ~~comparing~~ different meadows in the Mediterranean, ~~and also and~~ evaluating the plant’s vitality and the quality of the environment ~~in which where~~ it grows. Other monitoring ~~system, such as permanent transects~~ with seasonal monitoring, or acoustic surveys, can be used in ~~particular specific~~ situations like the monitoring of lagoons ~~environments~~ (Pasqualini et al., 2006) or for the study of relict meadows (Descamp et al., 2009).

~~71.~~ The sampling technique and the chosen descriptors define the nature of the monitoring (e.g., monitoring of chemical contamination ~~of in~~ the environment, discharge into the sea from a treatment plant, effects of beach nourishments, general evaluation of the meadow state of health) (Tab. 4). There are no ideal methods for mapping or universal descriptors for ~~the monitoring of~~ seagrass meadows, but rather a great diversity of efficient and complementary tools. They must be chosen depending on the objectives, the species present and the local context. Independently from the descriptors selected, particular attention must be paid to the validity of the measurements made (acquisition protocol, precision of the measurements, reproducibility; Lopez y Royo et al., 2010a). The following data processing and interpretation phase is thus fundamental to ensure the good quality of the monitoring programme.

Table 5: Descriptors measured within the framework of the SeagrassNet, the “Posidonia” monitoring Network, and the MedPosidonia monitoring programs (Pergent et al., 2007).

<u>Descriptors</u>	<u>SeagrassNet</u>	<u>“Posidonia” monitoring Network</u>	<u>MedPosidonia</u>
<u>Light</u>	×		
<u>Temperature</u>	×		×
<u>Salinity</u>	×		
<u>Lower limit</u>	<u>Depth</u>	<u>Depth, type, and cartography</u>	<u>Depth, type, and cartography</u>
<u>Upper limit</u>	<u>Depth</u>	<u>Depth, type, and cartography</u>	<u>Cartography</u>
<u>Density</u>	<u>12 measurements along each transect</u>	<u>Measurement at each of the 11 markers</u>	<u>Measurement at each of the 11 markers</u>
<u>% plagiotropic rhizomes</u>		<u>Measurement at each of the 11 markers</u>	<u>Measurement at each of 11 markers</u>
<u>Baring of rhizomes</u>		<u>Measurement at each of the 11 markers</u>	<u>Measurement at each of the 11 markers</u>
<u>Cover</u>	<u>12 measures along transect</u>	<u>At each marker using video (50 m)</u>	<u>Measurement at each of the 11 markers</u>
<u>Phenological analysis</u>	<u>12 measures along transect</u>	<u>20 shoots</u>	<u>20 shoots</u>
<u>Lepidochronological analysis</u>		<u>10 shoots</u>	<u>10 shoots</u>
<u>State of the apex</u>		<u>20 shoots</u>	<u>20 shoots</u>
<u>Biomass (g DW)</u>	<u>Leaves</u>		
<u>Necromass</u>	<u>Rhizome and scales</u>		
<u>Granulometry of sediments</u>		<u>1 measurement</u>	<u>1 measurement</u>
<u>% organic material in sediment</u>		<u>1 measurement</u>	<u>1 measurement</u>
<u>Trace-metal content</u>			<u>Ag and Hg</u>

72. As a final remark, the IMAP should also consider the long-term organic carbon stored in seagrass sediments from both *in situ* production by photosynthetic activity and sedimentation of particulate carbon from the water column, known as “Blue Carbon” (Nellemann et al., 2009). The estimation of the Blue Carbon should consider above and below ground living and dead biomass and soil fine and coarse carbon. Recent findings, however, suggested clearly that most of the carbon stored in seagrass is in the soil, being the fractions stored as living tissue virtually negligible. Hence, soil stocks rather than biomass stocks should be the focus of assessment in Mediterranean seagrass. International guidelines had been provided for this estimation from the Blue Carbon Initiative (Howard et al., 2014). Following this, soil carbon is determined by soil depth, bulk density and % of organic carbon in the first meter of the soil. Advanced techniques for large scale Blue Carbon inventories using high resolution sub-bottom profilers have been recently developed in the Mediterranean (Monnier et al., 2020). In the case additional carbon sequestration would like to be estimated, the methodology proposed by lepidochronology (i.e., the ‘retro-dation’ of *Posidonia* rhizomes) will provide estimations on the plant growth and accretion rates over a short timescale (although it is often very variable). The sequestration rate calculated using the accretion rate should be determined using C<sup>14</sup> to date the age at which soil was laid down. The following parameters are useful for the estimation of carbon contents in plant tissues:

64. Estimating the production of carbon obtained by photosynthetic activity from *P. oceanica* meadows (above and below ground production) at the Mediterranean basin scale

requires the following parameters (essential for the calculation of the Blue Carbon) from the lepidochronological analyses:

- Leaf Biomass Index (Leaf Standing Crop) (dry weight · m<sup>-2</sup>): it is calculated by multiplying the average leaf biomass per shoot by the density of the meadow reported per square meter.
- Leaf Surface Index (Leaf Area Index) (m<sup>2</sup> · m<sup>-2</sup>): it is calculated by multiplying the average leaf area per shoot by the density of the meadow reported per square meter.
- Height of the leaf canopy to be estimated by means of acoustic, optical, and *in situ* measurements.

65.73. The methodological approaches for estimating Blue Carbon consider both the use of satellite images, acoustic surveys (multibeam, single beam, and sub-bottom profiler), optical acquisitions, and measurements in situ and in the laboratory. Monitoring activities should also be planned on key typical species associated to seagrass meadows, such as for instance the bivalves *Pinna* spp. Given the critical situation of *P. nobilis* in the Mediterranean and the apparent incipient expansion of *P. rudis* within *P. oceanica* meadows, visual censuses of these species in monitored meadows should be seriously considered.

Table 5: Descriptors measured within the framework of the SeagrassNet, the “Posidonia” monitoring Network and the MedPosidonia monitoring programs (Pergent et al., 2007).

Descriptors	SeagrassNet	“Posidonia” monitoring Network	MedPosidonia
Light			
Temperature			
Salinity			
Lower limit	Depth	Depth, type and cartography	Depth, type and cartography
Upper limit	Depth	Depth, type and cartography	Cartography
Density	12 measurements along each transect	Measurement at each of the 11 markers	Measurement at each of the 11 markers
% Plagiotropic rhizomes		Measurement at each of the 11 markers	Measurement at each of 11 markers
Baring of rhizomes		Measurement at each of the 11 markers	Measurement at each of the 11 markers
Cover	12 measures along transect	At each marker using video (50 m)	Measurement at each of the 11 markers
Phenological analysis	12 measures along transect	20 shoots	20 shoots
Lepidochronological analysis		10 shoots	10 shoots
State of the apex		20 shoots	20 shoots
Biomass (g DW)	Leaves		
Necromass	Rhizome and scales		
Granulometry of sediments		1 measurement	1 measurement
% organic material in sediment		1 measurement	1 measurement
Trace metal content			Ag and Hg

### *Data processing and interpretation*

~~66-74.~~ 66-74. Measurements made *in situ* must be ~~analyzed~~analysed and archived. Samples collected during field activities must be properly stored for following laboratory analyses. Data interpretation needs expert judgment and evaluation and can be made by comparing the measured data with the data available in the literature, either directly or through classification scales. Checking that the results obtained respond to the monitoring objectives (reliability and reproducibility of the results, valid interpretations and coherence with the observations made) is another important step to validate monitoring effectiveness.

~~67-75.~~ 67-75. The huge increase of studies on *Posidonia oceanica* (over ~~2400-2700~~ publications indexed in the Web of Science on April 2021) means that in the last few decades a growing number of interpretation scales have been set up for the most widely used descriptors for monitoring this species (e.g., Giraud, 1977; Meinesz and Laurent, 1978; Pergent et al., 1995b; Pergent-Martini et al., 2005; Montefalcone et al., 2006, 2007; Montefalcone, 2009; Salivas-Decaux et al., 2010; Tab. 4).

~~68-76.~~ 68-76. As for cartography, an integration of the monitoring data into a geo-referenced information system (GIS), which can be freely consulted (like MedGIS implemented by RAC/SPA and the “Seagrass Atlas of Spain” available at <http://www.ieo.es/es/atlas-praderas-marinas>), is to be recommended and should be encouraged, so that the data acquired becomes available to the wider public and can be of benefit to the maximum number of users.

### Ecological indices

~~69-77.~~ 69-77. Ecological synthetic indices are today widespread for measuring the ecological status of ecosystems ~~in view given of~~ the Good Environmental Status (GES) achievement or maintenance. Ecological indices succeed in “capturing the complexities of the ecosystem yet remaining simple enough to be easily and routinely monitored” and may therefore be considered “user-friendly” (Montefalcone, 2009 and references therein). They are anticipatory, integrative, and sensitive to stress and disturbance. Many ecological indices had been employed in ~~the~~ seagrass monitoring programs ~~mes~~ in the past, e.g., the Leaf Area Index (Buia et al., 2004), the Epiphytic Index (Morri, 1991). Following the requirements of the WFD, the MSFD, and the EcAp in the European countries, many synthetic indices have been set up to provide, ~~on the basis of~~based on a panel of different descriptors, a global evaluation of the environmental quality based on the “seagrass” biological quality element. The most adopted indices in the regional/national monitoring programs are the following (Tab. 6):

- POSWARE (Buia et al., 2005)
- POMI (Romero et al., 2007)
- POSID (Pergent et al., 2008)
- Valencian CS (Fernandez-Torquemada et al., 2008)
- PREI (Gobert et al., 2009)
- BiPo (Lopez y Royo et al., 2009)
- Conservation Index (CI) (Moreno et al., 2001)
- Substitution Index (SI) (Montefalcone et al., 2007)
- Phase Shift Index (PSI) (Montefalcone et al., 2007)
- Patchiness Index (PI) (Montefalcone et al., 2010)
- EBQI (Personnic et al., 2014)

~~70-78.~~ 70-78. Most of the ecological indices integrate different ecological levels (Tab. 6). The POSWARE index is based on 6 descriptors working at the population and individual-species levels. The multivariate POMI index is based on a total of 14 structural and functional descriptors of *Posidonia oceanica*, from cellular to community level. The POSID index is based on 8 descriptors working at the community, population, individual-species and cellular levels. Some of the descriptors working at the cellular level and used for computing the POMI and the POSID index are very time-consuming (such as the chemical and biochemical composition and the contaminants in plant tissues), thus showing little usage in the *P. oceanica* monitoring programs (Pergent-Martini et al., 2005). The Valencian CS index integrates 9 descriptors from individual-species to community level. The PREI index is based on 5 descriptors working at the population, individual-species and community levels. The BiPo index is based only on 4 non-destructive descriptors at the population and individual-species levels and is particularly well suited for the monitoring of protected species or within MPAs.

~~71-79.~~ 71-79. Some not-destructive ecological indices have been developed to work at the seascape ecological level, such as the Conservation Index (CI; Moreno et al., 2001), the Substitution Index and the Phase Shift Index (SI and PSI, respectively; Montefalcone et al., 2007), and the Patchiness Index (PI; Montefalcone et al., 2010). The CI measures the proportional abundance of dead matte relative to living *P. oceanica* and can be used as a perturbation index (Boudouresque et al., 2006), although dead matte areas may also originate from natural causes (e.g., hydrodynamismwater movement). The SI has been proposed for measuring the amount of replacement of *P. oceanica* by the other common native Mediterranean seagrass *Cymodocea nodosa* and by the three species of green algae genus *Caulerpa*: the native *Caulerpa prolifera* and the two alien invaders *C. taxifolia* and *C. cylindracea*. The SI, applied repeatedly in the same meadow, can objectively measure whether the substitution is permanent or progressive or, as hypothesized by Molinier and Picard (1952), will in the long term facilitate the reinstallation of *P. oceanica*. While the application of the CI is obviously limited to those seagrass species that form a matte, the SI can be applied to all cases of substitution between two different seagrass species and between an alga and a seagrass. The PSI is another synthetic ecological index that identifies and measures the intensity of the phase shift occurring within the seagrass ecosystem; it provides a synthetic evaluation of the irreversibility of changes undergone by a regressed meadow. The biological characteristics and the reproductive processes of *P. oceanica* are not conducive to a rapid re-colonisation of dead matte (Meinesz et al., 1991). If a potentiality of recovery still exists in a meadow showing few and small dead matte areas, a large-scale regression of *P. oceanica* meadow must therefore be considered almost irreversible on human-life time scales. The PI has been developed to evaluate the level-degree of fragmentation of the habitat and uses the number of patches for measuring the fragmentation of seagrass meadows. All these seascape indices are useful tools for assessing the quality of coastal environments in their whole (as requested by the MSFD), not only for assessing the quality of the water bodies (as requested by the WFD).

~~72-80.~~ 72-80. One of the most recently proposed index/indices works at the ecosystem level (EBQI; Personnic et al., 2014). This index has been developed ~~on the basis of~~ based on a simplified conceptual model of the *P. oceanica* ecosystem, where a set of 17 representative functional compartments have been identified. The quality of each functional compartment is then evaluated ~~through the selection by selecting~~ of one or two specific descriptors (most of them not destructive) and the final index value integrates all compartment scores. Being an ecosystem-based index, it complies with the MSFD and the EcAp requirements. However, its complete ~~and thus~~ but also complex formulation makes this index more time-consuming when compared to other indices.

~~73-81.~~ 73-81. Intercalibration trials between the POMI and the POSID indices have shown that there is coherence in the classification of the sites studied (Pergent et al., 2008). Applying the BIPO index to 9 ~~Catalonia Mediterranean~~ sites yielded an identical classification ~~of the Catalonia sites as the classification to that~~ obtained with the POMI index (Lopez y Royo et al., 2010c). Concurrent application of the POMI, PREI, BiPo, and Valencian CS in the Eastern Mediterranean Sea showed high comparability among indices (Gerakaris et al., 2017). -Finally, using both the POSID and the BiPo indices within the framework of the “MedPosidonia” programme, ~~a~~ similar classifications of

the meadows studied ~~were~~ found (Pergent et al., 2008). A recent exercise to compare ~~a number of several~~ descriptors and ecological indices ~~working~~ at different ecological levels (~~individual species~~, population, community, and seascape) in 13 *P. oceanica* meadows of the Ligurian Sea (NW Mediterranean) showed a low consistency among the four levels, and especially between the plant (e.g., leaves surface) and the meadows (e.g., shoot density, lower limit depth) descriptors. Also, the PREI index showed inconsistency with most of the ~~compared~~ descriptors (Karayali, 2017; ~~Oprandi et al., 2019~~). In view of this result, ~~the a combined-concurrent~~ use of more descriptors and indices, covering different levels of ecological complexity, should be preferred in any monitoring programme.

74.82. At the present state of knowledge, it is difficult to prefer one or another of these synthetic indices, as it has not yet been possible to compare all of them ~~over several sites and to start wide intercalibration processes~~. As a general comment, those indices based on a high number of descriptors imply excessive costs in terms of acquisition time and ~~the~~ budget required (Fernandez-Torquemada et al., 2008), ~~although the use of a comparatively lower number of descriptors can lead to an oversimplification, particularly in those situations where specific pressures should be linked to the meadow state of health~~.

Table 6: Descriptors used in the mostly adopted synthetic ecological indices ~~mostly adopted~~ in the regional/national monitoring programs to evaluate the environmental quality based on the “seagrass” biological quality element. The ecological complexity level at which each descriptor works is also indicated (i.e., ~~physiological/cellular, individual/species~~, population, community, ecosystem, seascape).

Index	<del>Physiological</del> Cellular	<del>Individual</del> Species	Population	Community	Ecosystem	Seascape
POSWARE		Width of the intermediate leaves; leaves production; rhizomes production and elongation	Shoot density; meadow cover			
POMI	P, N and sucrose content in rhizomes; $\delta^{15}\text{N}$ and $\delta^{34}\text{S}$ isotopic ratio in rhizomes; Cu, Pb, and Zn content in rhizomes	Leaf <del>f</del> ves surface; percentage foliar necrosis	Shoot density; meadow cover; percentage of plagiotropic rhizomes	N content in epiphytes		
POSID	Ag, Cd, Pb, and Hg content in leaves	Leaf <del>f</del> ves surface; Coefficient A; rhizomes elongation	Shoot density; meadow cover; percentage of plagiotropic rhizomes; depth of the lower limit	<del>Epiphytes</del> Epiphytes biomass		
Valencian CS		Leaf <del>f</del> ves surface; percentage of foliar necrosis	Shoot density; meadow and dead matte cover; percentage of plagiotropic rhizomes; rhizome baring/burial	Herbivore pressure; leaf epiphyte's biomass		
PREI		Leaf <del>f</del> ves surface; leaf <del>f</del> ves biomass	Shoot density; lower limit depth and type	Leaf epiphytees biomass		
BiPo		Leaf <del>f</del> ves surface	Shoot density; lower limit depth and type			
CI			Meadow and dead matte cover			Relative proportion between <i>Posidonia oceanica</i> and dead matte
SI			Meadow cover	Substitutes cover		Relative proportion between <i>P. oceanica</i> and substitutes

<u>Index</u>	<u>Cellular</u>	<u>Species</u>	<u>Population</u>	<u>Community</u>	<u>Ecosystem</u>	<u>Seascape</u>
PSI			Meadow and dead matte cover	Substitutes cover		Relative proportion of <i>P. oceanica</i> , dead matte and substitutes
PI						Number of seagrass patches
EBQI		Growth rate of vertical rhizomes	Shoot density; meadow cover		Biomass, density, and species diversity in all the compartments; grazing index	

## References

- Alcocer A., Oliveira P., Pascoal A. 2006. Underwater acoustic positioning systems based on buoys with GPS. In: Proceedings of the Eighth European Conference on Underwater Acoustics 8, 1-8.
- Alcoverro T., Manzanera M., Romero J. 2001. Annual metabolic carbon balance of the seagrass *Posidonia oceanica*: the importance of carbohydrate reserves. Marine Ecology Progress Series 211, 105-116.
- Alcoverro T., Zimmerman R.C., Kohrs D.G., Alberte R.S. 1999. Resource allocation and sucrose mobilization in light-limited eelgrass *Zostera marina*. Marine Ecology Progress Series 187, 121-131.
- Amran M.A. 2017. Mapping seagrass condition using Google Earth imagery. Journal of Engineering Science & Technology Review 10 (1), 18-23.
- Bacci T., Rende S.F., Rocca D., Scalise S., Cappa P., Scardi M. 2015. Optimizing *Posidonia oceanica* (L.) Delile shoot density: Lessons learned from a shallow meadow. Ecological Indicators 58, 199-206.
- Barsanti M., Delbono I., Ferretti O., Peirano A., Bianchi C.N., Morri C. 2007. Measuring change of Mediterranean coastal biodiversity: diachronic mapping of the meadow of the seagrass *Cymodocea nodosa* (Ucria) Ascherson in the Gulf of Tigullio (Ligurian Sea, NW Mediterranean). Hydrobiologia 580, 35-41.
- Bellan-Santini D., Bellan G., Bitar G., Harmelin J.G., Pergent G. 2002. Handbook for interpreting types of marine habitat for the selection of sites to be included in the national inventories of natural sites of conservation interest. RAC/SPA (Ed.), UNEP publ., 217 pp.
- Bianchi C.N., Ardizzone G.D., Belluscio A., Colantoni P., Diviacco G., Morri C., Tunesi L. 2004. Benthic cartography. Biologia Marina Mediterranea 10 (Suppl.), 347-370.
- Boudouresque C.F., Meinesz A. 1982. Découverte de l'herbier de Posidonie. Cahier du Parc National de Port-Cros 4, 1-79.
- Boudouresque C.F., Bernard G., Bonhomme P., Charbonnel E., Diviacco G., Meinesz A., Pergent G., Pergent-Martini C., Ruitton S., Tunesi L. 2006. Préservation et conservation des herbiers à *Posidonia oceanica*. RAMOGE publ., Monaco, 202 pp.
- Boudouresque C.F., Bernard G., Pergent G., Shili A., Verlaque M. 2009. Regression of Mediterranean seagrasses caused by natural processes and anthropogenic disturbances and stress: a critical review. Botanica Marina 52, 395-418.
- Boudouresque C.F., Charbonnel E., Meinesz A., Pergent G., Pergent-Martini C., Cadiou G., Bertrand M.C., Foret P., Ragazzi M., Rico-Raimondino V. 2000. A monitoring network based on the seagrass *Posidonia oceanica* in the northwesternorth-western Mediterranean Sea. Biologia Marina Mediterranea 7 (2), 328-331.
- Buia M.C., Gambi M.C., Dappiano M. 2004. Seagrass systems. Biologia Marina Mediterranea 10 (Suppl.), 133-183.
- Buia M.C., Silvestre F., Iacono G., Tiberti L. 2005. Identificazione delle biocenosi di maggior preggiopregio ambientale al fine della classificazione della qualità delle acque costiere. Metodologie per il rilevamento e la classificazione dello stato di qualitaqualità ecologico e chimico delle acque, con particolare riferimento all'aplicazioneapplicazione del decreto legislativo 152/99. APAT, Rome, 269-303.
- Burgos E., Montefalcone M., Ferrari M., Paoli C., Vassallo P., Morri C., Bianchi C.N. 2017. Ecosystem functions and economic wealth: trajectories of change in seagrass meadows. Journal of Cleaner Production 168, 1108-1119.
- Charbonnel E., Boudouresque C.F., Meinesz A., Bernard G., Bonhomme P., Patrone J., Kruczek R., Cottalorda J.M., Bertrand C., Foret P., Ragazzi M., Direac'h L. 2000. Le réseau de surveillance

Posidonies de la Région Provence Alpes-Côte d'Azur. Première partie: présentation et guide méthodologique. GIS Posidonie publ., 76 pp.

- Ciraolo G., Cox E., La Loggia G., Maltese A. 2006. The classification of submerged vegetation using hyperspectral MIVIS data. *Annals of Geophysics* 49 (1), 287-294.
- Clabaut P., Augris C., Morvan L., Pasqualini V., Pergent G., Pergent-Martini C. 2006. Les fonds marins de Corse. Cartographie bio-morpho-sédimentaire par sonar à balayage latéral - Atlas de sonogrammes. Rapport Ifremer & Univ. Corse, N°GM 06-01, 78 pp.
- Costanza R., d'Arge R., de Groot R., Farber S., Grasso M., Hannon B., Limburg K., Naem S., O'Neill R.V., Paruelo J., Raskin R.G., Sutton P., van der Belt M. 1997. The value of the World's ecosystem services and natural capital. *Nature* 387, 253-260.
- Dattola L., Rende S.F., Dominici R., Lanera P., Di Mento R., Scalise S., ... Aramini, G. 2018. Comparison of Sentinel-2 and Landsat-8 OLI satellite images vs. high spatial resolution images (MIVIS and WorldView-2) for mapping *Posidonia oceanica* meadows. In: Remote Sensing of the Ocean, Sea Ice, Coastal Waters, and Large Water Regions. International Society for Optics and Photonics 10784, 1078419.
- de los Santos C.B., Krause-Jensen D., Alcoverro T., Marbà N., Duarte C.M., Van Katwijk M.M., ... Santos R. 2019. Recent trend reversal for declining European seagrass meadows. *Nature Communications* 10 (1), 1-8.
- Dekker A., Brando V., Anstee J. 2006. Remote sensing of seagrass ecosystems: use of spaceborne and airborne sensors. In: *Seagrasses: biology, ecology and conservation*, Larkum A.W.D., Orth R.J., Duarte C.M. (Eds), Springer publ., Dordrecht, 347-35.
- Denis J., Hervé G., Deneux F., Sauzade D., Bonhomme P., Bernard G., Boudouresque C.F., Leriche A., Charbonnel E., Le Direac'h L. 2003. Guide méthodologique pour la cartographie des biocénoses marines. Volet N°1: l'herbier à *Posidonia oceanica*. Guide méthodologique. Agence de l'Eau, Région Provence Alpes-Côte d'Azur et DIREN PACA. IFREMER, GIS Posidonie & Centre d'Océanologie de Marseille, GIS Posidonie publ., 93 pp.
- Descamp P., Holon F., Ballesta L. 2009. Microcartographie Micro cartographié par télémétrie acoustique de 9 herbiers de posidonie pour le suivi de la qualité des masses d'eau côtières méditerranéennes françaises dans le cadre de la DCE. Contrat L'OEil Andromède/Agence de l'Eau, CRLR, CRPACA. Andromède publ., Montpellier, 59 pp. + Annexes.
- Descamp P., Pergent G., Ballesta L., Foulquié M. 2005. Underwater acoustic positionning positioning systems as tool for *Posidonia oceanica* beds survey. *C.R. Biologies* 328, 75-80.
- Diaz R.J., Solan M., Valente R.M. 2004. A review of approaches for classifying benthic habitats and evaluating habitat quality. *Journal of Environmental Management* 73, 165-181.
- Duarte C.M., Kirkman H. 2001. Methods for the measurement of seagrass abundance and depth distribution. In: *Global Seagrass Research Methods*, Short F.T., Coles R.G. (Edits), Elsevier publ., Amsterdam, 141-153.
- EEC. 1992. Council Directive 92/43/EEC on the conservation of natural habitats and of wild fauna and flora. Official Journal of the European Communities. No L 206 of 22 July 1992.
- Evans D., Aish A., Boon A., Condé S., Connor D., Gelabert E., Michez N., Parry M., Richard D., Salvati E., Tunesi L. 2016. Revising the marine section of the EUNIS habitat classification. Report of a workshop held at the European Topic Centre on Biological Diversity, 12-13 May 2016. ETC/BD report to the EEA.
- Fernandez-Torquemada Y., Diaz-Valdes M., Colilla F., Luna B., Sanchez-Lizaso J.L., Ramos-Espla A.A. 2008. Descriptors from *Posidonia oceanica* (L.) Delile meadows in coastal waters of Valencia, Spain, in the context of the EU Water Framework Directive. *ICES Journal of Marine Science* 65 (8), 1492-1497.

- Foden J., Brazier D.P. 2007. Angiosperms (seagrass) within the EU water framework directive: A UK perspective. *Marine Pollution Bulletin* 55 (1-6), 181-195.
- Fornes A., Basterretxea G., Orfila A., Jordi A., Alvarez A., Tintoré J. 2006. Mapping *Posidonia oceanica* from IKONOS. *ISPRS Journal of Photogrammetry and Remote Sensing* 60 (5), 315-322.
- Frederiksen M., Krause-Jensen D., Holmer M., Laursen J.S. 2004. ~~Longterm~~Long-term changes in area distribution of eelgrass (*Zostera marina*) in Danish coastal waters. *Aquatic Botany* 78, 167-181.
- Gaeckle J.L., Short F.T., Ibarra-Obando S.E., Meling-Lopez A.E. 2006. Sheath length as a monitoring tool for calculating leaf growth in eelgrass (*Zostera marina* L.). *Aquatic Botany* 84 (3), 226-232.
- Gagnon P., Scheibling R.E., Jones W., Tully D. 2008. The role of digital bathymetry in mapping shallow marine vegetation from hyperspectral image data. *International Journal of Remote Sensing* 29 (3), 879-904.
- [Gerakaris V., Panayotidis P., Vizzini S., Nicolaidou A., Economou-Amilli A. 2017. Effectiveness of \*Posidonia oceanica\* biotic indices for assessing the ecological status of coastal waters in Saronikos Gulf \(Aegean Sea, Eastern Mediterranean\). \*Mediterranean Marine Science\* 18 \(1\), 161-178.](#)
- [Gerakaris V., Papathanasiou V., Salomidi M., Issaris Y., Panayotidis P. 2021. Spatial patterns of \*Posidonia oceanica\* structural and functional features in the Eastern Mediterranean \(Aegean and E-E Ionian Seas\) in relation to large-scale environmental factors. \*Marine Environmental Research\*. 165.](#)
- Giakoumi S., Sini M., Gerovasileiou V., Mazor T., Beher J., Possingham H.P., ... Karamanlidis A.A. 2013. Ecoregion-based conservation planning in the Mediterranean: dealing with large-scale heterogeneity. *PloS One* 8(10), e76449.
- Giovannetti E., Montefalcone M., Morri C., Bianchi C.N., Albertelli G. 2008. Biomassa fogliare ed epifita in una prateria di *Posidonia oceanica* (Prelo, Mar Ligure): possibilità di determinazione tramite un metodo indiretto. *Proceedings of the Italian Association of Oceanology and Limnology* 19, 229-233.
- Giovannetti E., Montefalcone M., Morri C., Bianchi C.N., Albertelli G. 2010. Early warning response of *Posidonia oceanica* epiphyte community to environmental alterations (Ligurian Sea, NW Mediterranean). *Marine Pollution Bulletin* 60, 1031-1039.
- Giraud G. 1977. Essai de classement des herbiers de *Posidonia oceanica* (Linné) Delile. *Botanica Marina* 20 (8), 487-491.
- Giraud G. 1979. Sur une méthode de mesure et de comptage des structures foliaires de *Posidonia oceanica* (Linnaeus) Delile. *Bulletin de Musée Histoire naturelle Marseille* 39, 33-39.
- 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* Rapid Easy Index: PREI. *Marine Pollution Bulletin* 58 (11), 1727-1733.
- Godet L., Fournier J., Toupoint N., Olivier F. 2009. Mapping and monitoring intertidal benthic habitats: a review of techniques and a proposal for a new visual methodology for the European coasts. *Progress in Physical Geography* 33 (3), 378-402.
- Green E., Short F. 2003. *World Atlas of Seagrass*. University of California Press, Los Angeles, 298 pp.
- Greene A., Rahman A.F., Kline R., Rahman M.S. 2018. Side scan sonar: a cost-efficient alternative method for measuring seagrass cover in shallow environments. *Estuarine, Coastal and Shelf Science* 207, 250-258.
- [Guenther G.C. 1985. Airborne laser hydrography: system design and performance factors. NOAA Professional Paper Series, National Ocean Service 1, Rockville, MD, 397 pp.](#)

- [Guenther G.C., Cunningham A.G., LaRocque P.E., Reid D.J. 2000. Meeting the accuracy challenge in airborne LiDAR bathymetry. Proceedings of the 20th EARSeL Symposium: Workshop on Lidar Remote Sensing of Land and Sea, June 16-17, Dresden, Germany, 29 pp.](#)
- Hossain M.S., Bujang J.S., Zakaria M.H., Hashim M. 2015. The application of remote sensing to seagrass ecosystems: an overview and future research prospects. *International Journal of Remote Sensing* 36, 61-114.
- [Howard J., Hoyt S., Isensee K., Pidgeon E., Telszewski M. 2014. Coastal Blue Carbon: Methods for assessing carbon stocks and emissions factors in mangroves, tidal salt marshes, and seagrass meadows. Conservation International, Intergovernmental Oceanographic Commission of UNESCO, International Union for Conservation of Nature \(IUCN\). Arlington, Virginia, USA, 184 pp.](#)
- [Irish J.L., McClung J.K., Lillycrop W.J. 2000. Airborne Lidar bathymetry: the SHOALS system. Bulletin of the International Navigation Association 103, 43-53.](#)
- [James D., Collin A., Houet T., Mury A., Gloria H., Le Poulain N. 2020. Towards better mapping of seagrass meadows using UAV multispectral and topographic data. Journal of Coastal Research 95 \(SI\), 1117-1121.](#)
- Karayali O. 2017. Evaluation of current status and change through time in some *Posidonia oceanica* (L.) Delile meadows in the Ligurian Sea. Master thesis in Marine Science. Izmir KâtipÇelebi University, Institute of Science, Izmir, 86 pp.
- Kenny A.J., Cato I., Desprez M., Fader G., Schuttenhelm R.T.E., Side J. 2003. An overview of seabed-mapping technologies in the context of marine habitat classification. *ICES Journal of Marine Science* 60 (2), 411-418.
- Komatsu T., Igarashi C., Tatsukawa K., Sultana S., Matsuoka Y., Harada S. 2003. Use of multi-beam sonar to map seagrass beds in Otsuchi Bay on the Sanriku Coast of Japan. *Aquatic Living Resources* 16 (3), 223-230.
- Leriche A., Boudouresque C.F., Bernard G., Bonhomme P., Denis J. 2004. A one-century suite of seagrass bed maps: can we trust ancient maps? *Estuarine, Coastal and Shelf Science* 59 (2), 353-362.
- Lopez y Royo C., Casazza G., Pergent-Martini C., Pergent G. 2010b. A biotic index using the seagrass *Posidonia oceanica* (BiPo), to evaluate ecological status of coastal waters. *Ecological Indicators* 10 (2): 380-389.
- Lopez y Royo C., Pergent G., Alcoverro T., Buia M.C., Casazza G., Martínez-Crego B., Pérez M., Silvestre F., Romero J. 2010c. The seagrass *Posidonia oceanica* as indicator of coastal water quality: experimental intercalibration of classification systems. *Ecological Indicators* 11 (2), 557-563.
- Lopez y Royo C., Pergent G., Pergent-Martini C., Casazza G. 2010a. Seagrass (*Posidonia oceanica*) monitoring in western Mediterranean: implications for management and conservation. *Environmental Monitoring and Assessment* 171, 365-380.
- Lopez y Royo C., Silvestri C., Salivas-Decaux M., Pergent G., Casazza G. 2009. Application of an angiosperm-based classification system (BiPo) to Mediterranean coastal waters: using spatial analysis and data on metal contamination of plants in identifying sources of pressure. *Hydrobiologia* 633 (1), 169-179.
- Lyons M., Phinn S., Roelfsema C. 2011. Integrating Quickbird multi-spectral satellite and field data: mapping bathymetry, seagrass cover, seagrass species and change in Moreton Bay, Australia in 2004 and 2007. *Remote Sensing* 3 (1), 42-64.
- Lyzenga D.R. 1978. Passive remote sensing techniques for mapping water depth and bottom features. *Applied Optics* 17 (3), 379-383.

Marbà N., Díaz-Almela E., Duarte C.M. 2014. Mediterranean seagrass (*Posidonia oceanica*) loss between 1842 and 2009. *Biological Conservation* 176, 183-190.

[Marre G., Deter J., Holon F., Boissery P., Luque S. 2020. Fine-scale automatic mapping of living \*Posidonia oceanica\* seagrass beds with underwater photogrammetry. \*Marine Ecology Progress Series\* 643, 63-74.](#)

Mc Kenzie L.J., Finkbeiner M.A., Kirkman H. 2001. Methods for mapping seagrass distribution. In: Short F.T., Coles R.G. (Eds), *Global Seagrass Research Methods*. Elsevier Scientific Publishers B.V., Amsterdam, 101-122.

McRoy C.P., McMillan C. 1977. Production ecology and physiology of seagrasses. In: *Seagrass ecosystems: a scientific prospective*, McRoy P.C., Helfferich C. (Eds), Marcel Dekker, New York, 53-87.

Meinesz A., Laurent R. 1978. Cartographie et état de la limite inférieure de l'herbier de *Posidonia oceanica* dans les ~~Alpes maritimes~~ [Alpes-Maritimes](#) (France). *Campagne Poséidon 1976*. *Botanica Marina* 21 (8), 513-526.

Meinesz A., Lefevre J.R., Astier J.M. 1991. Impact of coastal development on the infralittoral zone along the ~~southeastern~~ [south-eastern](#) Mediterranean ~~seashore~~ [shore](#) of continental France. *Marine Pollution Bulletin* 23, 343-347.

[MESH. 2007. MESH \(Mapping European Seabed Habitats\): Review of standards and protocols for seabed habitat mapping. Edited by Coggan, R., Populus, J., White, J., Sheehan, K., Fitzpatrick, F., Piel, S., 210 pp.](#)

Molinier R., Picard J. 1952. Recherches sur les herbiers de phanérogames marines du littoral méditerranéen français. *Annales de l'Institut Océanographique*, Paris 27 (3), 157-234.

[Monnier B., Pergent G., Mateo M.-Á., Clabaut P., Pergent-Martini C. 2020. Seismic interval velocity in the matte of \*Posidonia oceanica\* meadows: towards a non-destructive approach for large-scale assessment of blue carbon stock. \*Marine Environmental Research\* 161, 105085.](#)

Montefalcone M., 2009. Ecosystem health assessment using the Mediterranean seagrass *Posidonia oceanica*: a review. *Ecological Indicators* 9, 595-604

Montefalcone M., Albertelli G., Bianchi C.N., Mariani M., Morri C. 2006. A new synthetic index and a protocol for monitoring the status of *Posidonia oceanica* meadows: a case study at Sanremo (Ligurian Sea, NW Mediterranean). *Aquatic Conservation: Marine and Freshwater Ecosystems* 16, 29-42.

Montefalcone M., Morri C., Peirano A., Albertelli G., Bianchi C.N. 2007. Substitution and phase-shift in *Posidonia oceanica* meadows of NW Mediterranean Sea. *Estuarine, Coastal and Shelf Science* 75 (1), 63-71.

Montefalcone M., Parravicini V., Vacchi M., Albertelli G., Ferrari M., Morri C., Bianchi C.N. 2010. Human influence on seagrass habitat fragmentation in NW Mediterranean Sea. *Estuarine, Coastal and Shelf Science* 86, 292-298.

Montefalcone M., Rovere A., Parravicini V., Albertelli G., Morri C., Bianchi C.N. 2013. Evaluating change in seagrass meadows: a time-framed comparison of Side Scan Sonar maps. *Aquatic Botany* 104, 204-212.

[Montefalcone M., Tunesi L., Ouerghi A. 2021. A review of the classification systems for marine benthic habitats and the new updated Barcelona Convention classification for the Mediterranean. \*Marine Environmental Research\*, in press.](#)

Moreno D., Aguilera P.A., Castro H. 2001. Assessment of the conservation status of seagrass (*Posidonia oceanica*) meadows: implications for monitoring strategy and the decision-making process. *Biological Conservation* 102, 325-332.

- Morri C. 1991. Présentation Présentation d'un indice synthetiques synthétique pour l'évaluation évaluation de l'epiphytisme épiphytisme foliaire chez *Posidonia oceanica* (L.) Delile. Posidonia Newsletter 4 (1), 33-37.
- Mumby P.J., Edwards A.J. 2002. Mapping marine environments with IKONOS imagery: enhanced spatial resolution can deliver greater thematic accuracy. Remote Sensing of Environment 82 (2-3), 248-257.
- Mumby P., Hedley J., Chisholm J., Clark C., Ripley H., Jaubert J. 2004. The cover of living and dead corals from airborne remote sensing. Coral Reefs 23, 171-183.
- Nellemann C., Corcoran E., Duarte C.M., Valdés L., De Young C., Fonseca L., Grimsditch G. 2009. Blue carbon - The role of healthy oceans in binding carbon. United Nations Environment Programme, GRID-Arendal, BirkelandTrykkeri AS, Norway, 80 pp.
- Oprandi A., Bianchi C.N., Karayali O., Morri C., Rigo I., Montefalcone M. 2019. Confronto di descrittori a diversi livelli di complessità ecologica per definire lo stato di salute di *Posidonia oceanica* in Liguria. Biologia Marina Mediterranea 26 (1), 32-35.
- Orfanidis S., Papathanasiou V., Gounaris S., Theodosiou T. 2010. Size distribution approaches for monitoring and conservation of coastal *Cymodocea* habitats. Aquatic Conservation: Marine and Freshwater Ecosystems 20 (2), 177-188.
- Orth R.J., Carruthers T.J., Dennison W.C., Duarte C.M., Fourqurean J.W., Heck K.L., ..., Short F.T. 2006. A global crisis for seagrass ecosystems. Bioscience 56 (12), 987-996.
- Paillard M., Gravez V., Clabaut P., Walker P., Blanc J., Boudouresque C.F., Belsher T., Ursheler F., Poydenot F., Sinnassamy J., Augris C., Peyronnet J., Kessler M., Augustin J., Le Drezen E., Prudhomme C., Raillard J., Pergent G., Hoareau A., Charbonnel E. 1993. Cartographie de l'herbier de Posidonie et des fonds marins environnants de Toulon à Hyères (Var - France). Reconnaissance par sonar latéral et photographie aérienne. Notice de présentation. Ifremer & GIS Posidonie Publ., 36 pp.
- Pasqualini V. 1997. Caractérisation des peuplements et types de fonds le long du littoral corse (Méditerranée, France). Thèse de Doctorat in Ecologie Marine, Université de Corse, France, 172 pp.
- Pasqualini V., Pergent-Martini C., Clabaut P., Pergent G. 1998. Mapping of *Posidonia oceanica* using aerial photographs and side-scan sonar: application of the island of Corsica (France). Estuarine, Coastal and Shelf Science 47, 359-367.
- Pasqualini V., Pergent-Martini C., Fernandez C., Ferrat L., Tomaszewski J.E., Pergent G. 2006. Wetland monitoring : Aquatic plant changes in two Corsican coastal lagoons (Western Mediterranean Sea). Aquatic Conservation: Marine and Freshwater Ecosystems 16 (1), 43-60.
- Pasqualini V., Pergent-Martini C., Pergent G. 1999. Environmental impacts identification along the Corsican coast (~~Mediterranean sea~~ Mediterranean Sea) using image processing. Aquatic Botany 65, 311-320.
- Pasqualini V., Pergent-Martini C., Pergent G., Agreil M., Skoufas G., Sourbes L., Tsirika A. 2005. Use of SPOT 5 for mapping seagrasses: an application to *Posidonia oceanica*. Remote Sensing Environment 94, 39-45.
- Pergent G. 1990. Lepidochronological analysis of the seagrass *Posidonia oceanica* (L.) Delile: a standardised approach. Aquatic Botany 37, 39-54.
- Pergent G., Pergent-Martini C. 1995. Mise en œuvre d'un réseau de surveillance de la végétation marine en Méditerranée - Synthèse. Contract RA/SPA N°10/94, 25 pp. + 10 p-Annexes.
- Pergent G., Bazairi H., Bianchi C.N., Boudouresque C.F., Buia M.C., Clabaut P., Harmelin-Vivien M., Mateo M.A., Montefalcone M., Morri C., Orfanidis S., Pergent-Martini C., Semroud R., Serrano O., Verlaque M. 2012. Les herbiers de Magnoliophytes marines de ~~Méditerranée~~ Méditerranée.

- ~~Resilience~~Résilience et contribution ~~à~~ l'~~attenuation~~atténuation des changements climatiques. IUCN, Gland, Switzerland and Malaga, Spain, 80 pp.
- Pergent G., Chessa L., Cossu A., Gazale V., Pasqualini V., Pergent-Martini C. 1995a. Aménagement du littoral: apport de la cartographie benthique. *ResMediterranea* 2, 45-57.
- Pergent G., Leonardini R., Lopez Y Royo C., Mimault B., Pergent-Martini C. 2008. Mise en œuvre d'un réseau de surveillance Posidonies le long du littoral de la Corse - Rapport de synthèse 2004-2008. Contrat Office de l'Environnement de la Corse et GIS Posidonie Centre de Corse. GIS Posidonie Publ., Corte, France, 273 pp.
- Pergent G., Monnier B., Clabaut P., Gascon G., Pergent-Martini C., Valette-Sansevin A. 2017. Innovative method for optimizing Side-Scan Sonar mapping: The blind band unveiled. *Estuarine, Coastal and Shelf Science* 194, 77-83.
- Pergent G., Pergent-Martini C., Boudouresque C.F. 1995b. Utilisation de l'herbier à *Posidonia oceanica* comme indicateur biologique de la qualité du milieu littoral en ~~Méditerranée~~Méditerranée: ~~état~~état des connaissances. *Mésogée* 54, 3-29.
- Pergent G., Pergent-Martini C., Casalta B., Lopez y Royo C., Mimault B., Salivas-Decaux M., Short F. 2007. Comparison of three seagrass monitoring systems: SeagrassNet, "Posidonia" programme and RSP. Proceedings of the third Mediterranean Symposium on Marine Vegetation, Pergent-Martini C., El Asmi S., Le Ravallec C. (Eds), RAC/SPA publ., Tunis, 141-150.
- Pergent-Martini C., Leoni V., Pasqualini V., Ardizzone G.D., Balestri E., Bedini R., Belluscio A., Belsher T., Borg J., Boudouresque C.F., Boumaza S., Bouquegneau J.M., Buia M.C., Calvo S., Cebrian J., Charbonnel E., Cinelli F., Cossu A., Di Maida G., Dural B., Francour P., Gobert S., Lepoint G., Meinesz A., Molenaar H., Mansour H.M., Panayotidis P., Peirano A., Pergent G., Piazzini L., Pirrotta M., Relini G., Romero J., Sanchez-Lizaso J.L., Semroud R., Shembri P., Shili A., Tomasello A., Velimirov B. 2005. Descriptors of *Posidonia oceanica* meadows: use and application. *Ecological Indicators* 5, 213-230.
- Personnic S., Boudouresque C.F., Astruch P., Ballesteros E., Blouet S., Bellan-Santini D., ..., Pergent G. 2014. An ecosystem-based approach to assess the status of a Mediterranean ecosystem, the *Posidonia oceanica* seagrass meadow. *PloS One* 9 (6), e98994.
- UNEP/MAP. 2009. Rapport de la seizième réunion ordinaire des Parties contractantes à la Convention sur la protection du milieu marin et du littoral de la Méditerranée et à ses Protocoles. Document de travail, Marrakech (Maroc), 3-5 Novembre 2009, PAM publ., UNEP(DEPI)/MED IG.19/8, 22 pp. + Annexes.
- UNEP/MAP-Blue Plan. 2009. Etat de l'environnement et du développement en Méditerranée. RAC/SPA-Plan Bleu publ., Athènes, 212 pp.
- UNEP/MAP-RAC/SPA. 1999. Plan d'action relatif à la conservation de la végétation marine de Méditerranée. RAC/SPA publ., Tunis, 47 pp.
- UNEP/MAP-RAC/SPA. 2005. Rapport d'évaluation de la mise en œuvre du plan d'action pour la conservation de la végétation marine en mer Méditerranée. Document de travail pour la septième réunion des points focaux nationaux pour les ASP, Séville (Espagne), 31 Mai-3 Juin 2005, RAC/SPA publ., Tunis, UNEP(DEC)/MED WG.268/6, 51 pp. + Annexes.
- UNEP/MAP-RAC/SPA. 2009. Rapport sur le projet MedPosidonia. Rais C., Pergent G., Dupuy de la Grandrive R., Djellouli A. (Edits), Document d'information pour la neuvième réunion des points focaux nationaux pour les ASP, Floriana – Malte, 3-6 Juin 2009, RAC/SPA publ., Tunis, UNEP(DEPI)/MED WG.331/Inf.11, 107 pp. + Annexes.
- UNEP/MAP-RAC/SPA. 2015a. Guidelines for standardization of mapping and monitoring methods of Marine Magnoliophyta in the Mediterranean. Pergent-Martini C. (Ed.), RAC/SPA publ., Tunis, 48 pp. + Annexes.

- [UNEP/MAP-RAC/SPA, 2015b. Handbook for interpreting types of marine habitat for the selection of sites to be included in the national inventories of natural sites of conservation interest. In: Bellan-Santini, D., Bellan, G., Bitar, G., Harmelin, J.-G., Pergent, G. \(Eds\), RAC/SPA publ., Tunis, 168 pp.](#)
- UNEP/MAP-SPA/RAC, 2019. Report of the meeting of experts on the finalization of the classification of benthic marine habitat types for the Mediterranean region and the reference list of marine and coastal habitat types in the Mediterranean. SPA/RAC publ., Tunis, 49 pp.
- [Rende S.F., Irving A.D., Bacci T., Parlagreco L., Bruno F., De Filippo F., Montefalcone M., Penna M., Trabucco B., Di Mento R., Cicero A.M. 2015. Advances in micro-cartography: A two-dimensional photo-mosaicing technique for seagrass monitoring. Estuarine, Coastal and Shelf Science 167, 475-486.](#)
- [Rende S.F., Bosman A., Di Mento R., Bruno F., Lagudi A., Irving A.D., ... Cellini E. 2020. Ultra-high-resolution mapping of \*Posidonia oceanica\* \(L.\) Delile meadows through acoustic, optical data and object-based image classification. Journal of Marine Science and Engineering 8 \(9\), 647.](#)
- Riegl B.M., Purkis S.J. 2005. Detection of shallow subtidal corals from IKONOS satellite and QTC View (50, 200 kHz) single-beam sonar data (Arabian Gulf; Dubai, UAE). Remote Sensing of Environment 95 (1), 96-114.
- Romero J., Martinez-Crego B., Alcoverro T., Pérez M. 2007. A multivariate index based on the seagrass *Posidonia oceanica* (POMI) to assess ecological status of coastal waters under the water framework directive (WFD). Marine Pollution Bulletin 55, 196-204.
- [Rowan G.S., Kalacska M. 2021. A review of remote sensing of submerged aquatic vegetation for non-specialists. Remote Sensing 13 \(4\), 623.](#)
- Salivas-Decaux M. 2009. Caractérisation et valorisation des herbiers à *Posidonia oceanica* (L.) Delile et à *Cymodocea nodosa* (Ucria) Ascherson dans le bassin Méditerranéen. Thèse Doctorat in Ecologie Marine, Université de Corse, France, 168 pp.
- Salivas-Decaux M., Bonacorsi M., Pergent G., Pergent-Martini C. 2010. Evaluation of the contamination of the Mediterranean Sea based on the accumulation of trace-metals by *Posidonia oceanica*. Proceedings of the fourth Mediterranean symposium on marine vegetation (Hammamet, 2-4 December 2010). El Asmi S. (Ed.), RAC/SPA publ., Tunis, 120-124.
- Short F., Coles R.G. 2001 Global Seagrass Research Methods. Elsevier Science B.V. publ., Amsterdam, 473 pp.
- Short F., McKenzie L.J., Coles R.G., Vidler K.P. 2002. SeagrassNet - Manual for scientific monitoring of seagrass habitat. Queensland Department of Primary Industries, QFS, Cairns, 56 pp.
- [SPA/RAC-UN Environment/MAP. 2019a. Updated classification of benthic marine habitat types for the Mediterranean Region. UNEP/MAP-SPA/RAC publ., Tunis, 23 pp.](#)
- [SPA/RAC-UN Environment/MAP. 2019b. Updated reference list of marine habitat types for the selection of sites to be included in the national inventories of natural sites of conservation interest in the Mediterranean. UNEP/MAP-SPA/RAC publ., Tunis, 20 pp.](#)
- Telesca L., Belluscio A., Criscoli A., Ardizzone G., Apostolaki E.T., Frascchetti S., ..., Alagna A. 2015. Seagrass meadows (*Posidonia oceanica*) distribution and trajectories of change. Scientific Reports 5, 12505.
- Topouzellis K., Makri D., Stoupas N., Papakonstantinou A., Katsanevakis S. 2018. Seagrass mapping in Greek territorial waters using Landsat-8 satellite images. International Journal of Applied Earth Observation and Geoinformation 67, 98-113.
- [Traganos D., Cerra D., Reinartz P., 2017. Cubesat-derived detection of seagrasses using planet imagery following unmixing-based denoising: Is small the next big? International Archives of the](#)

[Photogrammetry, Remote Sensing and Spatial Information Sciences-ISPRS Archives, 42 \(W1\), 283-287.](#)

Traganos D., Reinartz P. 2018. Mapping Mediterranean seagrasses with Sentinel-2 imagery. *Marine Pollution Bulletin* 134, 197-209.

Vassallo P., Paoli C., Rovere A., Montefalcone M., Morri C., Bianchi C.N. 2013. The value of the seagrass *Posidonia oceanica*: a natural capital assessment. *Marine Pollution Bulletin* 75, 157-167.

Vacchi M., Montefalcone M., Bianchi C.N., Ferrari M. 2012. Hydrodynamic constraints to the seaward development of *Posidonia oceanica* meadows. *Estuarine, Coastal and Shelf Science* 97, 58-65.

Vacchi M., Montefalcone M., Schiaffino C.F., Parravicini V., Bianchi C.N., Morri C., Ferrari M. 2014. Towards a predictive model to assess the natural position of the *Posidonia oceanica* seagrass meadows upper limit. *Marine Pollution Bulletin* 83, 458-466.

[Vasquez M., Agnesi S., Al Hamdani Z., Annunziatellis A., Bekkby T., Askew A., Bentes L., Castle L., Doncheva V., Duncan G., Gonçalves J., Inghilesi R., Laamanen L., Lillis H., Manca E., McGrath F., Mo G., Monteiro P., Muresan M., O’Keeffe E., Pesch R., Pinder J., Teaca A., Todorova V., Tunesi L., Virtanen E. 2021a. Mapping seabed habitats over large areas: prospects and limits. EMODnet Phase III, Technical Report, 21 pp.](#)

[Vasquez M., Agnesi S., Al Hamdani Z., Annunziatellis A., Castle L., Laamanen L., Lillis H., Manca E., Mo G., Muresan M., Nikolova C., Ridgeway A., Teaca A., Todorova V., Tunesi L. 2021b. Method for classifying EUSeaMap according to the new version of EUNIS, HELCOM HUB and the Mediterranean habitat types. EMODnet Phase III, Technical Report, 27 pp.](#)

~~Ventura D., Bonifazi A., Gravina M., Belluscio A., Ardizzone G. 2018. Mapping and classification of ecologically sensitive marine habitats using unmanned aerial vehicle (UAV) imagery and Object-Based Image Analysis (OBIA). *Remote Sensing* 10 (9), 1331.~~  
[Ventura D., Bonifazi A., Gravina M.F., Ardizzone G.D. 2017. Unmanned aerial systems \(UASs\) for environmental monitoring: A review with applications in coastal habitats. \*Aerial Robots-Aerodynamics, Control and Applications\*, 165-184.](#)

[Ventura D., Bonifazi A., Gravina M., Belluscio A., Ardizzone G. 2018. Mapping and classification of ecologically sensitive marine habitats using unmanned aerial vehicle \(UAV\) imagery and Object-Based Image Analysis \(OBIA\). \*Remote Sensing\* 10 \(9\), 1331.](#)

Waycott M., Duarte C.M., Carruthers T.J.B., Orth R.J., Dennison W.C., Olyarnik S., Calladine A., Fourqurean J.W., Heck Jr. K.L., Hughes A.R., Kendrick G.A., Kenworthy W.J., Short F.T., Williams S.L. 2009. Accelerating loss of seagrasses across the globe threatens coastal ecosystems. *Proceedings of the National Academy of Sciences* 106, 12377-12381.

Zucchetto M., Venier C., Taji M.A., Mangin A., Pastres R. 2016. Modelling the spatial distribution of the seagrass *Posidonia oceanica* along the North African coast: Implications for the assessment of Good Environmental Status. *Ecological Indicators* 61, 1011-1023.

**Annex 1.1**

**Absolute classification scales of the ecological status available in literature for some descriptors of *Posidonia oceanica* meadow**

**Meadow (population level)**

Type of the lower limit (UNEP/MAP-RAC/SPA, 2009)

	High	Good	Moderate	Poor	Bad
<b>Lower limit</b>	Progressive	Sharp HC	Sharp LC	Sparse	Regressive

Type of the limit	Main characteristics
Progressive	Plagiotropic rhizome beyond the limit
Sharp – High cover (HC)	Sharp limit with cover higher than 25%
Sharp – Low cover (LC)	Sharp limit with cover lower than 25%
Sparse	Shoot density lower than 100 shoots · m <sup>-2</sup> , cover lower than 15%
Regressive	Dead matte beyond the limit

Depth of the lower limit (in m) (UNEP/MAP-RAC/SPA, 2009)

	High	Good	Moderate	Poor	Bad
<b>Lower limit</b>	> 34.2	34.2 to 30.4	30.4 to 26.6	26.6 to 22.8	< 22.8

Meadow cover at the lower limit (in percentage) (UNEP/MAP-RAC/SPA, 2009)

	High	Good	Moderate	Poor	Bad
<b>Lower limit</b>	> 35%	35% to 25%	25% to 15%	15% to 5%8	< 5%

Shoot density (number of shoots · m<sup>2</sup>) (Pergent-Martini et al., 2005)

Depth (m)	High	Good	Moderate	Poor	Bad
1	> 1133	1133 to 930	930 to 727	727 to 524	< 524
2	> 1067	1067 to 863	863 to 659	659 to 456	< 456
3	> 1005	1005 to 808	808 to 612	612 to 415	< 415
4	> 947	947 to 757	757 to 567	567 to 377	< 377
5	> 892	892 to 709	709 to 526	526 to 343	< 343
6	> 841	841 to 665	665 to 489	489 to 312	< 312
7	> 792	792 to 623	623 to 454	454 to 284	< 284
8	> 746	746 to 584	584 to 421	421 to 259	< 259
9	> 703	703 to 547	547 to 391	391 to 235	< 235
10	> 662	662 to 513	513 to 364	364 to 214	< 214
11	> 624	624 to 481	481 to 338	338 to 195	< 195
12	> 588	588 to 451	451 to 314	314 to 177	< 177
13	> 554	554 to 423	423 to 292	292 to 161	< 161
14	> 522	522 to 397	397 to 272	272 to 147	< 147
15	> 492	492 to 372	372 to 253	253 to 134	< 134
16	> 463	463 to 349	349 to 236	236 to 122	< 122
17	> 436	436 to 328	328 to 219	219 to 111	< 111
18	> 411	411 to 308	308 to 204	204 to 101	< 101
19	> 387	387 to 289	289 to 190	190 to 92	< 92
20	> 365	365 to 271	271 to 177	177 to 83	< 83
21	> 344	344 to 255	255 to 165	165 to 76	< 76
22	> 324	324 to 239	239 to 154	154 to 69	< 69
23	> 305	305 to 224	224 to 144	144 to 63	< 63
24	> 288	288 to 211	211 to 134	134 to 57	< 57
25	> 271	271 to 198	198 to 125	125 to 52	< 52
26	> 255	255 to 186	186 to 117	117 to 47	< 47
27	> 240	240 to 175	175 to 109	109 to 43	< 43
28	> 227	227 to 164	164 to 102	102 to 39	< 39
29	> 213	213 to 154	154 to 95	95 to 36	< 36
30	> 201	201 to 145	145 to 89	89 to 32	< 32
31	> 189	189 to 136	136 to 83	83 to 30	< 30
32	> 179	179 to 128	128 to 77	77 to 27	< 27
33	> 168	168 to 120	120 to 72	72 to 24	< 24
34	> 158	158 to 113	113 to 68	68 to 22	< 22
35	> 149	149 to 106	106 to 63	< 63	
36	> 141	141 to 100	100 to 59	< 59	
37	> 133	133 to 94	94 to 55	< 55	
38	> 125	125 to 88	88 to 52	< 52	
39	> 118	118 to 83	83 to 48	< 48	
40	> 111	111 to 78	78 to 45	< 45	

Plagiotropic rhizome at the lower limit (in percentage) (UNEP/MAP-RAC/SPA, 2009)

	High	Good	Moderate	Poor	Bad
Lower limit	> 70%	70% to 30%	< 30%		

**Plant (individual-species level)**

Foliar surface (in cm<sup>2</sup> per shoot), between June and July (UNEP/MAP-RAC/SPA, 2009)

Depth (m)	High	Good	Moderate	Poor	Bad
15 m	> 362	362 to 292	292 to 221	221 to 150	< 150

Number of leaves produced per year (UNEP/MAP-RAC/SPA, 2009)

Depth (m)	High	Good	Moderate	Poor	Bad
15 m	> 8.0	8.0 to 7.5	7.5 to 7.0	7.0 to 6.5	< 6.5

Rhizome elongation (in mm per year) (UNEP/MAP-RAC/SPA, 2009)

Depth (m)	High	Good	Moderate	Poor	Bad
15 m	> 11	11 to 8	8 to 5	5 to 2	< 2

**Cell (physiological/biochemical level): environment eutrophication**

Nitrogen concentration in adult leaves (in percentage), between June and July (UNEP/MAP-RAC/SPA, 2009)

Depth (m)	High	Good	Moderate	Poor	Bad
15 m	< 1.9%	1.9% to 2.4%	2.4% to 3.0%	3.0% to 3.5%	> 3.5%

Organic matter in the sediment (in percentage, fraction 0.063 mm) (UNEP/MAP-RAC/SPA, 2009)

Depth (m)	High	Good	Moderate	Poor	Bad
15 m	< 2.5%	2.5% to 3.5%	3.5% to 4.6%	4.6% to 5.6%	> 5.6%

**Cell (~~physiological/biochemical level~~physiological level): environment contamination**

Argent ~~c~~Concentration (mg per g DW), blade of adult leaves, between June and July (Salivas-Decaux, 2009)

Depth (m)	High	Good	Moderate	Poor	Bad
15 m	< 0.08	0.08 to 0.22	0.23 to 0.36	0.37 to 0.45	> 0.45

Cadmium ~~c~~Concentration (mg per g DW), blade of adult leaves, between June and July (Salivas-Decaux, 2009)

Depth (m)	High	Good	Moderate	Poor	Bad
15 m	< 1.88	1.88 to 2.01	2.02 to 2.44	2.45 to 2.84	> 2.84

Mercury ~~c~~Concentration (mg per g DW), blade of adult leaves, between June and July (Salivas-Decaux, 2009)

Depth (m)	High	Good	Moderate	Poor	Bad
15 m	< 0.051	0.051 to 0.064	0.065 to 0.075	0.075 to 0.088	> 0.088

Plumb ~~c~~Concentration (mg per g DW), blade of adult leaves, between June and July (Salivas-Decaux, 2009)

Depth (m)	High	Good	Moderate	Poor	Bad
15 m	< 1.17	1.17 to 1.43	1.44 to 1.80	1.81 to 3.23	> 3.23

## 2. Guidelines for monitoring coralligenous and other calcareous bioconstructions in in the upper- circallitoral circalittoral Mediterranean zone

### Introduction

1. The calcareous formations of biogenic origin in the Mediterranean Sea are represented by coralligenous reefs, vermetid reefs, reefs of *Sabellaria* spp., serpulid reefs, cold water corals reefs in deep waters, *Lithophyllum byssoides* encrustations encrusting Corallinales concretions/trottoirs made by *Lithophyllum byssoides*, *Titanoderma trochanter*, and *Tenarea tortuosa*, banks formed by the corals *Cladocora caespitosa*, *Astroides calycularis*, *Phyllangia americana mouchezii*, *Polycyathus muelleriae*, reefs formed by the stylasteridae *Errina aspera*, bryozoan nodules and biostalactites within semi-dark and dark caves, sabellariid and serpulid worm reefs, and rhodoliths seabeds. Among all, coralligenous reefs (Fig. 1) and rhodoliths seabeds (Fig. 2) are the two most typical and abundant bioconstructed habitats that develop in the Mediterranean upper circalittoral zone (sometimes also in the lower littoral zone), built-up by coralline algal frameworks that grow in dim light conditions, for which inventorying and mapping methods, as well as monitoring protocols, still lack of homogeneity and standardization.



Figure 1: Coralligenous habitat dominated by the gorgonian *Paramuricea clavata* (upper panel © by Simone Musumeci), and facies with *Corallium rubrum* in enclave in the coralligenous (lower panel © Monica Montefalcone).



Figure 2: Rhodoliths habitat (photo from UNEP/MAP-RAC/SPA, 2015).

2. The most important and widespread bioconstruction in the Mediterranean Sea is represented by coralligenous reefs (UNEP/MAP-RAC/SPA, 2008), an endemic and characteristic habitat considered as the climax biocoenosis ~~of-in~~ the upper circalittoral zone (Pérès and Picard, 1964). Coralligenous is characterised by high species richness, biomass, and carbonate deposition values comparable to tropical coral reefs (Bianchi, 2001), and with high economic values higher than seagrass meadows (Cánovas-Molina et al., 2014). Construction of coralligenous reefs started during the post-Würm transgression, about 15000 years ago, and developed s on rocky and biodetritic bottoms in relatively constant-stable conditions of temperature, currents, and salinity.

3. ~~Two main e~~Coralligenous reefs are distributed both on rocky and soft bottoms, developing different morphologies ~~typologies can be defined;~~ i) coralligenous developing on the upper circalittoral rocks and at the entrance of caves with (cliffs, ~~or~~ outcrops, banks, rims, atolls); and ii) coralligenous developing over circalittoral soft/detritic bottoms creating biogenic platforms (Bonacorsi et al., 2012; Piazzini et al., 2019b). Coralligenous structure-habitat results from the dynamic equilibrium between bioconstruction, mainly made by encrusting calcified Rhodophyta belonging to Corallinales and Peyssonneliales (such as species belonging to the genera *Lithophyllum*, *Lithothamnion*, *Mesophyllum*, *Neogoniolithon*, and *Peyssonnelia*), with an accessory contribution by serpulid polychaetes, bryozoans and scleractinian corals, and destruction processes (by borers and physical abrasion), which create a morphologically complex habitat where highly diverse benthic assemblages develop (Ballesteros, 2006). Light represents the main factor limiting bioconstruction, and coralligenous reefs are able to can develop in dim light conditions (<3% of the surface irradiance), from about 20 m down to 120 m depth. Also, the upper mesophotic zone (where the light is still present, from 40 m to about 120 m depth), embracing the continental shelf, is shaped by extremely rich and diverse coralligenous assemblages dominated by animal forests that grow over biogenic rocky reefs.

4. Rhodoliths beds are composed of a variable thickness of free-living aggregations of live and dead thalli of calcareous red algae (mostly Corallinales, but also Peyssonneliales) and their fragments. ~~They, creating~~ a biogenic, unstable, three-dimensional habitat typically exposed to bottom currents, which harbours greater biodiversity ~~in comparison compared~~ to surrounding ~~habitats bottoms~~, and thus ~~are~~ viewed as ~~an indicator of~~ biodiversity hotspots. ~~Rhodoliths beds~~ ~~They mostly (mainly?)~~ occur on coastal detritic bottoms in the upper ~~mesophotic circalittoral~~ zone, between 40-60 m depth (Basso et al., 2016). Rhodoliths are made by slow growing organisms and can be long-lived (>100 years) (Riosmena-Rodríguez and Nelson, 2017). These algae can display a branching or a laminar appearance, can sometimes grow as nodules that cover all the seafloor, or accumulate within ripple marks. In the literature, the terms rhodoliths and maërl are often used as synonyms (UNEP/MAP-RAC/SPA, 2009). Maërl is the original Atlantic term to identify deposits of calcified non-nucleated algae mostly composed of *Phymatolithon calcareum* and *Lithothamnion corallioides*. Rhodoliths are intended as unattached nodules formed by calcareous red algae and their growths, showing a continuous spectrum of forms with size spanning from 2 to 250 mm of mean diameter. Thus, rhodoliths beds also includes maërl and calcareous *Peyssonnelia* beds, but the opposite is not true (Basso et al., 2016). Rhodoliths bed is recommended as a generic name to indicate those sedimentary bottoms characterised by any morphology and species of unattached non-geniculate calcareous red algae with >10% of live cover (Basso et al., 2016). The name maërl should be restricted to those rhodoliths beds that are composed of non-nucleated, unattached growths of branching, twig-like coralline algae.

5. Coralligenous reefs provide different ecosystem services to humans (Paoli et al., 2017), ~~such as provisional (food, materials, habitat), regulating (carbon sequestration, nutrient recycling), and cultural services.~~ ~~but~~ They are vulnerable to ~~either~~ global ~~and/or~~ local ~~impacts pressures~~. Coralligenous is threatened by direct human activities, such as trawling, pleasure diving, illegal exploitation of protected species, artisanal and recreational fishery, aquaculture, and is also vulnerable to the indirect effects of climate change ~~and global warming~~ (e.g., positive thermal anomalies and ocean acidification) (UNEP/MAP-RAC/SPA, 2008). Some invasive algal species (e.g., *Womersleyella setacea*, *Acrothamnion preissii*, *Caulerpa cylindracea*) can also pose a severe threat to these communities, ~~either~~ by forming dense carpets or by increasing sedimentation rate.

6. Despite the occurrence of many species with high ecological value (some of which are also legally protected, e.g., *Savalia savaglia*, *Spongia (Spongia) officinalis* ~~*Spongia officinalis*~~), coralligenous reefs were not listed among the priority habitats defined by the EU Habitat Directive (92/43/EEC), even if they can be included under the habitat “1170 Reefs” of ~~this~~ Directive, and appear also in the Bern Convention. This implies that the most important Mediterranean bioconstruction ~~still remains remains~~ without formal protection as it is not included within the list of ~~Special sites of Areas of Community Interest Conservation (SACs)~~. Few years after the adoption of the Habitat Directive, coralligenous reefs were listed among the “special habitats types” needing rigorous protection by the ~~P~~protocol concerning the ~~s~~Special ~~p~~Protected ~~a~~Areas and ~~b~~Biological ~~d~~Diversity (SPA/BD Protocol) of the Barcelona Convention (1995). Only recently, in the frame of the ~~“Action Plan for the Conservation of Coralligenous and other Mediterranean bio-constructions”~~ (UNEP/MAP-RAC/SPA, 2008) adopted by Contracting Parties to Barcelona Convention in 2008 and updated in 2016, the legal conservation of coralligenous assemblages has been encouraged by the establishment of marine protected areas and the need for standardized programs for its monitoring ~~has been~~ emphasized. Coralligenous has also been included in the European Red List of marine habitats ~~by IUCN~~, where ~~the lower infralittoral coralligenous bioconcretions (code A5.6x) are classified as “near-threatened”, and the circalittoral coralligenous bioconcretions (code A5.6y) as it is classified as “data deficient”~~ (Gubbay et al., 2016), thus demonstrating the urgent need for thorough investigations and accurate monitoring plans. In the same year, the Marine Strategy Framework Directive (MSFD, 2008/56/EC) included “seafloor integrity” as one of the descriptors to be evaluated for assessing the Good Environmental ~~Statuse~~ of the marine environment. Biogenic structures, such as coralligenous reefs, have thus been recognized as important biological indicators of environmental quality.

7. Similarly, rhodoliths seabeds are expected to be damaged by dredging, heavy anchors and mooring chains, ~~and trawling~~ and ~~are~~ adversely affected by rising temperatures ~~and~~ ~~and~~ ocean acidification ~~and trawling~~. Two maërl forming species, *Phymatolithon calcareum* and *Lithothamnion corallioides*, are protected under the EU Habitats Directive (92/43/EEC) in the Annex V and, in some locations, maërl is also a key habitat within the Annex I list of priority habitats of the Directive and therefore is given protection through the designation of Special Areas of Conservation (SACs). Moreover, a special plan for the legal protection of Mediterranean rhodoliths beds has been adopted within the framework of the “Action Plan for the Conservation of Coralligenous and other Mediterranean bio-constructions” (UNEP/MAP-SPA/RAC, 2017). Rhodoliths seabeds have also been included in the Natura 2000 sites and in the Red List of Mediterranean threatened habitats by IUCN.

8. The Action Plan (UNEP/MAP-SPA/RAC, 2017) identified many priority actions for these two benthic habitats, which mainly concern:

- (i) Increase the knowledge on the distribution (compiling existing information, carrying out field activities in new sites or in sites of particular interest) and on the composition (list of species) of these habitats;
- (ii) Set up a standardized spatiotemporal-temporal monitoring protocol for coralligenous and rhodoliths habitats.

9. Detailed information on habitat geographical distribution and bathymetrical ranges is a prerequisite ~~knowledge~~ for ~~a the~~ sustainable use of marine coastal areas. Coralligenous and rhodoliths distribution maps are ~~thus~~ a fundamental prerequisite to any conservation action on these habitats ~~and on their associated species~~ (Azzola et al., 2021). The scientific knowledge concerning several aspects of biogenic concretions (e.g., taxonomy, processes, functioning, biotic relationships, and dynamics) ~~has been~~ currently increasing. ~~However, but~~ it is still far away from the knowledge we have ~~from on~~ other coastal ecosystems, such as seagrass meadows, shallow coastal rocky reefs, etc. One of the major gaps concerning the current state of knowledge on coralligenous and rhodoliths habitats is the limited spatiotemporal-temporal studies on their geographical and depth distribution both at regional level and basin-wide scale. This information is essential ~~in order~~ to know the real extent of these habitats in the Mediterranean Sea and to implement appropriate management measures to guarantee their conservation (UNEP/MAP-SPA/RAC, 2017). Inventory and monitoring of coralligenous and rhodoliths raise several problems, due to their large bathymetric distribution and the consequent sampling constraints, ~~and the often limited~~ often-limited accessibility, ~~their~~ heterogeneity, and the lack of standardized protocols used by different teams working in this field. The operational restrictions imposed by scuba diving (Gatti et al., 2012 and references therein) reduce the amount of collected data during each dive and increase the sampling effort. If some protocols for the inventory and monitoring of coralligenous habitat ~~do~~ exist, common methods for monitoring rhodoliths are comparatively less documented.

10. Responding to the need of practical guides aimed at harmonising existing methods for monitoring bioconstructed habitats ~~monitoring~~ and for subsequent comparison of results obtained by different countries, the Contracting Parties asked the Specially Protected Areas Regional Activity Centre (SPA/RAC) to improve the existing inventory tools and to propose a standardization of the mapping and monitoring techniques for coralligenous and rhodoliths. Thus, the main methods used in the Mediterranean for inventory and monitoring ~~of the~~ coralligenous habitat and other bioconstructions were summarised in the “Standard Methods for Inventorying and Monitoring Coralligenous and Rhodoliths Assemblages” (UNEP/MAP-RAC/SPA, 2015). These monitoring guidelines have been the base-basis for the updating and harmonization process undertaken in this document.

11. For mapping coralligenous and other bioconstructed habitats, the previous Guidelines (UNEP/MAP-RAC/SPA, 2015) highlighted the following main findings:

- If underwater scuba diving is recommended ~~often used~~ for mapping and monitoring at small areasspatial scales and at shallower depths, it becomes unsuitable when the study area and/or the depth increase (usually at depths >40 m);

- ~~The use of a~~Acoustic survey methods (side scan sonar or multibeam echosounder) or ~~underwater—visual~~ observation systems (ROV, towed camera) becomes ~~then necessary~~ indispensable at depths greater than 40 m. However, acoustic techniques must be always integrated and verified by visual inspections with ground-truth data a large number of “field” underwater data.

12. For monitoring the condition of coralligenous and other bioconstructed habitats, the previous ~~G~~guidelines (UNEP/MAP-RAC/SPA, 2015) highlighted the following main findings:

- Assessment of the condition of the populations is heavily dependent on the working scale and the resolution requested. Monitoring activities ~~relies-rely~~ mainly on underwater scuba diving activities but given the above listed constraints, using other tools of investigation (e.g., ROV, towed camera) should be also considered because ~~it-they~~ allows monitoring ~~-with less precision but~~ on larger areas and at greater depths;
- Although the use of underwater photography or ~~videorecording~~ videorecording may be relevant, the ~~use—presence~~ of specialists in taxonomy with a good experience in ~~seaba diving surveying methods~~ is often essential given the complexity of these habitats. ~~If it is possible to estimate the a~~Abundance or coverage of specific taxa can be visually estimated underwater by standardized indices on defined surfaces or along transects through standardized indices, detailed characterisations often require the use of square frames (quadrates), transects, or even the removal of all organisms on a given surface. The presences of broken individuals and of areas of necrosis are other factors to be considered;
- Monitoring of coralligenous habitat starts with the realisation of micro-mapping and then ~~the application of applying~~ descriptors and/or ecological indices. However, these descriptors vary widely from one team to another, as well as their measurement protocols;
- Monitoring of rhodoliths habitats can be done by underwater scuba diving, ~~but as well as the byand visual observation—inspection~~ using ROVs or towed cameras and ~~with the collection of collecting~~ samples using dredges, grabs, ~~or—and~~ box corers, ~~are privileged because of the greater homogeneity of these populations. However At present,~~ there is not ~~yet~~ any standardized method yet that has been widely accepted ~~to-date~~ for monitoring rhodoliths, also because the action of hydrodynamics—water movement may cause a shift of these habitats on the seabed making their inventory rather difficult.

13. In the framework of the Barcelona Convention Ecosystem Approach (EcAp) implementation and based on the recommendations raised during of the ~~M~~meeting of the Ecosystem Approach Correspondence Group on Monitoring (CORMON), Biodiversity and Fisheries (Madrid, Spain, 28 February — 1 March 2017), the Contracting Parties requested SPA/RAC to develop standardized monitoring protocols to be used in the context of the Integrated Monitoring and Assessment Programme (IMAP), in order to ease the task for the countries when implementing their monitoring programmes. ~~by The two considering the previous work—guidelines elaborated—published by SPA/RAC, the ‘Standard methods for inventorying and monitoring coralligenous and rhodoliths assemblages’ Guidelines for monitoring coralligenous and other bioconstructed habitats in Mediterranean (UNEP/MAP-RAC/SPA, 2015) and the ‘Guidelines for inventorying and monitoring of dark habitats in the Mediterranean Sea’ (SPA/RAC-UN Environment/MAP, OCEANA, 2017), have been, considered in the elaboration of this document. to be updated in the context of the IMAP common indicators in order to ease the task for the contries when implementing their monitoring programmes.—~~ A reviewing process on the available scientific literature, ~~taking into account~~ considering the latest techniques and the recent works carried out by the scientific community at the international level, has ~~also—been~~ also carried out. If standardized protocols for seagrass mapping and monitoring exist and are well-implemented, and a number of several ecological indices have already been validated and inter-calibrated among different regions, this is not the case for coralligenous and rhodoliths habitats. In this document a number of some “minimal of the most adopted” descriptors ~~to be taken into account~~ for inventorying and monitoring the coralligenous and rhodoliths populations in the Mediterranean are described. ~~The main methods adopted for their monitoring,~~ with the relative advantages, restrictions, and conditions for their of use, are presented.

Some of the ~~existing~~ monitoring methods for coralligenous have already been compared or cross-calibrated and ~~results~~ are ~~here briefly introduced~~~~reported~~~~briefly reported here.~~ ~~and, finally, a~~ standardized ~~method~~~~procedure~~ recently proposed for coralligenous monitoring is ~~also~~ described.

## Monitoring methods

### a) COMMON INDICATOR 1: Habitat distributional range and extent

#### *Approach*

14. The CII ~~is aimed at providing~~~~aims to provide~~ information about the geographical area in which coralligenous and rhodoliths habitats occur in the Mediterranean and the total extent of surfaces covered. Following the overall procedure suggested for mapping seagrass meadows in the Mediterranean, three main steps can be identified also for mapping bioconstructions (refer to the “Guidelines for monitoring marine vegetation in ~~the~~ Mediterranean” ~~in this document~~ for major details):

- 1) Initial planning, which includes the definition of the objectives ~~in order~~ to select the minimum surface to be mapped and the necessary resolution, tools, and equipments;
- 2) Ground survey is the practical phase for data collection, it is the costliest phase as it generally requires field activities;
- 3) Processing and data interpretation requires knowledge and experience to ensure that data collected are usable and reliable.

#### *Resolution*

15. Measures of the total habitat extent may be subjected to high variability, as the final value is influenced by the methods used to obtain maps and by the resolution during both data acquisition and final cartographic restitution. Selecting an appropriate scale is ~~a~~ critical ~~stage~~ in the initial planning phase (Mc Kenzie et al., 2001). When large surface areas have to be mapped and global investigations carried out, an average precision and a lower detail ~~level~~ can be accepted, which means that the habitat distribution and the definition of its ~~extension limits~~~~boundaries~~ are often only indicative. When smaller areas have to be mapped, ~~a~~ much higher precision and resolution ~~level~~ ~~is~~ ~~are~~ required and ~~it~~ is easily achievable, thanks to the high-resolution mapping techniques (~~e.g.~~ ~~multibeam echosounder~~) available to date. However, obtaining detailed maps is costly, thus practically impossible when time or resources are limited (Giakoumi et al., 2013). These detailed maps provide ~~an~~ accurate localisation of the habitat distribution and a precise definition of its ~~extension limits~~~~boundaries~~ and total habitat extent, all features necessary for future control and monitoring purposes over ~~a period of~~ time. These high-resolution scales are also used to select remarkable (~~great?~~) sites where monitoring actions must be concentrated.

16. A scale of 1:10000 is the best choice for mapping rhodoliths beds at regional level. On this scale, it is possible to delimit areas down to about 500 m<sup>2</sup>, which is a good compromise between precise rhodoliths beds delimitation and study effort on a regional basis. Conversely, a scale equal to 1:1000 (or larger) is suggested for detailed monitoring studies of selected rhodoliths beds, where the areal definition and the rhodoliths boundaries should be more accurately located and monitored through time. Two adjacent rhodoliths beds are considered separate if, at any point along their limits, a minimum distance of 200 m occurs (Basso et al., 2016).

17. Although we have an overall knowledge about the composition and distribution occurrence of coralligenous and rhodoliths habitats in the Mediterranean (Ballesteros, 2006; Relini, 2009; Relini and Giaccone, 2009; UNEP-MAP-RAC/SPA, 2009), the scarceness of fine-scale cartographic data on the overall-geographical distribution of these habitats is one of the greatest lacunae from the conservation point of view. A first summary by Agnesi et al. (2008) highlighted the scarcity of available cartographic data, with less than 50 cartographies listed for the Mediterranean basin in that period. Most of the available maps are recent (less than ten years old) and are geographically disparate, mostly concerning the north-western Mediterranean basin. Another recent review (Martin et al., 2014) evidenced the occurrence of few datasets on coralligenous reefs and rhodoliths seabeds distribution, coming from 17 Mediterranean countries, and most of them being heterogeneous and with un-standardized legends, even within the same country. Updated data have also been collected in the last few years in some countries, thanks to the new monitoring activities afferent to the MSFD, and this information will become available in the coming years (see for instance Aguilar et al., 2018; SPA/RAC-UNEP/MAP, 2020).

18. Two global maps showing the distribution of coralligenous (Giakoumi et al., 2013) (Fig. 3) and maërl habitats (Martin et al., 2014) (Fig. 4) in the Mediterranean have been were produced based on the review of available information. Coralligenous habitats cover a surface area of about 2763 km<sup>2</sup> in 16 Mediterranean countries, i.e. Albania, Algeria, Croatia, Cyprus, France, Greece, Italy, Israel, Lebanon, Libya, Malta, Monaco, Morocco, Spain, Tunisia, and Turkey. All other ecoregions presented lower coverage, with the Alboran Sea having the lowest. Very limited data were found for on the presence of coralligenous formations in the southern and the eastern coasts of the Levantine Sea, although recent information has become available from Lebanon (Aguilar et al., 2018; SPA/RAC-UNEP/MAP, 2020). Information was substantially greater for the northern than the southern part of the Mediterranean. The Adriatic and Aegean Seas presented the highest coverage in terms of presence of coralligenous formations, followed by the Tyrrhenian Sea and the Algero-Provencal Basin. This uneven distribution of data on coralligenous distribution in the Mediterranean is not only a matter of invested research effort or data availability, but also depends on the geomorphologic heterogeneity of the Mediterranean coastline and seafloor: the northern basin encompasses 92.3% of the Mediterranean rocky coastline, while the southern and the extreme south-eastern areas are dominated by sandy coasts (Giakoumi et al., 2013 and references therein). Hence, the extensive distribution of coralligenous in the Adriatic, Aegean, and Tyrrhenian Seas is highly related to the presence of extensive rocky coasts in these areas, with Italy, Greece, and Croatia covering 74% of the Mediterranean's rocky coasts.

19. Knowledge on rhodoliths/maërl seabeds was somewhat limited compared to what is available for coralligenous. Rhodoliths Maërl habitats cover a surface area of about 1654 km<sup>2</sup>. Only sporadic and punctual information are available, mainly from the North Adriatic, the Aegean Seas, and the Tyrrhenian Sea. Datasets are available for Greece, France (Corsica), Cyprus, Turkey, Spain, Lebanon, and Italy. Malta and Corsica, in particular, have have significant datasets for on this habitat, as highlighted by fine-scale surveys in targeted areas (Martin et al., 2014).

20. These low-resolution global maps on coralligenous and rhodoliths distribution are still incomplete being the available information highly heterogeneous due to the high variability in the mapping and monitoring efforts across the Mediterranean basin; further mapping is thus required to determine the full extent of these highly variable habitats at the Mediterranean spatial scale. However, these global maps can be very useful for an overall knowledge of the bottom areas covered by coralligenous and rhodoliths, and to evaluate where surveys must be enforced in the future to collect missing data.

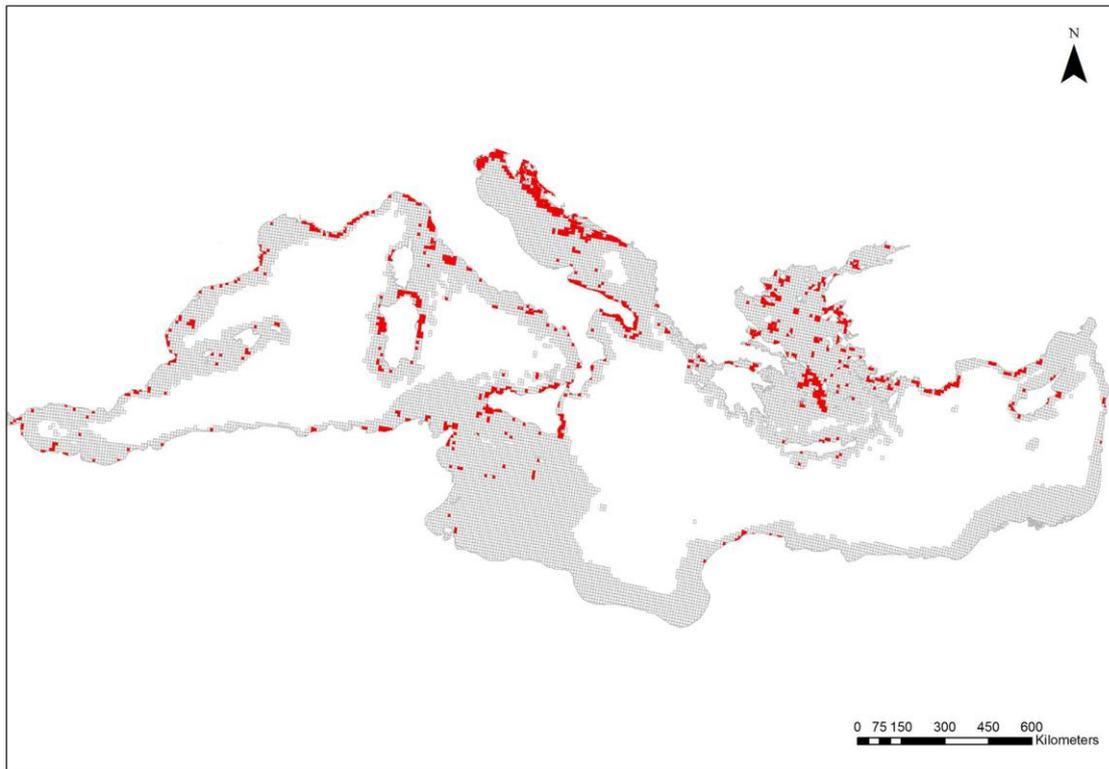


Figure 3: Global scale ~~D~~distribution of coralligenous habitats in the Mediterranean Sea (red areas) (from Giakoumi et al., 2013).

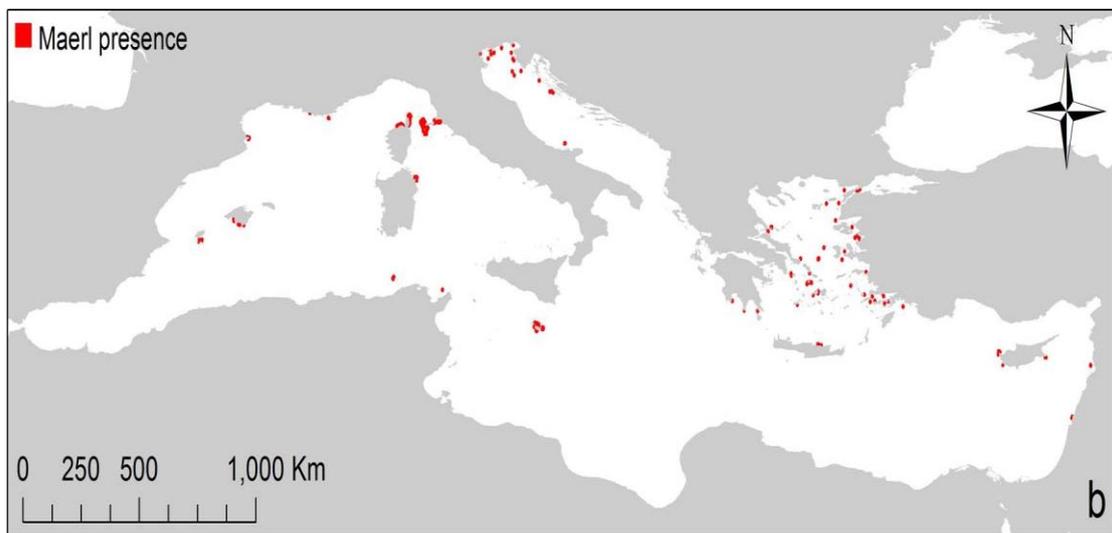


Figure 4: Global scale ~~D~~distribution of rhodoliths/maërl habitats in the Mediterranean Sea (red areas) (from Martin et al., 2014).

### Methods

21. Definition of distributional range-boundaries and extent of coralligenous and rhodoliths habitats requires “traditional” habitat mapping techniques, similar-to-like those used for seagrass meadows in deep waters (Tab. 1). Indirect-instrumentalRemote sensing -mapping techniques and/or direct-underwater field-visual surveys can-bemust be used and are often integrated. The simultaneous use of two or more mapping methods makes it possible to optimise the results

being the information obtained complementary. The strategy to be adopted will ~~thus~~ depend on the ~~aim of the study's aim~~ and the area concerned, means, and time available. ~~(The strategy to be adopted will depend on the study's aim and the area concerned, means, and time available ?).~~

### Underwater observations and sampling methods

22. Although underwater direct observation by scuba diving (e.g., ~~visual assessments along transects using transects, permanent square frames~~) is often used for mapping small areas, this method of investigation quickly shows its limits when the ~~study area of study and the~~ depth increase significantly, even if the ~~e-technique assessment~~ can be ~~optimised improved for a general description of the site~~ through ~~the integration with a towed diver or~~ video transects ~~(Cinelli, 2009)~~. Direct ~~underwater~~ observations provide discrete punctual data that are vital for ground-truthing the instrumental surveys, and for the validation of modelled/~~interpolated~~ continuous information (*i.e.*, complete coverage of surface areas) obtained from data on limited portions of the study area or along the pathway. Field surveys must be sufficiently numerous and distributed appropriately to obtain the necessary precision, and especially in view of the high heterogeneity of the coralligenous ~~and rhodoliths~~ habitats.

23. *In situ* underwater observations represent the most reliable, although time-consuming, mapping technique of coralligenous habitat ~~up to 30-40 m depth, according to local rules for safe scientific diving (Tab. 1)~~. Surveys can be done along lines (transects), or over small surface areas (permanent ~~square frames quadrates~~) positioned on the seafloor and located to follow the limits of the habitat. ~~The A~~ transect consists of a marked line wrapped on a rib and laid on the bottom from fixed points and in a precise direction, typically perpendicular or parallel ~~with respect~~ to the coastline (Bianchi et al., 2004a). Any changes in the habitat and ~~in~~ the substrate typology, within a belt at both sides of the line (considering a surface area of about 1-2 m per side), ~~are is~~ recorded on underwater slates. The information registered allows precise and detailed mapping of the sector studied (Tab. 1).

24. Scuba diving is also suggested as a safe and cost-effective tool to obtain a visual description and sampling of shallow rhodoliths beds ~~up to 30-40 m depth, according to local rules for scientific diving (Tab. 1)~~. Underwater observations are effective for a first characterisation of the aboveground facies of this habitat, ~~whilst to describe while describing~~ the belowground community samples on the bottom become necessary. The surface of a living rhodoliths bed is naturally composed ~~of (of )~~ a variable amount of live thalli and their fragments, lying on a ~~variable-varying~~ thickness of dead material and finer sediment. There ~~are is~~ no literature data about the required minimum spatial extent for a portion of the seafloor to be defined as a rhodoliths bed. A rhodoliths bed is defined as a habitat that is distinguished from the surrounding seafloor by having >10% of the mobile substrate ~~cum~~ covered by live calcareous coralline algae as unattached branches and/or nodules (Basso et al., 2016). Live rhodoliths beds are naturally accompanied by a variable quantity of dead rhodoliths and their fragments; thus, a threshold of >50% of the surface covered by dead rhodoliths and their fragments is defined as the condition to identify a dead rhodoliths bed. A seafloor covered by incomplete algal coatings of lithic pebbles and shell remains should not be considered as a rhodoliths bed. The mandatory information needed for a first description of rhodoliths beds includes depth ranges, areal extent, occurrence of sedimentary structures ~~onf~~ the seafloor (such as ripples, mega-ripples, and underwater dunes), thickness of live layer, ~~the~~ mean percentage cover of live thalli, live/dead rhodoliths ratio, dominant morphologies of rhodoliths ~~(see Fig. 5)~~, and identification of the most common and volumetrically important species of calcareous algae. In this first description, the need for specialized taxonomists and the time-consuming laboratory analyses are kept to a minimum.

25. Recently an innovative tool, namely the BioCube, ~~which is~~ a 1 m high device that enables the acquisition of 80 cm × 80 cm frame photo-quadrates, has been implemented ~~for the characterisation to characterise~~ of the aboveground detritic and rhodoliths seabottoms without scuba diving (Astruch et al., 2019). Photo-quadrates were made with a digital video camera with 30 second-time lapse triggering. Another camera linked to a screen at the surface is fixed to the BioCube to control the workflow and the position of the frame in real time. During the data acquisition, a third

camera is filming the surrounding ~~land~~ seascape for complementary information on demersal fish and extent of assemblages.

26. Sampling methods from vessels involving blind grabs, dredges, and box corers in a number of randomly selected points within a study area can be used to check for the occurrence of deep rhodoliths beds (to ground-truth ~~of the~~ acoustic data) and for a complete taxonomical and structural description of the habitat (Tab. 1). The thickness of the live cover could be measured through the transparent or removable side of a box-corer. Alternatively, a sub-sample could be taken from the recovered box-core using a Plexiglas core of about 10 cm in diameter and at least 20 cm long. Box-coring with a cross-section  $\geq 0.16 \text{ m}^2$  is recommended because it has the advantage of preserving the original substrate ~~stratification~~ stratification. The use of destructive sampling methods from vessel for characterizing rhodoliths beds should be, however, as much as possible discouraged, in order to minimize the impact of the investigation.

26-27. The potential contribution of citizen science networks for mapping and monitoring coralligenous habitat should be mentioned (Gerovasileiou et al., 2017), especially for the assessment assessing mass mortality events linked with global warming and heat waves (Garrahou et al., 2019). See for instance the initiatives available at <http://cs.cigesmed.eu/en> and <https://t-mednet.org/mass-mortality/mass-mortality-events>). The CIGESMED protocol, in particular, has already been applied in different parts of the Mediterranean (David et al., 2014; Çinar et al., 2020).

#### Remote sensing surveys

27-28. Being the ~~bioconstructed~~ biogenic coralligenous and rhodoliths habitats mainly distributed ~~in deep waters~~ (down to 20-30 m depth), the remote sensing acoustic techniques (e.g., side scan sonar, ~~and~~ multi-beam echosounder) ~~or and the~~ underwater video recordings (through ROVs and, towed cameras) are usually recommended (Georgiadis et al., 2009). The use of remote sensing allows characterising extensive coastal areas ~~for assessment of the~~ to define the overall spatial patterns of coralligenous and rhodoliths habitats. From maps obtained through remote sensing surveys, the presence/absence of the habitat, its ~~distributional~~ bathymetrical ranges, its boundaries, and the total habitat extent can be ~~easily~~ obtained. Acoustic methods are presently the most convenient technique for mapping rhodoliths beds, associated with ground-truthing by ROV and/or box-coring. The percentage cover of live thalli over a wide area can also be assessed from a ROV survey. Using acoustic techniques, associated with a good geo-location system, allow monitoring change in the extent of rhodoliths habitat over time (Bonacorsi et al., 2010).

28-29. Visual ~~Observations~~ observations from the surface can be made by using imagery techniques such as photography and video recording. Photographic equipment and cameras can be mounted on a vertical structure (sleigh or platform) or within remotely operated vehicles (ROVs). The camera on a vertical structure is submerged at the back of the vessel and is towed by the vessel that advances very slowly (under 1 knot), ~~while~~ est the ROVs have their own propulsion system and are remotely controlled from the surface. The use of towed ~~video cameras~~ video cameras (or ROVs) during surveys makes it possible to see the images on the screen in real time, ~~to~~ identify specific features of the habitat, and ~~to~~ evaluate any changes in the habitat or in any other characteristic elements of the seafloor, ~~and~~ this preliminary video survey may be also useful to locate specific monitoring stations. Recorded images are then reviewed to obtain a cartographical restitution on a GIS platform for each ~~of the areas~~ surveyed. To facilitate and ~~to~~ improve the results obtained with the camera, joint acquisition modules integrating the depth, images of the seafloor, and geographical positioning have been developed (UNEP/MAP-RAC/SPA, 2015).

30. Sonar provides images of the seafloor through the emission and reception of ultrasounds. Amongst the main acoustic mapping techniques available (Kenny et al., 2003), wide acoustic beam systems like the side scan sonar (SSS) and the multi-beam echosounder are usually employed in mapping coralligenous and rhodoliths habitats. All the acoustic mapping techniques are intrinsically affected by uncertainties due to manual classification of the different acoustic signatures ~~of associated~~ to with substrate types on sonograms. Errors in sonograms interpretation may arise when two substrate types are not easily distinguished by the observer. Interpretation of remote

sensing data requires extensive field calibration and the ground-truthing process remains essential. As the interpretation of sonograms is time-requiring, several automatic supervised processing techniques ~~were have been recently~~ proposed ~~in order~~ to rapidly automate the interpretation and the classification of acoustic signatures sonograms and to make this interpretation more reliable (Montefalcone et al., 2013 and references therein; Viala et al., 2021), also considering that current technology provides systems of neural networks and artificial intelligence to support these operations. These classification methods allow for a good discrimination between soft sediments and rocky reefs. Human eye, however, always remains the final judge.

## Modelling

29-31. Modelling techniques can be used to fill the gaps in the knowledge of the spatial distribution of habitats by predicting the areas that are likely to be suitable for a community to live. Models are usually based on physical and environmental variables (e.g., water temperature, salinity, depth, water movement, nutrient concentrations, seabed types), which are typically easier to record and map at ~~the~~ regional and global scales, in contrast to data on species and habitats ~~data~~. A recent study shows the correlation between wind-wave energy at the sea bottom and the rhodoliths bed presence (Agnesi et al., 2020); it also provides the confidence interval of this environmental variable associated with the probability to the of rhodoliths beds to occur, probability therefore informing on the wave energy values required for the modelling in the off-shore continental shelf (Agnesi et al., 2020). Despite inherent limitations and associated uncertainties, predictive modelling is a cost-effective alternative to field surveys as it can help identifying and mapping areas where sensitive marine ecosystems may occur. Based on the spatial datasets available for coralligenous and rhodoliths populations, a predictive modelling was carried out to produce two continuous maps of these two habitats across the Mediterranean Sea (Martin et al., 2014). For coralligenous, bathymetry, slope of the seafloor, and nutrient input were the three main contributors to the model. Predicted areas with suitable conditions for the occurrence of coralligenous habitat have been ~~reported defined~~ in the North African coast, ~~for which where~~ there are no available cartographic data to date. For rhodoliths, phosphate concentration, geostrophic velocity of sea surface current, silicate concentration, and bathymetry were the four main contributors to the model. Given the paucity-lack of occurrence data for this habitat across the Mediterranean, and especially in the North African coast, and the sSouthern Levantine coast, the model output is relatively informative in highlighting several suitable areas where no cartographic data are available to date.

30-32. A recent application of predictive spatial modelling was done starting from a complete acoustic coverage of the seafloor ~~together combined~~ with a comparatively low number of sea-truthings underwater observations made by scuba diving (Vassallo et al., 2018). This approach was applied to the coralligenous reefs of the Marine Protected Area of Tavolara - Punta Coda Cavallo (NE Sardinia, Italy), through a fuzzy clustering on a set of *in situ* observations. The model allowed recognising and mapping the coralligenous habitats within the MPA and showed that the distribution of the habitats was mainly driven by the distance from coast, the depth, and the lithotypes. ~~Another~~ Other examples of habitat predictions can be found in Zapata-Ramírez et al. (2016) and Rossi et al. (2021).

Table 1: Synthesis of the main-survey tools used for defining the Common Indicator 1\_Habitat distributional range and extent for coralligenous and rhodoliths habitats. When available, the depth range, the surface area mapped, the spatial resolution, the efficiency (expressed as area mapped in km<sup>2</sup> per hour), the main advantages or ~~the~~ limits of each tool are indicated, with some bibliographic ~~al~~ references.

Survey tool	Depth range	Surface area	Resolution	Efficiency	Advantages	Limits	References
Underwater diving <u>and visual surveys</u>	0 m up to 40 m, according to local rules on <u>safe</u> scientific diving	Small areas, less than 250 m <sup>2</sup>	From 0.1 m	0.0001 to 0.001 km <sup>2</sup> /hour	<ul style="list-style-type: none"> <li>• Very great precision <del>for</del> <u>in</u> the identification (taxonomy) and distribution of species (micro-mapping)</li> <li>• Non-destructive</li> <li>• Low cost, easy to implement</li> </ul>	<ul style="list-style-type: none"> <li>• Small area inventor<u>i</u>ied</li> <li>• Very time-consuming</li> <li>• Limited operational depth</li> <li>• Highly qualified <u>scientific</u> divers required (safety constraints)</li> <li>• <del>Variable</del> geo-referencing of the dive site</li> </ul>	Piazzini et al. (2019a <sub>1</sub> and references therein)
<del>Transects by towed divers</del>	<del>0 m up to 40 m, according to local rules on scientific diving</del>	<del>Intermediate areas (less than 1 km<sup>2</sup>)</del>	<del>From 1 to 10 m</del>	<del>0.025 to 0.01 km<sup>2</sup>/hour</del>	<ul style="list-style-type: none"> <li>• <del>Easy to implement and possibility of taking pictures</del></li> <li>• <del>Good identification of populations</del></li> <li>• <del>Non-destructive and low cost</del></li> </ul>	<ul style="list-style-type: none"> <li>• <del>Time-consuming</del></li> <li>• <del>Limited operational depth</del></li> <li>• <del>Highly qualified divers required (safety constraints)</del></li> <li>• <del>Variable geo-referencing of the diver route</del></li> <li>• <del>Water transparency</del></li> </ul>	<del>Cinelli (2009)</del>
Sampling from vessels with blind grabs, dredges <sub>2</sub> or box corers	0 m to about 50 m (until the lower limit of the rhodoliths <u>habitatbed</u> )	Intermediate areas (a few km <sup>2</sup> )	From 1 to 10 m	0.025 to 0.01 km <sup>2</sup> /hour	<ul style="list-style-type: none"> <li>• Very great precision for the identification (taxonomy) and distribution of species (micro-mapping)</li> <li>• All species <del>taken into account</del> <u>identified</u></li> <li>• Possibility of a <i>posteriori</i> identification</li> <li>• Low cost, easy to <del>implement</del></li> </ul>	<ul style="list-style-type: none"> <li>• Destructive method</li> <li>• Small area inventor<u>i</u>ied</li> <li>• <u>Need of S</u>ampling materials <u>needed</u></li> <li>• <u>Analyses on samples Work takes a lot of time</u> <u>very time-consuming</u></li> <li>• Limited operational depth</li> </ul>	UNEP/MAP-RAC/SPA (2015)
<del>Survey tool</del>	<del>Depth range</del>	<del>Surface area</del>	<del>Resolution</del>	<del>Efficiency</del>	<del>Advantages</del>	<del>Limits</del>	<del>References</del>

<u>Side scan sonar</u>	<u>8 m to over 120 m (until the lower limit of the coralligenous habitat)</u>	<u>From intermediate to large areas (50-100 km<sup>2</sup>)</u>	<u>&lt;1 m</u>	<u>1 to 4 km<sup>2</sup>/hour</u>	<ul style="list-style-type: none"> <li>• <u>Wide bathymetric range</u></li> <li>• <u>Realistic representation of the seafloor</u></li> <li>• <u>Good identification of the nature of the bottom and of assemblages (rhodoliths)</u></li> <li>• <u>Quick execution</u></li> <li>• <u>Very big mass of data</u></li> <li>• <u>Non-destructive</u></li> </ul>	<ul style="list-style-type: none"> <li>• <u>Flat (2D) picture to represent 3D complex habitats</u></li> <li>• <u>Possible errors in sonograms interpretation</u></li> <li>• <u>Acquisition of field data necessary to validate sonograms</u></li> <li>• <u>High cost</u></li> <li>• <u>Not effective for mapping vertical slopes</u></li> </ul>	<u>Cánovas-Molina et al. (2016b)</u>
<u>Side scan sonar</u>	<u>8 m to over 120 m (until the lower limit of the coralligenous habitat)</u>	<u>From intermediate to large areas (50-100 km<sup>2</sup>)</u>	<u>From &lt;1 m</u>	<u>1 to 4 km<sup>2</sup>/hour</u>	<ul style="list-style-type: none"> <li>• <u>Wide bathymetric range</u></li> <li>• <u>Realistic representation of the seafloor</u></li> <li>• <u>Good identification of the nature of the bottom and of assemblages (rhodoliths) with location of edges</u></li> <li>• <u>Quick execution</u></li> <li>• <u>Very big mass of data</u></li> <li>• <u>Non-destructive</u></li> </ul>	<ul style="list-style-type: none"> <li>• <u>Flat (2-D) picture to represent 3-D complex habitat</u></li> <li>• <u>Possible errors in sonograms interpretation</u></li> <li>• <u>Acquisition of field data necessary to validate sonograms</u></li> <li>• <u>High cost</u></li> <li>• <u>Not very used for mapping vertical slopes</u></li> </ul>	<u>CánovasMolina et al. (2016b)</u>
<u>Survey tool</u>	<u>Depth range</u>	<u>Surface area</u>	<u>Resolution</u>	<u>Efficiency</u>	<u>Advantages</u>	<u>Limits</u>	<u>References</u>

Multi-beam echosounder	2 m to over 120 m (until the lower limit of the coralligenous habitat)	From small areas (a few hundred square meters) to large areas (50-100 km <sup>2</sup> )	From 50 cm (linear) and lower than few centimetres	0.5 to 6 km <sup>2</sup> /hour	<ul style="list-style-type: none"> <li>• Possibility <del>of to</del> obtaining 3-D <del>picture</del> <u>representation of the seafloor</u></li> <li>• Double information collected (bathymetry and seafloor image)</li> <li>• Very precise and wide bathymetric range</li> <li>• Quick execution</li> <li>• Very big mass of data</li> <li>• Non-destructive</li> </ul>	<ul style="list-style-type: none"> <li>• Less precise <del>imaging</del> <u>recognition of the nature of the seabed</u> than side scan sonar</li> <li>• Acquisition of field data necessary to validate <u>the sonograms</u> <del>interpretation of</del> <u>acoustic data</u></li> <li>• High cost</li> </ul>	Cánovas- <del> Molina et al.</del> (2016b)
Remote Operating Vehicle (ROV)	2 m to over 120 m (until the lower limit of the coralligenous habitat)	Small-intermediate areas (a few km <sup>2</sup> )	From 1 m to 10 m	0.025 to 0.01 km <sup>2</sup> /hour	<ul style="list-style-type: none"> <li>• Non-destructive</li> <li>• Possibility <del>of taking to</del> <u>collect</u> pictures</li> <li>• Good identification of habitat and <u>conspicuous</u> species</li> <li>• <del>Wide bathymetric range</del></li> </ul>	<ul style="list-style-type: none"> <li>• High cost</li> </ul>	Cánovas- <del> Molina et al.</del> (2016a); Enrichetti et al. (2019)
<b>Survey tool</b>	<b>Depth range</b>	<b>Surface area</b>	<b>Resolution</b>	<b>Efficiency</b>	<b>Advantages</b>	<b>Limits</b>	<b>References</b>

Towed camera	2 m to over 120 m (until the lower limit of the coralligenous habitat)	Intermediate- <u>large</u> areas ( <del>a</del> <u>fewsome</u> km <sup>2</sup> )	From 1 m to 10 m	0.025 to 1 km <sup>2</sup> /hour	<ul style="list-style-type: none"> <li>• Easy to implement and possibility <u>to collect of taking</u> pictures</li> <li>• Good identification of habitat and <u>conspicuous</u> species</li> <li>• Non-destructive</li> <li>• Large area covered</li> </ul>	<ul style="list-style-type: none"> <li>• Limited to homogeneous and horizontal bottoms</li> <li>• Slow recording and processing of information</li> <li>• Variable positioning (geo-referencing)</li> <li>• Water transparency</li> <li>• Hard to handle <del>in</del> <u>in the case of heavy nautical heavy surface</u></li> </ul>	UNEP/MAP-RAC/SPA (2015)
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### Data interpretation

~~31.33.~~ 33. Once the surveying is completed, data collected need to be organized so ~~that they can~~ be used in the future by everyone and can be appropriately archived and easily consulted. A clear definition of all metadata must be provided with the dataset ~~in order to~~ ensure future integration with similar data from other sources. To produce a habitat map, Four important steps ~~for the production of a habitat map~~ must be followed:

- a. Processing, analysis and classification of ~~the~~ biological data, and their correct and precise geolocation, through a process of interpretation of acoustic images when available;
- b. Selecting the most appropriate physical layers (e.g., substrate, bathymetry, hydrodynamics);
- c. Integration of biological data and physical layers, and use of statistical modelling to predict habitat distribution and interpolate punctual information;
- d. The map produced must then be evaluated for its accuracy, i.e. its capacity to represent reality, and ~~therefore~~ its reliability.

34. During the first processing analysis and classification step, a standardised classification system must be used to label and classify benthic habitats on resulting maps and to ensure the uniformity and the readability of the final maps. The two recently updated lists of benthic marine habitat types should be consulted, which are: 1) the EUROpean Nature Information System (EUNIS) proposed for the European seas (available at <http://eunis.eea.europa.eu>; Evans et al., 2016); and 2) the Barcelona Convention classification of marine benthic habitat types adopted for the Mediterranean region by the Contracting Parties (available at [https://www.rac-spa.org/sites/default/files/doc\\_fsd/habitats\\_list\\_en.pdf](https://www.rac-spa.org/sites/default/files/doc_fsd/habitats_list_en.pdf); SPA/RAC-UN Environment/MAP, 2019a, b; Montefalcone et al., 2021). The two updated lists identify the specific coralligenous and rhodolith habitats that may be found from the infralittoral zone to the circalittoral zone, with their main characteristic associations and facies. The first original description of habitat types for the Mediterranean has been revised in 2015 (UNEP/MAP-RAC/SPA, 2015b), but a new updated interpretation manual of all the updated reference habitat types for the Mediterranean region is under elaboration, which also provides the criteria for their identification. Habitats of coralligenous and rhodoliths listed in the updated Barcelona Convention classification system are the following (SPA/RAC-UN Environment/MAP, 2019a, b):

~~the updated list of benthic marine habitat types for the Mediterranean region<sup>†</sup> should be consulted (UNEP/MAP SPA/RAC, 2019) to recognize any specific habitat type (i.e., coralligenous or rhodoliths) and its main characteristic associations and facies. A description of these habitats and the criteria for their identification are also available in Bellan Santini et al. (2002). Habitats that must be reported on maps are the following (UNEP/MAP SPA/RAC, 2019):~~

## INFRALITTORAL

### MB1.5 Infralittoral rock

MB1.55 Coralligenous (enclave of circalittoral, ~~see MC1.51~~)

## CIRCALITTORAL

### MC1.5 Circalittoral rock

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<sup>†</sup>The updated list of benthic marine habitat types for the Mediterranean region is in a draft stage. It was endorsed by the Meeting of Experts on the finalization of the Classification of benthic marine habitat types for the Mediterranean region and the Reference List of Marine and Coastal Habitat Types in the Mediterranean (Roma, Italy 22-23 January 2019). The draft updated list will be examined by the 14th Meeting of SPA/BD Focal Points (Portoroz, Slovenia, 18-21 June 2019) and submitted to the MAP Focal Points meeting and to the 21st Ordinary Meeting of the Contracting Parties, for adoption.

MC1.51 Coralligenous cliffs

MC1.51a Algal-dominated coralligenous

MC1.511a Association with encrusting Corallinales

MC1.512a Association with Fucales or Laminariales

MC1.513a Association with sciaphilic algae; (except Fucales, Laminariales, encrusting Corallinales, and Caulerpales)

MC1.514a Association with non-indigenous Mediterranean *Caulerpa* spp.

MC1.51b Invertebrate-dominated coralligenous

MC1.511b Facies with small sponges

MC1.512b Facies with large and erect sponges

MC1.513b Facies with Hydrozoa

MC1.514b Facies with Alcyonacea

MC1.515b Facies with Ceriantharia

MC1.516b Facies with Zoantharia

MC1.517b Facies with Scleractinia ~~MC1.51b Invertebrate-dominated coralligenous~~

MC1.518b Facies with Vermetidae and/or Serpulidae

MC1.519b Facies with Bryozoa

MC1.51Ab Facies with Ascidiacea

MC1.51c Invertebrate-dominated coralligenous covered by sediment

See MC1.51b for examples of facies

MC1.52 Continental shelf rock

MC1.52a Coralligenous outcrops

MC1.521a Facies with small sponges

MC1.522a Facies with Hydrozoa

MC1.523a Facies with Alcyonacea

MC1.524a Facies with Antipatharia

MC1.525a Facies with Scleractinia

MC1.526a Facies with Bryozoa

MC1.527a Facies with Polychaeta

MC1.528a Facies with Bivalvia

MC1.529a Facies with Brachiopoda

MC1.52b Coralligenous outcrops covered by sediment

See MC1.52a for examples of facies

MC1.52c Deep banks

MC1.521c Facies with Antipatharia

MC1.522c Facies with Alcyonacea

MC1.523c Facies with Scleractinia MC1.511b Facies with small sponges  
(sponge ground, e.g. *Ircinia* spp.)

MC1.512b Facies with large and erect sponges (e.g. *Spongia lamella*,  
*Sarcotragus foetidus*, *Axinella* spp.)

————— MC1.513b Facies with Hydrozoa

MC1.514b Facies with Alcyonacea (e.g. *Eunicella* spp., *Leptogorgia* spp.,  
*Paramuricea* spp., *Corallium rubrum*)

————— MC1.515b Facies with Ceriantharia (e.g. *Cerianthus*  
spp.)

MC1.516b Facies with Zoantharia (e.g. *Parazoanthus axinellae*, *Savalia*  
*savaglia*)

MC1.517b Facies with Scleractinia (e.g. *Dendrophyllia* spp., *Leptopsammia*  
*pruvoti*, *Madracis pharensis*)

————— MC1.518b Facies with Vermetidae and/or Serpulidae

MC1.519b Facies with Bryozoa (e.g. *Reteporella grimaldii*, *Pentapora*  
*fascialis*)

————— MC1.51Ab Facies with Ascidiacea

————— MC1.51c Invertebrate dominated coralligenous covered by  
sediment

————— See MC1.51b for examples of facies

————— MC1.52 Shelf edge rock

————— MC1.52a Coralligenous outerops

————— MC1.521a Facies with small sponges (sponge ground)

————— MC1.522a Facies with Hydrozoa

MC1.523a Facies with Alcyonacea (e.g. *Aleyonium* spp., *Eunicella* spp.,  
*Leptogorgia* spp., *Paramuricea* spp., *Corallium rubrum*)

————— MC1.524a Facies with Antipatharia (e.g. *Antipathella*  
*subpinnata*)

MC1.525a Facies with Scleractinia (e.g. *Dendrophyllia* spp., *Madracis*  
*pharensis*)

MC1.526a Facies with Bryozoa (e.g. *Reteporella grimaldii*, *Pentapora*  
*fascialis*)

————— MC1.527a Facies with Polychaeta

————— MC1.528a Facies with Bivalvia

————— MC1.529a Facies with Brachiopoda

————— MC1.52b Coralligenous outerops covered by sediment

————— See MC1.52a for examples of facies

————— MC1.52c Deep banks

~~MC1.521c Facies with Antipatharia (e.g. *Antipathella subpinnata*)~~

~~MC1.522c Facies with Aleyonacea (e.g. *Nidalia studeri*)~~

MC2.5 Circalittoral biogenic habitat

MC2.51 Coralligenous platforms

MC2.511 Association with encrusting Corallinales

MC2.512 Association with Fucales

MC2.513 Association with non-indigenous Mediterranean *Caulerpa* spp.

MC2.514 Facies with small sponges

MC2.515 Facies with large and erect sponges

MC2.516 Facies with Hydrozoa

MC2.517 Facies with Alcyonacea

MC2.518 Facies with Zoantharia

MC2.519 Facies with Scleractinia

MC2.51A Facies with Vermetidae and/or Serpulidae

MC2.51B Facies with Bryozoa

MC2.51C Facies with Ascidiacea ~~MC1.523c Facies with Scleractinia (e.g. *Dendrophyllia* spp.)~~

~~MC1.531d Facies with Heteroscleromorpha sponges~~

MC2.5 Circalittoral biogenic habitat

MC2.51 Coralligenous platforms

MC2.511 Association with encrusting Corallinales

MC2.512 Association with Fucales

MC2.513 Association with non-indigenous Mediterranean *Caulerpa* spp.

MC2.514 Facies with small sponges (sponge ground, e.g. *Ireinia* spp.)

MC2.515 Facies with large and erect sponges (e.g. *Spongia lamella*, *Sarcotragus foetidus*, *Axinella* spp.)

MC2.516 Facies with Hydrozoa

MC2.517 Facies with Alcyonacea (e.g. *Alcyonium* spp., *Eunicella* spp., *Leptogorgia* spp., *Paramuricea* spp., *Corallium rubrum*)

MC2.518 Facies with Zoantharia (e.g. *Parazoanthus axinellae*, *Savalia savaglia*)

MC2.519 Facies with Scleractinia (e.g. *Dendrophyllia* spp., *Madracis pharensis*, *Phyllangiamouchezii*)

MC2.51A Facies with Vermetidae and/or Serpulidae

MC2.51B Facies with Bryozoa (e.g. *Reteporella grimaldii*, *Pentapora fascialis*)

MC2.51C Facies with Ascidiacea

MC3.5 Circalittoral coarse sediment

MC3.51 Coastal detritic bottoms

MC3.511 Association with Laminariales

MC3.512 Facies with large and erect sponges

MC3.513 Facies with Hydrozoa

MC3.514 Facies with Alcyonacea

MC3.515 Facies with Pennatulacea

MC3.516 Facies with Polychaeta (*Salmacina-Filograna* complex included)

MC3.517 Facies with Bivalvia

MC3.518 Facies with Bryozoa

MC3.519 Facies with Crinoidea

MC3.51A Facies with Ophiuroidea

MC3.51B Facies with Echinoidea

MC3.51C Facies with Ascidiacea

MC3.52 Coastal detritic bottoms with rhodoliths

MC3.521 Association with maërl

MC3.522 Association with *Peyssonnelia* spp.

MC3.523 Association with Laminariales

MC3.524 Facies with large and erect sponges

MC3.525 Facies with Hydrozoa

MC3.526 Facies with Alcyonacea

MC3.527 Facies with Pennatulacea

MC3.528 Facies with Zoantharia

MC3.529 Facies with Ascidiacea

~~MC3.52 Coastal detritic bottoms with rhodoliths~~

~~MC3.521 Association with maërl (e.g. *Lithothamnion* spp., *Neogoniolithon* spp., *Lithophyllum* spp., *Spongitesfruticulosa*)~~

~~MC3.522 Association with *Peyssonnelia* spp.~~

~~MC3.523 Association with Laminariales~~

~~MC3.524 Facies with large and erect sponges (e.g. *Spongia lamella*, *Sarcotragusfoetidus*, *Axinella* spp.)~~

~~MC3.525 Facies with Hydrozoa~~

~~MC3.526 Facies with Alcyonacea (e.g. *Aleyonium* spp., *Paraleyoniumspinulosum*)~~

~~MC3.527 Facies with Pennatulacea (e.g. *Veretillumcynomorium*)~~

~~MC3.528 Facies with Zoantharia (e.g. *Epizoanthus* spp.)~~

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### MC3.529 Facies with Ascidiacea

~~32-35.~~ The selection of physical layers to be shown on maps and to be used for following predictive statistical analyses may be an interesting approach within the general framework of mapping coralligenous and rhodolith habitats, ~~reducing, as it would reduce~~ the processing time. However, it is still of little use as only few physical parameters are able to clearly predict the distribution of these two habitats, e.g., bathymetry, slope of the seafloor, ~~and~~ nutrient input ~~for coralligenous~~ and phosphate concentration for coralligenous, geostrophic velocity of sea surface current, silicate concentration, and bathymetry for rhodoliths (Martin et al., 2014).

~~33-36.~~ The data integration and modelling ~~is-are~~ often ~~a~~ necessary ~~step~~ because indirect visual or remote sensing surveys from vessels are limited due to time and costs involved, and only rarely allow obtaining a complete coverage of the study area. Coverage under 100% automatically means that it is impossible to ~~obtain-get~~ high resolution maps and therefore interpolation procedures ~~have~~ ~~to~~must be used, so that from partial surveys a lower resolution map can be obtained. Spatial interpolation is a statistical procedure for estimating data values at unsampled sites between locations where actual data have been collected ~~on locations~~. For elaborating the final distribution map of benthic habitats on a GIS platform, different spatial interpolation tools (e.g., Inverse Distance Weighted, Kriging) can be used and are provided by the GIS software. Even though this is rarely mentioned, it is important to provide information on the number and the percentage of data acquired on field and the percentage of interpolations run.

~~34-37.~~ The processing and digital analysis of acoustic data on GIS allows creating charts where each tonality of grey is associated ~~to~~ with a specific texture representing a type of habitat or substrate, also on the basis of the *in situ* observations. Although remote sensing data must be always integrated by a great amount of field visual inspections for ground-truthing, especially given the 3-D distribution and complexity of the coralligenous seascape developing over hard substrates, high quality bathymetric data often constitutes an indispensable and appreciated element.

~~35-38.~~ To facilitate the comparison among maps, the standardized red colour is generally used for the graphic representation of coralligenous and rhodolith habitats. On the resulting maps the habitat distributional range (its boundaries and bathymetric limits) and its total extent (expressed in square meters or hectares) can be defined. ~~This~~ ~~ese~~ maps could also be ~~also~~ compared with previous historical available data from literature to evaluate any changes experienced by benthic habitats over ~~a period of~~ time (Giakoumi et al., 2013). Using the overlay vector methods on GIS, a diachronic analysis can be done, where temporal changes are measured in terms of percentage gain or loss of the habitat extension, through the creation of concordance and discordance maps (Canessa et al., 2017).

~~36-39.~~ Finally, reliability of the map produced should be evaluated. No evaluation scales of reliability have been proposed for coralligenous and rhodolith ~~ss~~ habitat mapping; however, scales of reliability evaluation available for seagrass meadows can be adapted also for these two habitats (see the "Guidelines for monitoring marine vegetation in the Mediterranean" ~~Guidelines on marine vegetation~~ ~~-in this document~~ for further details). These scales usually ~~take into account~~ consider the processing of sonograms, the scale of data acquisition and restitution, the methods adopted, and the positioning system.

**b) COMMON INDICATOR 2: Condition of the habitat's typical species and communities**

*Approach*

~~37.40.~~ 37.40. Monitoring ~~are~~is necessary for conservation purposes, which require efficient management measures to ensure that marine benthic habitats, their constituent ~~species~~species, and their associated communities are and remain in ~~a satisfactory~~a good ecological status. The good state of health of both coralligenous and rhodolith habitats will then reflect the Good Environmental Status (GES) pursued by the Contracting Parties to the Barcelona Convention under the Ecosystem Approach (EcAp) and under the Marine Strategy Framework Directive (MSFD).

~~38.41.~~ 38.41. Monitoring the condition (i.e., the ecological status) of coralligenous and rhodolith habitats is today mandatory also because:

- Two maërl forming species, *Phymatolithon calcareum* and *Lithothamnion corallioides*, are protected under the EU Habitats Directive (92/43/ EEC) in the Annex V;
- Coralligenous reefs and rhodoliths seabeds are listed among the “special ~~habitat~~habitat types” needing rigorous protection by the ~~p~~Protocol concerning the Specially Protected Areas and Biological Diversity in the Mediterranean (SPA/BD Protocol) of the Barcelona Convention.

~~39.42.~~ 39.42. According to the EcAp, the CI2 fixed by the Integrated Monitoring and Assessment Programme and related Assessment Criteria (IMAP) guidelines and related to “biodiversity” (EO1) is aimed at providing information about the condition (i.e., ecological status) of coralligenous and rhodoliths habitats, ~~as they being represent~~ two ~~of the main~~ hotspots of biodiversity in the Mediterranean (UNEP/MAP, 2008). The MSFD (2008/56/EC) included both “biological diversity” (D1) and “seafloor integrity” (D6) as descriptors to be evaluated for assessing the GES of the marine environment. In this regard, biogenic structures, such as coralligenous reefs and rhodoliths seabeds, have been recognized as important biological indicators of environmental quality.

~~40.43.~~ 40.43. A defined and standardized procedure for monitoring the status of coralligenous and rhodoliths habitats, comparable to that provided for their mapping, should follow these three main steps:

- a. Initial planning, to define objective(s), duration, sites to be monitored, descriptors to be evaluated, sampling strategy, human, technical and financial needs;
- b. Setting-up the monitoring system and realisation of the monitoring program. This phase includes costs for going out to sea during field activities, equipment for sampling, and human resources. To ensure effectiveness of the program, field activities should be planned during a favourable season, and it would be preferred to ~~repeat monitor~~monitoring during the same season;
- c. ~~M~~Monitoring over time and data analysis. ~~During these activities, is a step where clear~~ robust scientific competences are needed because the acquired data must be interpreted. Duration of the monitoring, ~~in order~~ to be useful, must be medium time at least.

~~41.44.~~ 41.44. The objectives of the monitoring are primarily linked with the conservation of ~~bio-constructed-genic~~ habitats, but they also answer to the necessity of using them as ecological indicators of the marine environment quality. The main aims of the monitoring programs are generally:

- Preserve and conserve the heritage of bioconstructions, ~~with the aim of ensuring that~~ ensure that coralligenous and rhodoliths habitats are in ~~a satisfactory~~a good ecological status (GES), ~~and also~~ and identify as early as possible any degradation of these habitats or any changes in their distributional range and extent. Assessment of the ecological status of these habitats allows measuring the effectiveness of local or regional policies in terms of management of the coastal environment;

- Build and implement a regional integrated monitoring system of the quality of the environment, as requested by the ~~Integrated Monitoring and Assessment Programme and related Assessment Criteria (IMAP)~~ during the implementation of the EcAp in the framework of the Mediterranean Action Plan (UNEP/MAP, 2008). The main goal of IMAP is to gather reliable quantitative and updated data on the status of marine and coastal Mediterranean environment.

~~42. Evaluate effects of any coastal activity and construction likely to impact coralligenous and rhodoliths habitats during environmental impact assessment (EIA) procedures. This specific kind of monitoring aims to establish the condition of the habitat at the time “zero” (i.e., before the beginning of activities), then the state of health of the habitat is monitored during the development of the work phase or at the end of the phase, to check for any impact on the environment evaluated as changes in the habitat state of health. The EIA procedure is not intended as a typical monitoring activity, although it provides the state of the system at the “zero” time, which can be very useful in the time series obtained during a monitoring programme. Unfortunately, most of the EIA studies are qualitative and are often performed by environmental consultants without specialized personnel, using unspecific guidelines and without following any standardised procedure, which prevent their use in effective monitoring programs. This type of monitoring aims to establish the condition of the habitat at the time “zero” before the beginning of activities, then monitor the state of health of the habitat during the development works phase or at the end of the phase, to check for any impacts.~~

~~45.~~

~~43-46.~~ The objective(s) of the monitoring system chosen will influence the choices of the monitoring criteria in the following steps (e.g., duration, sites to be monitored, descriptors, and sampling methods; Tab. 2). The duration of the monitoring should be at least medium-long term (minimum 5-10 years long) for heritage conservation and for monitoring environmental quality objectives. The interval of data acquisition could be annual, as most of the typical species belonging to coralligenous assemblages and to rhodoliths beds display slow grow rates and long generation times. In general, and irrespective of the objective advocated, it is judicious to focus initially on a small number of sites that are easily accessible and that can be regularly monitored after short intervals of time. The sites chosen must be: i) representative of the portion of the coastal area investigated, ii) cover most of the possible range of environmental situations (e.g., depth range, slope, substrate type), and iii) include sensitive zones, stable zones, or reference zones with low anthropogenic pressures (i.e., MPAs) and possibly also areas with high pressure related to human activities for comparison. Then, with the experience gained by the surveyors and the means (funds) available, this network could be extended to a larger number of sites. For environmental impact assessment, short term monitoring (generally 1-2 years) is recommended and should be initiated before the interventions (“zero” time), and possibly continued during, or just after the conclusion of the works. A further control monitoring can be made one year after the conclusion. The ecological status of the site subjected to coastal interventions (i.e., the impact site) must be contrasted with the status of at least 2 reference/control sites.

~~44-47.~~ To ensure the sustainability of the monitoring system, the following final remarks must be taken into account considered:

- Identify the partners, competences and means available;
- Planning the partnership modalities (who is doing what? when? and how?);
- Ensure training for the stakeholders so that they can set up standardized procedures to guarantee the validity of the results, and so that comparisons can be made for a given site and among sites;
- Individuate a regional or national coordinator depending on the number of sites concerned for monitoring and their geographical distribution;

- Evaluate the minimum budget necessary for running the monitoring network (e.g., costs for permanent operators, temporary contracts, equipment, data acquisition, processing, and analysis).

### Methods

45-48. Following the preliminary definition of the distributional range and extent of coralligenous and rhodoliths habitats (the previous CI1), the assessment of the condition of the two habitats starts with an overall descriptive characterisation of the typical species and assemblages occurring within each habitat. Monitoring of these two habitats ~~basically~~ relies on underwater diving activities, although this technique gives rise to many operational constraints due to the conditions of the environment in which these habitats develop (e.g., great depths, weak luminosity, low temperatures, presence of currents, etc.). Underwater surveys ~~:- it can must only~~ be done by confirmed and expert scientific divers (for safety), within a limited range of depths (from the surface down to the maximum depths of 30-40 m, according to local rules on safe scientific diving), and over a limited underwater time (Bianchi et al., 2004b; Tetzaff and Thorsen, 2005). ~~Adoption of~~ Adopting new alternative visual investigation tools (e.g., ROVs) allows for a less precise assessment but over larger spatial scales. A first characterisation of the habitat (e.g., species present, abundance, vitality, etc.) can be done by direct visual underwater inspections, indirect ROVs or towed camera ~~video recordings~~ video recordings, or sampling procedures with dredges, grabs or box corers in the case of rhodoliths seabeds. The acoustic methods ~~that were~~ described above are totally inoperative for detailed characterisations of the se habitats, especially for coralligenous. The survey method depends greatly on the scale of the work and the spatial resolution requested (Tab. 2). The complementarityies of these techniques must be ~~taken into account~~ considered when planning an operational strategy (Cánovas-Molina et al., 2016b). A list of the main conspicuous species/taxa or morphological groups recognisable underwater, or on images, in the two habitats is presented in the Annex 1. This species list is not exhaustive but includes species/taxa frequently reported from coralligenous habitat and rhodoliths beds at the Mediterranean scale. Each Contracting Party can regularly improve these lists and chose the most appropriate species/taxa according to its waters geographical situation.

46-49. The use of ROVs or towed cameras can be useful to optimise information obtained and sampling effort (in term of working time) and become essential for monitoring deep coralligenous assemblages and rhodoliths seabeds that developing in the upper mesophotic zone (down to 40 m depth), where scuba diving procedures are usually not recommended. High quality videos and photographs recorded by ROV or towed camera will be analysed in laboratory (also with the help of taxonomists) to list the main conspicuous species/taxa or morphological groups recognisable on images and to evaluate their abundance (coverage or surface area in cm<sup>2</sup>). Videos and photographs can then be archived to create temporal datasets.

47-50. At shallower depths (up to about 30-40 m, and according to local rules for scientific diving), direct underwater visual surveys by scuba diving are strongly recommended. Good experience in underwater diving is requested to operate an effective work at these depths. Scientific divers annotate on their slates the list of the main conspicuous species/taxa characterising the assemblages. Given the complexity of the coralligenous habitat (3-D distribution of species structure and high biodiversity), divers must be specialists in taxonomy of the main coralligenous species to ensure the validity of the information recorded underwater. Photographs or video collected with underwater cameras can be usefully integrated ~~to~~ into visual survey to speed the work (Gatti et al., 2015a). The use of operational taxonomical units (OTUs), or taxonomic surrogates such as morphological groups (lumping species, genera or higher taxa displaying similar morphological features; Parravicini et al., 2010), may represent a useful compromise when a consistent species distinction is not possible (either underwater or on photographs) or to reduce the surveying/analysis time.

48-51. For a rough and rapid characterisation of coralligenous assemblages, semi-quantitative evaluations often give sufficient information (Bianchi et al., 2004b); ~~thus,~~ it is possible to estimate the abundance (usually expressed as % cover) by standardized indices directly *in situ* or using photographs (UNEP/MAP-RAC/SPA, 2008). However, a high-quality and fine characterisation of the assemblages often requires ~~the use of~~ square frames (quadrates) of defined surface or transects (with or without photographs; Piazzi et al., 2018) to collect quantitative data on the assemblages' composition. ~~, or even~~ The sampling by scraping of all the organisms present over a given area ~~for~~ and further laboratory analyses (Bianchi et al., 2004b) represents an alternative. ~~Destructive procedures by scraping which however should /must be avoided because of the importance of to preserve coralligenous ation of this habitat. are not usually recommended on coralligenous being a time-consuming technique and due to the limited available time underwater.~~ *In situ* observation and samples must be done over defined and, possibly, standardized surface areas (Piazzi et al., 2018), and the number of replicates must be adequate and high enough to catch the heterogeneity of the habitat.

49-52. As well as the presence and abundance of a given species, assessing its vitality seems a particularly interesting parameter. The presence of broken individuals (especially of ~~the~~ branching colonies occurring in the intermediate and upper layers of coralligenous, such as bryozoans and gorgonians) and of signs of necrosis and bleaching are important elements to be taken into consideration to assess specific pressures, such as mechanical damages or effects of thermal anomalies (Garrahou et al., 1998, 2001, 2019; Gatti et al., 2012). Finally, the nature of the substrate ~~um~~ (silted up, roughness, interstices, exposure, slope), the temperature of the water, the vagile fauna associated, the coverage by ~~epibionta~~ epibiont, and the presence of invasive species must also be considered to give a clear characterisation of bioconstructed habitats (Harmelin, 1990; Gatti et al., 2012).

Table 2: Synthesis of the main methods used to characterise coralligenous and rhodolith habitats in the Mediterranean, as the first necessary step for defining the Common Indicator 2\_Condition of the habitat’s typical species and communities. When available, the depth range, the surface area surveyed, the spatial resolution, the efficiency (expressed as area surveyed in km<sup>2</sup> per hour), the main advantages and the limits of each tool are indicated, with some bibliographic references.

Methods	Depth range	Surface area	Resolution	Efficiency	Advantages	Limits	References
Remote Operating Vehicle (ROV) <u>or</u> <u>towed camera</u>	From 2 m to over 120 m	Small-Intermediate areas of about 1 km <sup>2</sup> ( <u>larger areas in the case of towed camera</u> )	From 1 m to 10 m	0.025 to 0.01 km <sup>2</sup> /hour	<ul style="list-style-type: none"> <li>• Non-destructive method</li> <li>• Possibility of collecting pictures</li> <li>• Wide bathymetric range</li> <li>• Good identification of facies and associations</li> <li>• Possibility of semi-quantitative/quantitative evaluation</li> <li>• <u>Possibility to collect samples (for ROV)</u></li> </ul>	<ul style="list-style-type: none"> <li>• High cost, major means out at sea</li> <li>• Difficulty of observation and access according to the complexity of the habitat (multilayer assemblages)</li> <li>• Quali-quantitative assessments only on conspicuous species/taxa <u>Need of specialists in taxonomy</u></li> </ul>	Cánovas-Molina et al. (2016a); Enrichetti et al. (2019); Piazzi et al. (2019b)
Underwater <u>diving-visual</u> observation	0 m up to 40 m, according to local rules for scientific diving	Small areas (less than 250 m <sup>2</sup> )	From 1 m	0.0001 to 0.001 km <sup>2</sup> /hour	<ul style="list-style-type: none"> <li>• Non-destructive</li> <li>• Good precision in the identification (taxonomy) and characterisation of the habitat (also its 3D)</li> <li>• Low cost, easy to implement</li> <li>• Possibility to collect samples</li> <li>• Data already available after dive</li> </ul>	<ul style="list-style-type: none"> <li>• Small area inventoried</li> <li>• Very time-consuming underwater activities</li> <li>• Limited operational depths</li> <li>• Highly qualified scientific divers required</li> <li>• Subjectivity of the observer</li> <li>• Quali-quantitative assessments only on conspicuous species/taxa</li> <li>• <u>Need of specialists in taxonomy</u></li> </ul>	Gatti et al. (2012, 2015a); Piazzi et al. (2019a)

Methods	Depth range	Surface area	Resolution	Efficiency	Advantages	Limits	References
Underwater sampling by scraping or collection	0 m up to 40 m, according to local rules for scientific diving	Small areas (less than 10 m <sup>2</sup> )	From 1 m	0.0001 to 0.001 km <sup>2</sup> /hour	<ul style="list-style-type: none"> <li>• Very good precision in the identification (taxonomy) and characterisation of the habitat</li> <li>• All species identified</li> <li>• <i>A posteriori</i> identification</li> <li>• <del>Low cost</del>, Easy to implement</li> </ul>	<ul style="list-style-type: none"> <li>• Destructive method, usually not recommended</li> <li>• Very small area inventoried</li> <li>• Sampling material needed</li> <li>• Limited operational depths</li> <li>• Highly qualified scientific divers required</li> <li>• Very time-consuming underwater activities</li> <li>• <u>Analysis of samples in laboratory very time-consuming</u></li> <li>• <u>Involvement of many taxonomists</u></li> </ul>	Bianchi et al. (2004b)

Underwater <del>diving</del> photography or video recording	0 m up to 40 m, according to local rules for scientific diving	Small areas (less than 250 m <sup>2</sup> )	From 0.1 m	0.0001 to 0.001 km <sup>2</sup> /hour	<ul style="list-style-type: none"> <li>• Non-destructive</li> <li>• Good precision <del>for in</del> the identification (taxonomy) and characterisation of the habitat</li> <li>• <i>A posteriori</i> identification possible</li> <li>• Low cost, easy to implement</li> <li>• Possibility to collect samples</li> <li>• Possibility to create archives</li> </ul>	<ul style="list-style-type: none"> <li>• <del>Need of specialists in taxonomy</del></li> <li>• Small area inventoried</li> <li>• Photographs <del>or and</del> video analysis very time-consuming</li> <li>• Limited operational depths</li> <li>• Highly qualified scientific divers required</li> <li>• <del>Tools to collect photos/video necessary</del></li> <li>• <del>Limited number of species/taxa observed</del></li> <li>• <del>Only 2-D observation</del></li> <li>• <del>Quali-quantitative assessments only on conspicuous species/taxa</del></li> </ul>	Gatti et al. (2015b); Montefalcone et al. (2017); Piazzini et al. (2017a, 2019a); <del>Çinar et al. (2020)</del>
Methods	Depth range	Surface area	Resolution	Efficiency	Advantages	Limits	References
Sampling from vessels with blind grabs, dredges, or box corers	0 m to about 120 m (until the lower limit of the rhodoliths habitat)	Intermediate areas (a few km <sup>2</sup> )	From 1 to 10 m	0.025 to 0.01 km <sup>2</sup> /hour	<ul style="list-style-type: none"> <li>• Very good precision <del>for in</del> the identification (taxonomy) and characterisation of the habitat</li> <li>• <del>All species-identified taken into account</del></li> <li>• <i>A posteriori</i> identification</li> <li>• <del>Low cost, easy to implement</del></li> </ul>	<ul style="list-style-type: none"> <li>• Destructive method, usually not recommended</li> <li>• Small area inventoried</li> <li>• Sampling material needed</li> <li>• Samples analysis in laboratory very time-consuming <del>and costly</del></li> </ul>	UNEP/MAP-RAC/SPA (2015a)



50-53. ~~E~~An effective monitoring should be done at defined intervals over ~~a period of~~ time, even if it could mean ~~a reduced number of fewer~~ sites being monitored. The reference “zero-state” will be ~~then~~ contrasted with data coming from subsequent monitoring periods, always assuring reproducibility of data over time. Thus, the experimental ~~design and~~ protocol ~~has~~ ~~ahave~~ capital importance. ~~The g~~Geographical position of surveys and sampling stations must be located with precision (using buoys on the surface and recording their coordinates with a ~~d~~GPS), and it often requires the use of marks ~~sing~~ underwater (with fixed pickets into the rock) for positioning the ~~square frames-quadrate~~s or transects in the exact original position (~~García-Gómez et al., 2020~~).~~;~~ Finally, even if it cannot be denied that there are logistical constraints linked to the ~~underwater~~ observation of coralligenous and rhodoliths habitats, their long generation time enables sampling to be done at long intervals of time (> 1 year) to monitor them in the long term (Garrabou et al., 2002).

51-54. Although destructive methods (~~total~~-scraping of the substrate ~~with all the~~ organisms present over a given area, ~~dredges, grabs, or box-corers~~) have long been used and recognized as the most suitable approach to describe the structure of assemblages and an irreplaceable method for exhaustive species lists, they are not desirable for long-term regular ~~monitorings~~ ~~monitoring~~ (UNEP/MAP-RAC/SPA, 2008), and especially within MPAs. Moreover, identification of ~~all~~ organisms needs great taxonomic ~~expertise~~ ~~expertise~~ and a long time to analyse samples, making it difficult to process the large number of replicates required for ecological studies and monitoring surveys. It is more suitable to ~~favour~~ ~~favor~~ non-destructive methods, like photographic sampling, ~~ROV survey~~, or direct underwater observation in given areas (using ~~square frames-quadrate~~s or transects) to collect ~~quali~~-quantitative data. These methods do not require sampling of organisms and are therefore ~~absolutely appropriate~~ ~~appropriate~~ for long-term monitoring. ~~The D~~ifferent methods can be used ~~either~~ separately or together, according to the ~~aims-objective~~ of the study, the area inventoried, and means available (Tab. 3). Non-destructive methods ~~are have been~~ increasingly used and, ~~—~~mainly for ~~video and~~ photographic sampling, ~~—~~ enjoy significant technological advances.

Table 3: Comparison ~~between-among~~ three traditional methods used to monitor coralligenous and other bioconstructions (Bianchi et al., 2004b).

<b><i>In situ</i> sampling</b>	
Advantages	Taxonomical precision, objective evaluation, reference samples
Limits	High cost, slow laborious work, intervention of specialists, limited area inventoried, destructive method, <del>depth-limitations when done by divers</del>
Use	Studies integrating a strong taxonomical element
<b>Video or photography</b>	
Advantages	Objective evaluation, can be reproduced, reference samples, can be automated, speedy diving work, <del>big-large</del> area inventoried, non-destructive method, <del>no depth-limitations</del>
Limits	Low taxonomical precision, problem of <i>a posteriori</i> interpretation of pictures
Use	Studies on the biological cycle or over-time monitoring, large depth-range investigated
<b>Underwater visual observation</b>	
Advantages	Low cost, results immediately available, large area inventoried, can be reproduced, non-destructive method
Limits	Risk of taxonomic subjectivity, slow diving work, <del>depth-limitations</del>
Use	Exploratory studies, monitoring of populations, bionomic studies

55. ~~\_\_\_\_\_~~ Differently from seagrass, the descriptors used to ~~evaluate the status of~~ coralligenous assemblages vary greatly from one team to another and from one region to another, as well as their measuring protocols (Piazzi et al., 2019a and references therein). A first standardized sheet for coralligenous monitoring was created in the context of the Natura 2000 programmes, which solved only partially the issues about comparability among data (Fig. 5). However, methods and descriptors

~~taken into account~~considered must be the subject of a standardized protocol. Although many disparities among data acquisition methods still occur, an integrated and standardized procedure named STAR (STAndaRdized\_coralligenous evaluation procedure) for monitoring the condition of coralligenous reefs has recently been proposed (Piazzini et al., 2019a; Gennaro et al., 2020).

*Natura 2000 - Fiche Coralligène - ANTONIOLI 2010 - GIS Posidonie*

- Date : ..... - Observateur : ..... - N° de plongée & site : .....

• **Type de faciès :** *Cystoseira zosteroides*  *Eunicella singularis*   
*Eunicella cavolinii*  *Lophogorgia sarmentosa*   
*Paramuricea clavata*  Autre : .....

• **Gorgone :** Non → Oui

	--	-	+	++	Gorgonaire	Espèce : .....
Toutes les classes de taille					.....cm	.....cm
Nécrose					.....cm	.....cm
Gorgone arrachée					.....cm	.....cm
Epibiontes					.....cm	.....cm
Recrutement (<3cm)					.....cm	.....cm

• **Aspect général :** Non → Oui

	--	-	+	++	Filet	<input type="checkbox"/> Profondeur d'observation des gorgonaires : • Max : • Min :
Sédimentation / vase					<input type="checkbox"/>	
Voiles algales					<input type="checkbox"/>	
Impression de diversité (très coloré)					<input type="checkbox"/>	
Faune cryptique riche					<input type="checkbox"/>	

• **Inventaire :**

Macrophytes	Ichtyofaune
Lithophyllum & Mesophyllum en 3D	Présence d'espèces-cibles avec grands individus
Couverture de <i>Lithophyllum incrusans</i> sans relief	Poissons benthiques ou nectobenthiques
Taches blanches sur Lithophyllum ou Mesophyllum	
Présence d'espèces dressées <i>Halimeda</i> , <i>Udotea</i> ; <i>Cystoseira</i> ...	

• **Observation :**

*Photos quadrats et paysagères à réaliser*



Figure 5: Example of a standardized sheet for coralligenous monitoring created in the context of the Natura 2000 programmes by GIS Posidonie (Antonoli, 2010).

***A standardized protocol for monitoring shallow water (up to 40 m depth) coralligenous habitatreefs***

52-56. The protocol STAR (STAndaRdized\_coralligenous evaluation procedure) (Piazzini et al., 2019a; Gennaro et al., 2020) has been proposed for monitoring the ecological status of coralligenous reefs to obtain information about most of the descriptors used-adopted by-in the different ecological indices that have been developed adopted-to date ~~on coralligenous reefs~~, through a single sampling

effort and data analysis. The CIGESMED protocol, applied in different parts of the Mediterranean (David et al., 2014; Çinar et al., 2020), should also be mentioned.

53-57. Monitoring plans should at first distinguish between the two major bathymetrical ranges where coralligenous reefs develop, i.e., the shallow and the deep reefs, within and deeper than about 40 m depth respectively (UNEP/MAP-RAC/SPA, 2008). In fact, shallow and deep coralligenous habitats can show different structure of assemblages, and they are usually subject to different types of anthropogenic pressures. Shallow reefs can be effectively surveyed by scuba diving, allowing obtaining information about descriptors that cannot be evaluated or measured through any other instrumental methods (Gatti et al., 2012, 2015a). Deep coralligenous reefs can be surveyed only by means of ROV inspections.

54-58. Season: coralligenous assemblages comprise mostly organisms with long life cycles that are subjected to less evident seasonal changes (mainly in water temperature) than shallower assemblages. In contrast, several temporal changes throughout the year have been observed for macroalgal assemblages, and some seasonal erect algae and filamentous species constituting turfs decrease in cover during the cold season. In addition, coralligenous assemblages are often subjected to the invasion of alien macroalgae and most of the invasive macroalgae display seasonal dynamics, thus contributing to modify the structure of coralligenous assemblages. The most widespread invasive species on coralligenous reefs are the turf-forming Rhodophyta *Womersleyella setacea* and the Chlorophyta *Caulerpa cylindracea*. These two species reach their highest abundance between the end of summer and autumn. The seasonal dynamics of native and invasive macroalgae thus suggest planning monitoring activities between April and June, and no more ~~that~~ than once per year.

55-59. Depth and slope: the depth range where coralligenous reefs can develop changes with latitude and characteristics of the water. Moreover, different kinds of assemblages may develop within the depth range of shallow coralligenous reefs. The slope of the rocky substrate is also important to determine the structure of coralligenous assemblages. ~~In order to~~ To define a standardized sampling procedure suitable to collect comparable data, the range of sampling depth and substrate inclination must be fixed. In this context, a depth of around 35 m on a vertical substrate (i.e., slope 85--90°) can be considered as optimal to ensure the presence of coralligenous assemblages in most of the Mediterranean Sea, including the southern areas in oligotrophic waters. Vertical rocky substrates at about 35 m depth can also be easily found near the coast, which is in the zone mostly subjected to anthropogenic impacts.

56-60. Sampling design, sampling surface, and number of replicates: Coralligenous assemblages show a homogeneous structure when subjected to similar environmental conditions, at least within the same geographic area. They are thus characterised by low variability at spatial scales between hundreds of metres to kilometres, while variability at smaller spatial scales (from metres to tens of metres) is usually high (Abbiati et al., 2009; Ferdeghini et al., 2000; Piazzini et al., 2016). These findings suggest planning sampling designs focusing on high replication at small scales (i.e., tens of metres), whereas intermediate or large scales (i.e., hundreds of metres to kilometres respectively) will require fewer replicates.

57-61. The sampling surface is related to the number of replicates and represents an important factor to be considered. A minimum surface suitable to sample coralligenous assemblages has never been established unambiguously, so different replicated sampling surfaces have been proposed depending on the methods adopted (Piazzini et al., 2018 and references therein). Researchers agree that the replicated sampling surface ~~has to~~ must be larger than that utilized for shallow Mediterranean rocky habitats (i.e.,  $\geq 400$  cm<sup>2</sup>; Boudouresque, 1971), since the abundance of large colonial animals that characterise coralligenous assemblages could be underestimated when using small sampling areas (Bianchi et al., 2004b). Independent of the number of replicates, most of the proposed approaches suggest a total sampling area ranging between 5.6 and 9 m<sup>2</sup>. Parravicini et al. (2009) reported that a sufficiently large sampling surface is more important than the specific method (e.g., visual quadrates or photography) to measure human impacts on Mediterranean rocky reef communities. Larger sampling areas with a lower number of replicates are used for seascape approaches (Gatti et al., 2012). On the contrary, most of the proposed sampling techniques for

~~bioecenotie~~biocenotic approaches consider a greater number of replicates with a comparatively smaller sampling area, usually disposed along horizontal transects (Kipson et al., 2011, 2014; Deter et al., 2012; Teixidó et al., 2013; Cecchi et al., 2014; Piazzi et al., 2015; Sartoretto et al., 2017;) or in a square design (3 × 3 square structure) (Çinar et al., 2020). A comparison between ~~these~~ two sampling designs tested in the field showed no significant differences (Piazzi et al., 2019a), suggesting that both approaches can be usefully employed. Thus, three areas of 4 m<sup>2</sup> located tens of metres apart should be sampled, and a minimum of 10 replicated photographic samples of 0.2 m<sup>2</sup> each should be collected in each area by scientific divers, for a total sampling surface area of 6 m<sup>2</sup>. This design can be repeated depending on the size of the study site and allows for the analysis of the data through both seascape and ~~bioecenotie~~biocenotic approaches (see the 'Ecological Indices' paragraph below).

58-62. Sampling techniques: coralligenous assemblages have been usually studied by destructive methods employing the total scraping of the substrate, by photographic methods associated with determination of taxa and/or morphological groups and by visual census techniques. The best results can be obtained integrating photographic sampling and *in situ* visual observations. The former is the most cost-effective method that requires less time spent underwater and allows collecting the large number of samples required for community analysis in a habitat with high spatial variability at small spatial scales. The latter method, using ~~square frames~~frames-enclosing a standard area of the substrate, has been shown equally effective, but requires longer working time underwater (Parravicini et al., 2010), which may represent a limiting factor at ~~the~~ depths where coralligenous assemblages thrive. A rapid visual assessment (RVA) method has been proposed for a seascape approach (Gatti et al., 2012, 2015a). RVA allows capturing additional information compared ~~with to~~ the photographic technique, such as the size of colonies of erect species and the thickness and consistency of the calcareous accretion (see the 'Descriptors' paragraph below). A combination of photographic and visual approaches, using photographic sampling to assess the structure of assemblages and integrating information by collecting a reduced amount of data with the RVA method (i.e., the size of colonies of erect species and the thickness and consistency of the calcareous accretion) is thus suggested.

59-63. Photographic samples analysis: the analysis of photographic samples can be performed by different methods (Piazzi et al., 2019a and reference therein); the use of a very dense grid (e.g., 400 cells) or the manual contouring techniques through appropriate ~~softwares~~software may be useful ~~in order to~~ reduce the subjectivity of the operator's estimate.

60-64. Descriptors:

- *Sediment load.* Coralligenous reefs are particularly exposed to sediment deposition, especially of fine sediments. Both correlative and experimental studies have demonstrated that the increase of sedimentation rate can lead to changes in the structure of coralligenous assemblages, facilitating the spread of more tolerant and opportunistic species and causing the reduction of both  $\alpha$ - and  $\beta$ -diversity. Increased sedimentation may affect coralligenous assemblages by covering sessile organisms, clogging filtering apparatus and inhibiting the rate of recruitment, growth, and metabolic processes. Moreover, sediment re-suspension can increase water turbidity, limiting algal production, and can cause death and removal of sessile organisms through burial and scouring. Thus, the amount of sediment deposited on coralligenous reefs has been considered by several researchers (Deter et al., 2012; Gatti et al., 2012, 2015a) and represents a valuable information, together with biotic descriptors, to assess the ecological quality of a study area. The amount of sediment may be indirectly evaluated as percentage cover ~~o~~in photographic samples, as this method showed consistent results with those obtained through ~~underwater techniques~~measurements of ~~ing directly the~~ sediment deposition (i.e., by a suction pump).
- *Calcareous accretion.* The calcareous accretion of coralligenous reefs may be impaired by human-induced impacts. The growth of the calcareous organisms that deposit calcium carbonate on coralligenous reefs is a slow process that can be easily disrupted by environmental alterations. Thus, the thickness and consistency of the calcareous deposit can be considered an effective indicator of the occurrence of a positive balance in the bioconstruction process (Gatti et al., 2012, 2015a). The thickness and consistency of the calcareous deposit can be measured underwater through a hand-held

penetrometer, with six replicated measures in each of the three areas of about 4 m<sup>2</sup> and located tens of metres apart. For each measure, the hand-held penetrometer marked with a millimetric scale must be pushed into the carbonate layer, allowing the direct measurement of the calcareous thickness. By definition, a penetrometer measures the penetration of a device (a thin blade in this case) into a substrate, and the penetration will depend on the force exerted and on the strength of the material. In the case of a hand-held penetrometer, the force is that of the diver, and thus cannot be measured properly and provides a semi-quantitative estimate only. Supposing that the diver always exerts approximately the same force, the measure of the penetration will provide a rough estimate of the thickness of the material penetrated. A null penetration is indicative of a hard rock and suggests that the biogenic substrate is absent or the ~~bioconstructional~~ bioconstruction process is no longer active; a millimetric penetration indicates the presence of active bioconstruction resulting in a calcareous biogenic substrate; and a centimetric penetration reveals a still unconsolidated bioconstruction.

- *Erect anthozoans.* The long-living erect anthozoans, such as gorgonians, are considered key species in coralligenous reefs, as they contribute to the typical three-dimensional structure of coralligenous assemblages, providing biomass and biogenic substrates and contributing greatly to the aesthetic value of the Mediterranean sublittoral seascape. However, presence and abundance of these organisms may not necessarily be related to environmental quality, but rather to specific natural factors acting at the local scale (Piazzi et al., 2017a). Accordingly, coralligenous reefs without erect anthozoans may anyway possess a good ecological quality status. Most erect species are, however, affected by local or global physical and climatic factors, such as global warming, ocean acidification and increased water turbidity, independent of local measures of protection. Several human activities acting locally, such as fishing, anchoring or scuba diving, may also damage erect species. Thus, where erect anthozoans are structuring elements of coralligenous assemblages, they can be usefully adopted as ecological indicators through the measure of different variables. The size (mean height) and the percentage of necrosis and epibiosis of erect anthozoans should be assessed through the RVA visual approach, measuring the height of the tallest colony for each erect species, and estimating the percentage cover of the colonies showing necrosis and epibiosis signs in each of the three areas of about 4 m<sup>2</sup> and located tens of metres apart.

- *Structure of assemblages.* Coralligenous assemblages are considered very sensitive to human induced pressures (Piazzi et al., 2019a and references therein). Correlative and experimental studies highlighted severe shifts in the structure of coralligenous assemblages subjected to several kinds of stressors. The most effective bioindicators used to assess the ecological quality of coralligenous reefs are erect bryozoans, erect anthozoans, and sensitive macroalgae, such as Udoteaceae, Fucales, and erect Rhodophyta. On the other hand, the dominance of algal turfs, hydroids and encrusting sponges seems to indicate degraded conditions. Thus, the presence and abundance of some taxa/morphological groups may be considered as an effective indicator of the ecological status of coralligenous assemblages. A value of sensitivity level (SL) has been assigned to each taxon/morphological group ~~on the basis of~~ based on its abundance in areas subjected to different levels of anthropogenic stress, with SL values varying within a numerical scale from 1 to 10, where low values correspond to the most tolerant organisms and high values to the most sensitive ones (Piazzi et al., 2017a; Fig. 6). Recently, a method has been proposed to distinguish and measure sensitivity to disturbance (DSL) and sensitivity to stress (SSL), the former causing mortality or physical damage and the latter physiological alteration, of the sessile organisms thriving in coralligenous assemblages (Montefalcone et al., 2017). Discriminate effects of stress from effects of disturbance may allow a better understanding of the impacts of human and natural pressures on coralligenous reefs.

The percentage cover of the conspicuous taxa/morphological groups can be evaluated ~~for on~~ on each photographic sample. The cover values (in %) of each taxon/morphological group are then classified in eight classes of abundance (Boudouresque, 1971): (1) 0 to ≤0.01%; (2) 0.01 to ≤0.1%; (3) 0.1 to ≤1%; (4) 1 to ≤5%; (5) 5 to ≤25%; (6) 25 to ≤50%; (7) 50 to ≤75%; (8) 75 to ≤100%. The overall SL of a sample is then calculated by multiplying the value of the SL of each taxon/group (Fig. 6) for its class of abundance and then summing up all the final values. Coralligenous assemblages are characterised by high biodiversity that is mostly related to the heterogeneity of the biogenic substrate,

which increases the occurrence of microhabitats and exhibits distinct patterns at various temporal and spatial scales. A decrease in species richness (i.e.,  $\alpha$ -diversity) in stressed conditions has been widely described for coralligenous reefs (Balata et al., 2007), but also the number of taxa/morphological groups per sample can be considered a further effective indicator of ecological quality. Thus, the richness ( $\alpha$ -diversity, i.e., the mean number of the taxa/groups per photographic sample) should be computed.

Taxon/group	SL
Algal turf	1
Hydrozoans (e.g. <i>Eudendrium</i> spp.)	2
<i>Pseudochlorodesmis furcellata</i>	2
Perforating sponges (e.g. <i>Cliona</i> spp.)	2
Dyctiotaales	3
Encrusting sponges	3
Encrusting bryozoans	3
Encrusting ascidians (also epibiotic)	3
Encrusting Corallinales, articulated Corallinales	4
<i>Peyssonnelia</i> spp.	4
<i>Valonia</i> spp., <i>Codium</i> spp.	4
Sponges prostrate (e.g. <i>Chondrosia reniformis</i> , <i>Petrosia ficiformis</i> )	5
Large serpulids (e.g. <i>Protula tubularia</i> , <i>Serpula vermicularis</i> )	5
<i>Parazoanthus axinellae</i>	5
<i>Leptogorgia samentosa</i>	5
<i>Flabellia petiolata</i>	6
Erect corticated terete Ochrophyta (e.g. <i>Sporochnus pedunculatus</i> )	6
Encrusting Ochrophyta (e.g. <i>Zanardinia typus</i> )	6
Azooxantellate individual scleractinians (e.g. <i>Leptopsammia pruvoti</i> )	6
Ramified bryozoans (e.g. <i>Caberea boryi</i> , <i>Cellaria fistulosa</i> )	6
<i>Palmophyllum crassum</i>	7
Arborescent and massive sponges (e.g. <i>Axinella polypoides</i> )	7
<i>Salmacina-Filigrana</i> complex	7
<i>Myriapora truncata</i>	7
Erect corticated terete Rodophyta (e.g. <i>Osmundea pelagosae</i> )	8
Bushy sponges (e.g. <i>Axinella damicomis</i> , <i>Acanthella acuta</i> )	8
<i>Eunicella verrucosa</i> , <i>Alcyonium acaule</i>	8
Erect ascidians	8
<i>Corallium rubrum</i> , <i>Paramuricea davata</i> , <i>Alcyonium coralloides</i>	9
Zooxantellate scleractinians (e.g. <i>Cladocora caespitosa</i> )	9
<i>Pentapora fascialis</i>	9
Flattened Rhodophyta with cortication (e.g. <i>Kallymenia</i> spp.)	10
<i>Halimeda tuna</i>	10
Fucales (e.g. <i>Cystoseira</i> spp., <i>Sargassum</i> spp.), <i>Phyllariopsis brevipes</i>	10
<i>Eunicella singularis</i> , <i>Eunicella cavolini</i> , <i>Savalia savaglia</i>	10
<i>Aedonella calveti</i> , <i>Reteporella grimaldii</i> , <i>Smittina cervicomis</i>	10

Figure 6: Values of the sensitivity level (SL) assigned to each of the main taxon/morphological group in the coralligenous assemblages (Piazzi et al., 2017a).

- *Spatial heterogeneity.* Coralligenous assemblages are also characterised by a high variability at small spatial scale, and consequently by high values of  $\beta$ -diversity, which is linked to the patchy distribution of the organisms. Under stressed conditions, the importance of biotic factors in regulating ~~an the distribution of~~ organism's ~~distribution~~ decreases, and ~~their~~ occurrence and abundance mostly follow the gradient of stress intensity (Balata et al., 2005). The loss of structuring perennial species and the proliferation of ephemeral algae lead to widespread biotic homogenization (Balata et al., 2007; Gatti et al., 2015b, 2017), and to a consequential reduction of  $\beta$ -diversity (Piazzi et al., 2016). Thus, the  $\beta$ -diversity of assemblages may be considered a valuable indicator of human pressure on coralligenous reefs.  $\beta$ -diversity, in general, can be calculated through different methods; in the case of coralligenous assemblages, variability of species composition among sampling units (heterogeneity of assemblages) has been measured in terms of multivariate dispersion calculated ~~on the basis of as the~~ distance from centroids (Piazzi et al., 2017a) through permutational analysis of multivariate dispersion (PERMDISP). Thus, any changes in ~~the~~ compositional variability displayed by PERMDISP may be directly interpretable as changes ~~of in the~~  $\beta$ -diversity.

### **Protocol for monitoring *deep water mesophotic (down to 40 m depth) coralligenous habitatreefs***

~~61-65.~~ The use of unmanned vehicles, such as ROVs, may be considered suitable to survey deep coralligenous reefs in mesophotic environments, down to 40 m depth (UNEP/MAP-RAC/SPA, 2008; Cánovas-Molina et al., 2016a; Ferrigno et al., 2017). The Italian MSFD protocol (MATTM/ISPRA, 2016) for monitoring mesophotic coralligenous and rocky reefs includes a standard sampling design conceived to gather various quantitative components, such as the occurrence and extent of the habitat (either biogenic or rocky reefs), the siltation level, and the abundance, condition, and population structure of habitat-forming megabenthic species (i.e., animal forests), as well as presence and typology of marine litter.

~~62-66.~~ Three replicated video-transects, each at least 200 m long, should be collected in each area investigated (Enrichetti et al., 2019). Footages can be obtained by means of a ROV, equipped with a ~~high-definition~~ ~~high-definition~~ digital camera, a strobe, a ~~high-definition~~ ~~video-camera~~ ~~video camera~~, lights, and a 3-jaw grabber. The ROV should also host an underwater acoustic positioning system, a depth sensor, and a compass to obtain georeferenced tracks to be overlapped to multi-beam maps when available. Two parallel laser beams (90° angle) can provide a scale for size reference. ~~In order to~~ ~~To~~ guarantee the best quality of video footages, ROV is expected to move along linear tracks, in continuous recording mode, at constant slow speed ( $< 0.3 \text{ ms}^{-1}$ ) and at a constant height from the bottom ( $< 1.5 \text{ m}$ ), thus allowing for adequate illumination and facilitating the taxonomic identification of the megafauna. Transects are then positioned along dive tracks by means of a GIS software editing. Each video transect is analysed through any of the ROV-imaging techniques, using starting and ending time of the transect track as reference. Visual census of megabenthic species is carried out along the complete extent of each 200 m-long transect and within a 50 cm-wide visual field, for a total of 100 m<sup>2</sup> of bottom surface covered per transect.

~~63-67.~~ From each transect the following parameters are measured on videos:

- Extent of hard bottom, calculated as percentage of total video time showing this type of substrat~~um~~ (rocky reefs and biogenic reefs) and subsequently expressed in m<sup>2</sup>;
- Species richness, considering only the conspicuous megabenthic sessile and sedentary species of hard bottom in the intermediate and canopy layers (*sensu* Gatti et al., 2015a). Organisms are identified to the lowest taxonomic level and counted. Fishes and encrusting organisms are not considered, as well as typical soft-bottom species. Some hard-bottom species, especially cnidarians, can occasionally invade soft bottoms by settling on small hard debris dispersed in the sedimentary environment. For this reason, typical hard-bottom species (e.g., *Eunicella verrucosa*) encountered ~~on in~~ highly silted environments have to be considered in the analysis;

- Structuring species are counted, measured (height expressed in cm) and the density of each structuring species is computed and referred to the hard-bottom surface (as n° of colonies or individuals  $\cdot m^{-2}$ );
- The percentage of colonies with signs of epibiosis, necrosis and directly entangled in lost fishing gears are calculated individually for all structuring anthozoans;
- Marine litter is identified and counted. The final density (as n° of items  $\cdot m^{-2}$ ) is computed considering the entire transect (100 m<sup>2</sup>).

64-68. Within each transect, 20 random high-definition photographs targeting hard bottom must be obtained, and for each of them four parameters are estimated, following an ordinal scale. Modal values for each transect are calculated. Evaluated parameters on photos include:

- Slope of the substrate: 0°, <30° (low), 30°-80° (medium), >80° (high);
- Basal living cover, estimated considering the percentage of hard bottom covered by organisms of the basal (encrusting species) and intermediate (erect species but smaller than 10 cm in height) layers: 0, 1 (<30%), 2 (30-60%), 3 (>60%);
- Coralline algae cover (indirect indicator of biogenic reef), estimated considering the percentage of basal living cover represented by encrusting coralline algae: 0, 1 (sparse), 2 (abundant), 3 (very abundant);
- Sedimentation level, estimated considering the percentage of hard bottom covered by sediments: 0%, <30% (low), 30-60% (medium), >60% (high).

#### ***Protocol for monitoring rhodoliths habitat beds***

65-69. A standardized and common sampling method for monitoring rhodoliths sea beds is not available to date (UNEP/MAP-RAC/SPA, 2008). Mediterranean rhodoliths sea beds appear to possess seem to display more diverse species-assemblages of coralline and peyssonneliacean algae species than their Atlantic counterparts, and to be structured by a suite of combinations of rhodolith shapes and coralline compositions: from monospecific branched growth-forms, to multispecific rhodoliths (Basso et al., 2016). Therefore, the monitoring protocols available for sampling and monitoring rhodoliths in shallow subtidal waters of the Atlantic Ocean cannot be applied as such and require calibration to the Mediterranean specificities.

66-70. A recent proposal of protocol for monitoring rhodoliths beds can be found in Basso et al. (2016). Monitoring of the rhodoliths habitats can be done by underwater diving and direct visual observation, with sampling and following taxa identification in laboratory, as well as by blind sampling from vessel using grabs, dredges, and box corers (Tab. 4). However, surveys using ROVs and towed cameras are also effective because of the great homogeneity of this habitat, although they do not provide a complete quantitative information on composition and abundance of rhodolith community as that provided by destructive sampling techniques. sampling from vessels using blind grabs, dredges or box corers (Tab. 4). Monitoring should address all the variables already described for the first descriptive characterisation of the habitat, with the addition of the a full quantitative description of the rhodoliths community composition, through periodical surveys, including number of typical or indicator species. A decrease in rhodoliths beds extent, live/dead rhodoliths ratio, live rhodoliths percentage cover, associated with changes in the composition of the macrobenthic community (calcareous algal engineers and associated taxa) may reveal potential negative impacts acting on rhodoliths beds. All possible variations in growth form, shape, and internal structure of rhodoliths have been simplified in a scheme with three major categories as focal points along a continuum: 1) compact and nodular pralines; 2) larger and vacuolar box work rhodoliths; and 3) unattached branches (Fig. 75). Each of the three end-members within rhodoliths morphological variability corresponds to a typical (but not exclusive) group of composing coralline algal species and associated biota and it is possibly correlated with environmental variables, among which substrate instability (mainly due to hydrodynamics water movement) and sedimentation rate are the most obvious. Thus, the indication of the percentage cover (in %) by the three live rhodoliths

categories at the surface of each rhodoliths beds is a proxy of the rhodoliths habitat structural and ecological complexity. The high species diversity hosted by rhodoliths beds requires time-consuming and expensive laboratory analysis for species identification. Videos and photos ~~provide~~allow for a less fine assessment on the composition information of a rhodoliths community composition ~~owing due~~ to the absence of conspicuous, easy-to-detect species. Moreover, since most coralline algal species belong to ~~a~~ few genera only, the use of taxonomic ranks higher than species is not useful.

Table 4: Comparison ~~between~~among four traditional methods used to monitor rhodoliths habitat.

<b>Underwater visual observation</b>	
Advantages	Low cost, results immediately available, non-destructive method, reference samples, taxonomical precision, information on the distribution of species
Limits	Work limited as regards to depth, small area inventoried
Use	Exploratory studies, monitoring of assemblages, bionomic studies
<b>Blind sampling (dredges, grabs, <del>or</del> and box corers)</b>	
Advantages	<del>Low cost</del> , easy to implement, taxonomical precision, reference samples, analysis <del>of</del> <u>on the substratum</u> (granulometry, calcimetry, % of organic matter), large depth-range investigated
Limits	Low precision of observation, several replicates needed, limited area inventoried, destructive method, <u>high costs for taxonomic analysis</u>
Use	Localised studies integrating a taxonomical element, validation of acoustic methods
<b>ROV and towed camera</b>	
Advantages	Objective evaluation, reference samples (images), large area inventoried, non-destructive method, information on the distribution of <u>conspicuous</u> species, large depth-range investigated
Limits	High cost, low taxonomical precision, problem of <i>a posteriori</i> interpretation of images, observation only of the superficial layers, little information on the substratum and on the basal layer
Use	Studies on distribution and temporal <u>monitoring change</u> , validation of acoustic methods
<b>Acoustic methods</b>	
Advantages	Very large areas inventoried, information on <u>hydrodynamics-water movement</u> (sedimentary figures), can be reproduced, non-destructive method, large depth-range investigated
Limits	High cost, <u>uncertainties in the interpreting of sonograms interpretations</u> , additional validation (inter-calibration), observation only of the superficial layers, no taxonomical information
Use	Studies over large spatial scales, monitoring of populations, bionomic studies

67.71. When necessary, for a detailed characterization of rhodolith communities, a minimum of three box-cores with opening  $\geq 0.16 \text{ m}^2$  should be collected in each rhodoliths bed at the same depth, and to a depth of about 20 cm of sediment. One additional box-corer sample must be collected within the rhodoliths area with the highest percentage of live cover (~~on the basis of~~based on preliminary ROV surveys that remain necessary to pilot blind samplings from vessel), and the others as far as possible from it, following the depth gradient in opposite directions of the maximum rhodoliths bed extension. In many instances grab samples could be useful, but attention must be paid to seafloor surface disruption and mixing, and the possible loss of material during recovery. In those extreme cases of very coarse material preventing box-core penetration and closure, a grab could be used instead, although it cannot preserve stratification. Once the box-core is recovered a colour photograph of the whole surface of the box-core, at a high enough resolution to recognise the morphology of single live rhodoliths and other conspicuous organisms, must be collected. In

addition, the possible occurrence of heavy overgrowths of fleshy algae that may affect rhodoliths growth rate must be reported. The following descriptors must then be assessed: 1) visual estimation of the percentage cover of live red calcareous algae; 2) visual estimation of the live/dead rhodoliths ratio calculated for the surface of the box-core; 3) visual assessment of the rhodoliths morphologies characterising the sample (Fig. 75); 4) measurement of the thickness of the live rhodoliths layer. According to the specific objective of investigation, the sediment sample is-can then be washed through a sieve (e.g., 0.5 mm mesh) and the sample treated with Rose Bengal to stain living material before being preserved for sorting under a microscope for taxa identification. All live calcareous algae and accompanying phytobenthos and zoobenthos ~~should-could~~ be identified and quantified, ~~in order to allow for the detection of~~ detect variability in space and time, and for any changes after possible impacts. Algal species must be evaluated using a semi-quantitative approach (classes of abundance of algal coverage: absent, 1-20%, 21-40%, 41-60%, 61-80%, >81%). For molecular investigations, samples from voucher rhodoliths morphotypes should be air-dried, and then preserved in silica gel. The sediment sample should be analysed for grain-size (mandatory), and carbonate content.

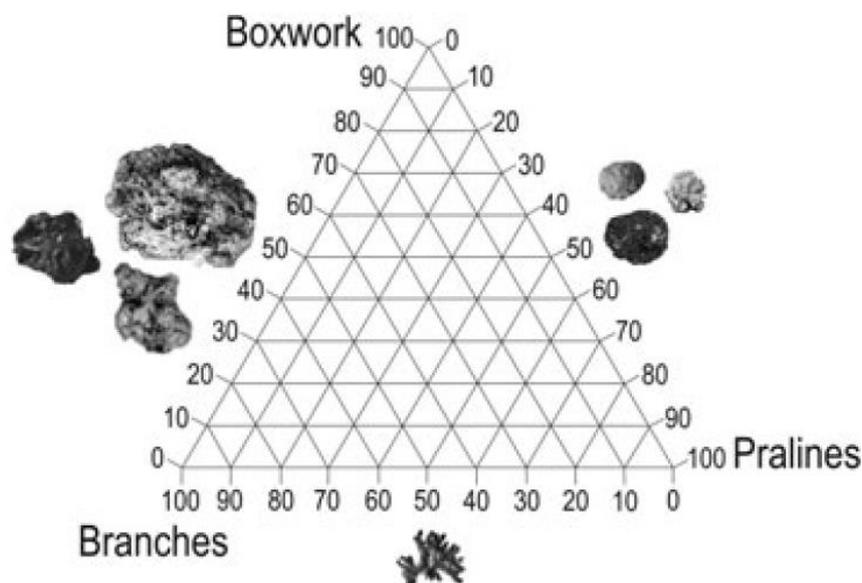


Figure 75: Ternary diagram for the description of the rhodoliths bed-tridimensionality. The percentage cover of each rhodoliths morphotype, relative to the total rhodoliths cover, can be plotted on the correspondent axis. The three main rhodoliths morphotypes (box\_work\_rhodoliths, pralines, and unattached branches) are intended as focal points of a continuum, to which any possible rhodoliths morphology can be approximately assigned. From Basso et al. (2016).

### Ecological indices

68-72. At present, an ecological index to evaluate the status of rhodolith beds has not been proposed yet. On the contrary, to assess the ecological status of coralligenous reefs, several ecological indices have been developed based on different approaches (Kipson et al., 2011, 2014; Teixidó et al., 2013; Zapata-Ramírez et al., 2013; David et al., 2014; Féral et al., 2014; Piazzini et al., 2019a), which are summarised in Table 5. Most of the ecological indices available for monitoring shallow (up to about 40 m depth) coralligenous reefs require underwater surveys by scuba diving. These indices ~~have been developed following different approaches and~~ adopt distinct descriptors and sampling techniques, thus hampering the comparison of data and results, and requiring inter-calibration procedures. However, as described before, the protocol STAR (STAndaRdized coralligenous evaluation procedure; Piazzini et al., 2019a; Gennaro et al., 2020) has been recently

proposed as an effective procedure to obtain standardized data on most of the descriptors adopted in the different ecological indices through a single sampling effort and a shared data analysis. Detailed descriptions of the sampling tools and the methodologies ~~adopted~~ needed to apply for each ecological index listed in Table 5 can be found in the relative bibliographic references.

~~69-73.~~ ESCA (Ecological Status of Coralligenous Assemblages; Cecchi et al., 2014; Piazzini et al., 2015, 2017a, 2021), ISLA (Integrated Sensitivity Level of coralligenous Assemblages; Montefalcone et al., 2017), and CAI (Coralligenous Assessment Index; Deter et al., 2012) indices are based on a ~~bioecoenotic~~ biocenotic approach where coralligenous assemblages are investigated in terms of composition and abundance of all species for ESCA and ISLA, and of percentage cover of mud and builder organisms (i.e., Corallinales, bryozoans, and scleractinians) for CAI.

~~70-74.~~ EBQI (Ecosystem-Based Quality Index; Ruitton et al., 2014) adopts a trophic web approach at the ecosystem level, in which the different functional components are identified, and an ecological status index is measured for each of them.

~~71-75.~~ COARSE (COralligenous Assessment by ReefScape Estimate; Gatti et al., 2012, 2015a) uses a seascape approach to provide information about the structure of coralligenous reefs ~~in order to~~ assess the seafloor integrity. Since the coralligenous is characterised by high heterogeneity, extreme patchiness and coexistence of several biotic assemblages, a seascape approach seems to be the most reasonable solution for its characterisation.

~~72-76.~~ OCI (Overall Complexity Index; Paoli et al., 2016) combines measures of structural and functional complexity, while the INDEX-COR (Sartoretto et al., 2017) integrates three descriptors (the sensitivity of taxa to organic matter and sediment deposition, the observable taxonomic richness, and the structural complexity of assemblages) to assess the health ~~status~~ of coralligenous assemblages.

~~73-77.~~ Inter-calibrations among some of the above listed ecological indices have already been carried out. Comparison between ESCA and COARSE (Montefalcone et al., 2014; Piazzini et al., 2014, 2017a, 2017b), which are the two indices with the greatest number of successful applications to date (Piazzini et al., ~~2014~~ 2017b, 2021), in 24 sites of the NW Mediterranean Sea showed that the two indices provided different but complementary information to determine the intrinsic quality of coralligenous reefs and to detect the effects of human pressures on the associated assemblages. The concurrent use of ESCA and COARSE ~~can~~ is thus ~~be~~ effective in providing information about the alteration of ecological quality of coralligenous reefs. A recent comparison among ESCA, ISLA, and COARSE has also been carried out (Piazzini et al., 2018), which proved that the main differences among indices are linked to the different approaches used, ~~and that with~~ ESCA and ISLA showing ~~the~~ highest ~~by~~ consistency ~~results~~ being based on a ~~bioecoenotic~~ biocenotic approach. Finally, CAI, ESCA, COARSE, and INDEX-COR have been compared in 21 sites along the southern coasts of France (Gatti et al., 2016). Results showed that the four indices are not always concordant in indicating the ecological quality of coralligenous habitats, some metrics being more sensitive than others to the increasing pressure levels.

~~74-78.~~ Comparatively ~~F~~ fewer efforts have been made to ~~define~~ propose ecological indices for mesophotic environments based on ROV footages, resulting in three seascape indices (Tab. 6), namely MAES (Mesophotic Assemblages Ecological Status; Cánovas-Molina et al., 2016a), CBQI (Coralligenous Bioconstructions Quality Index; Ferrigno et al., 2017), and MACS (Mesophotic Assemblages Conservation Status; Enrichetti et al., 2019). MACS is a new multi-parametric index that is composed ~~by~~ of two independent units, the Index of Status (*Is*) and the Index of Impact (*Ii*) following a DPSIR (Driving forces — Pressures — Status — Impacts — Response) approach. The MACS index integrates three descriptors included in the MSFD and listed by the Barcelona Convention to define the environmental status of seas, namely biological diversity, seafloor integrity, and marine litter. The *Is* depicts the ~~bioecoenotic~~ biocenotic complexity of the investigated ecosystem, whereas the *Ii* describes ~~the~~ its impacts, ~~affecting it~~. Environmental status is the outcome of the status of benthic communities plus the ~~effects amount~~ (the number?) of impacts ~~(effects)~~ upon them: the integrated MACS index measures the resulting environmental status of deep coralligenous habitats reflecting the combination of the two units and their ecological significance. The MACS index has

been effectively calibrated on 14 temperate mesophotic reefs of the Ligurian and Tyrrhenian seas, all characterised by the occurrence of temperate reefs ~~but~~ and subjected to different environmental conditions and levels of human pressures.

### Final remarks

75-79. Inventorying and monitoring the condition of coralligenous reefs and rhodoliths seabeds in the Mediterranean constitutes a unique challenge given the ecological and economic importance of these habitats and the threats that hang over their continued existence. Long ignored due to their difficult accessibility and the limited means of investigation, today these habitats are widely included in monitoring programs to assess environmental quality.

76-80. A standardized approach must be encouraged for monitoring the condition of coralligenous reefs and rhodoliths seabeds, and in particular:

- Knowledge on coralligenous reefs and rhodoliths seabeds distribution should be continuously enhanced at the Mediterranean scale, especially in the its Eastern basin, and reference areas/sites should be individuated;
- Long chronological dataset must be envisaged, and a network of Mediterranean experts settled up;
- Monitoring networks, locally managed and coordinated on a regional scale, should be started, and the standardized protocols here proposed should be applied to the entire Mediterranean both on coralligenous reefs and rhodoliths seabeds.

Table 5: Descriptors used in the ecological indices mostly adopted in the regional/national monitoring programs to evaluate environmental quality of shallow water (up to 40 m depth) coralligenous habitat reefs and based on different approaches.

Index	Method	Image analysis	Descriptors
<u>Biocenotic</u>			
ESCA	Photographic samples: 30 photographic quadrates (50 cm × 37.5 cm) in two areas hundreds of metres apart	Software Image J' for the estimation of the % cover of the main taxa and/or morphological groups of sessile macro-invertebrates and macroalgae	3 descriptors: Sensitivity Level of all species (SL); $\alpha$ diversity (diversity of assemblages); $\beta$ diversity (heterogeneity of assemblages)
ISLA	Photographic samples: 30 photographic quadrates (50 cm × 37.5 cm) in two areas hundreds of metres apart	Software Image J' for the estimation of the % cover of the main taxa and/or morphological groups of sessile macro-invertebrates and macroalgae	2 descriptors: Integrated Sensitivity Level of all species (ISL), i.e. Sensitivity Level to <u>stress</u> (SSL) and Sensitivity Level to disturbance (DSL)
CAI	Photographic samples: 30 photographic quadrates (50 cm×50 cm) along a 40 m long transect	Software CPCe 3.6 for the estimation of the % cover by each species	3 descriptors: % cover of mud; % cover of builders; % cover of bryozoans
<u>Ecosystem</u>			
EBQI	Direct <i>in situ</i> observations and samples. A simplified conceptual model of the functioning of the ecosystem with 10 functional compartments		11 descriptors: % cover of builders; % cover of non-calcareous species; abundance of filter and suspension feeders; occurrence of bioeroders and density of sea urchins; abundance of browsers and grazers; biomass of planktivorous fish; biomass of predatory fish; biomass of piscivorous fish; Specific Relative Diversity Index for fish; % cover of benthic detritus matter; density of detritus feeders
<u>Seascape</u>			
COARSE	Direct <i>in situ</i> observations with <u>the</u> Rapid Visual Assessment (RVA): 3 replicated visual estimations over an area of about 2 m <sup>2</sup> each		9 descriptors, 3 per each layer: <u>Basal layer</u> : % cover of encrusting calcified rhodophyta, non-calcified encrusting algae, encrusting animals, turf-forming algae and sediment; amount of boring species marks; thickness and consistency of calcareous layer with a hand-held penetrometer (5 replicates) <u>Intermediate layer</u> : specific richness; n° of erect calcified organisms; sensitivity of bryozoans <u>Upper layer</u> : total % cover of species; % of necrosis of each population; maximum height of the tallest specimen

<u>Index</u>	<u>Method</u>	<u>Image analysis</u>	<u>Descriptors</u>
<i>Integrated</i>			
INDEX-COR	Photographic samples and direct observations: 30 photographic quadrates (60 cm × 40 cm) along two 15 m long transects (15 photos per transect); visual census of marine litter, conspicuous benthic sessile and mobile species (echinoderms, crustacean decapods, and nudibranchs), estimation of the % cover of gorgonians and sponges, % of necrotic gorgonian colonies	Free software photoQuad, using the uniform point count technique	3 descriptors: Taxa Sensitivity level (TS) to organic matter and sediment input; taxonomic richness of conspicuous taxa that <del>were</del> <u>are</u> recognizable visually on photo-quadrates and <i>in situ</i> ; structural complexity of the habitat, defined from the % cover of the taxa belonging to basal and intermediate layers estimated from the photo-quadrates and the % cover of gorgonians and large sponges observed <i>in situ</i> along the transects for the upper layer
OCI	Available detailed maps of benthic habitats		Surface area covered by coralligenous obtained from maps; list of the main taxonomic groups found in the habitat; biomass per unit area of each taxonomic group obtained from the literature. These descriptors are used to compute exergy and specific exergy as a measure of structural complexity, whilst throughput and information as a measure of functional complexity

Table 6: Descriptors used in the ecological indices mostly adopted in the regional/national monitoring programs to evaluate environmental quality of deep water (from about 40 m to about 120 m depth) coralligenous habitat-reefs occurring in the shallow-mesophotic zone.

Index	Method	Image analysis	Descriptors
<i>Seascape</i>			
MAES	ROV survey: 500 m long video transects per area and 20 random high-resolution photographs frontally on the seafloor	VLC program for video and Image J' software for photos	6 descriptors: n° of megabenthic taxa; % biotic cover in the basal layer; density of erect species; average height and % cover of the dominant erect species; % of colonies with epibiosis/necrosis; density of marine litter
CBQI	ROV survey and photographs	VisualSoft software for video and DVDVideoSoft software to obtain random frames every 10 <u>-seconds</u> for quantitative analysis	9 descriptors: % cover of coralligenous on the bottom; n° of morphological groups; density of fan corals; % of colonies with epibiosis/necrosis; % of colonies with covered/entangled signs; % of fishing gear; depth; slope; substrate type
MACS	ROV survey: three replicated video transects, each at least 200 m long, and 20 random high-resolution photographs frontally on the seafloor	VLC program for video and Image J' software for photos	12 descriptors: species richness of the conspicuous megabenthic sessile and sedentary species in the intermediate and canopy layers; % cover of basal encrusting species; % cover of coralline algae; dominance of structuring species; density of structuring species; height of structuring species; % cover of sediment; % of colonies with signs of epibiosis; % of colonies with signs of necrosis; % of colonies <u>-</u> directly entangled in lost fishing gears; density of marine litter; typology of marine litter

## References

- Abbiati M., Airoldi L., Costantini F., Fava F., Ponti M., Virgilio M. 2009. Spatial and temporal variation of assemblages in Mediterranean coralligenous reefs. In: Pergent-Martini C., Bricchet M. (Eds.), Proceedings of the first symposium on the coralligenous and other calcareous bio-concretions of the Mediterranean Sea, Tabarka, Tunisia, 15--16 January 2009. Tunis, Tunisia, UNEP/MAP--RAC/SPA, 34-39.
- [Agnesi S., Annunziatellis A., Inghilesi R., Mo G., Orasi A. \(2020\). The contribution of wind-wave energy at sea bottom to the modelling of rhodolith beds distribution in an off-shore continental shelf. Mediterranean Marine Science, 21 \(2\), 433-441. DOI: <http://dx.doi.org/10.12681/mms.22462>.](#)
- Agnesi S., Annunziatellis A., Cassese M.L., La Mesa G., Mo G., Tunesi L. 2008. Synthesis of the cartographic information on the coralligenous assemblages and other biogenic calcareous formations in the Mediterranean Sea. Avenant N° 3/2008/RAC/SPA en référence au Mémorandum de coopération N° 6/2002/RAC/SPA, 50 pp.+ 4 Annexes.
- Antonioli P.A. 2010. Fiche d'aide à la caractérisation de l'Habitat Natura 2000 Coralligène. GIS Posidonie publ., France.
- Astruch P., Goujard A., Rouanet E., Boudouresque C.F., Verlaque M., Berthier L., Daniel B., Harmelin J.G., Peirache M., Peterka A., Ruitton S., Thibaut T. 2019. Assessment of the conservation status of coastal detrital sandy bottoms in the Mediterranean Sea: an ecosystem-based approach in the framework of the ACDSEA project. In: Langar H., Ouerghi A. (Eds), Proceedings of the 3<sup>rd</sup> Mediterranean Symposium on the conservation of Coralligenous & other Calcareous Bio-Concretions (Antalya, Turkey, 15-16 January 2019), SPA/RAC publ., Tunis, 23-29.
- [Azzola A., Bavestrello G., Bertolino M., Bianchi C.N., Bo M., Enrichetti F., Morri C., Oprandi A., Toma M., Montefalcone M. 2021. Cannot conserve a species that has not been found: the case of the marine sponge \*Axinella polypoides\* in Liguria, Italy. Aquatic Conservation: Marine and Freshwater Ecosystems 31 \(4\), 737-747.](#)
- Balata D., Piazzì L., Benedetti-Cecchi L. 2007. Sediment disturbance and loss of  $\beta$  diversity on subtidal rocky reefs. Ecology 8, 2455-2461.
- Balata D., Piazzì L., Cecchi E., Cinelli F. 2005. Variability of Mediterranean coralligenous assemblages subject to local variation in sediment deposits. Marine Environmental Research 60, 403-421.
- Ballesteros E. 2006. Mediterranean coralligenous assemblages: a synthesis of present knowledge. Oceanography and Marine Biology Annual Review 44, 123-195.
- Basso D., Babbini L., Kaleb S., Bracchi V.A., Falace A. 2016. Monitoring deep Mediterranean rhodolith beds. Aquatic Conservation: Marine and Freshwater Ecosystems 26 (3), 549-561.
- [Bellan-Santini D., Bellan G., Bitar G., Harmelin J.G., Pergent G. 2002. Handbook for interpreting types of marine habitat for the selection of sites to be included in the national inventories of natural sites of conservation interest. RAC/SPA \(Ed.\), UNEP publ., 217 p.](#)
- Bianchi C.N. 2001. Bioconstruction in marine ecosystems and Italian marine biology. Biologia Marina Mediterranea 8, 112-130.
- Bianchi C.N., Ardizzone G.D., Belluscio A., Colantoni P., Diviacco G., Morri C., Tunesi L. 2004a. Benthic cartography. Biologia Marina Mediterranea 10 (Suppl.), 347-370.
- 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. 2004b. Hard bottoms. Biologia Marina Mediterranea 10 (Suppl.), 185-215.
- Bonacorsi M., Clabaut P., Pergent G., Pergent-Martini C. 2010. Cartographie des peuplements coralligènes du Cap Corse - Rapport de mission CAPCORAL, 4 Août--11 Septembre 2010. Contrat Agence des Aires Marines Protégées/GIS Posidonies, 1-34 + Annexes.

- [Bonacorsi M., Pergent-Martini C., Clabaut P., Pergent G. 2012. Coralligenous “atolls”: discovery of a new morphotype in the Western Mediterranean Sea. \*Comptes Rendus Biologies\* 335 \(10-11\), 668-672.](#)
- Boudouresque C.F. 1971. Méthodes d'étude qualitative et quantitative du benthos (en particulier du phytobenthos). *Téthys* 3, 79-104.
- Canessa M., Montefalcone M., Bavestrello G., Povero P., Coppo S., Morri C., Bianchi C.N. 2017. Fishery maps contain approximate but useful information for inferring the distribution of marine habitats of conservation interest. *Estuarine, Coastal and Shelf Science* 187, 74-83.
- Cánovas-Molina A., Bavestrello G., Cau A., Montefalcone M., Bianchi C.N., Morri C., Canese S., Bo M. 2016a. A new ecological index for the status of deep circalittoral Mediterranean megabenthic assemblages based on ROV photography and video footage. *Continental Shelf Research* 121, 13-20.
- Cánovas-Molina A., Montefalcone M., Canessa M., Coppo S., Diviacco G., Morri C., Ferrari M., Cerrano C., Bavestrello G., Bianchi C.N. 2014. Coralligenous reefs in Liguria: distribution and characterization. In: Bouafif C., Langar H., Ouerghi A. (Eds), *Proceedings of the 2nd Mediterranean Symposium on the conservation of Coralligenous and other Calcareous Bio-Concretions* (Portorož, Slovenia, 29-30 October 2014). UNEP/MAP-RAC/SPA, RAC/SPA publ., Tunis, 55-60.
- Cánovas-Molina A., Montefalcone M., Vassallo P., Morri C., Bianchi C.N., Bavestrello G. 2016b. Combining historical information, acoustic mapping and in situ observations: An overview from coralligenous in Liguria (NW Mediterranean Sea). *Scientia Marina* 80 (1), 7-16.
- Cecchi E., Gennaro P., Piazzini L., Ricevuto E., Serena F. 2014. Development of a new biotic index for ecological status assessment of Italian coastal waters based on coralligenous macroalgal assemblages. *European Journal of Phycology* 49, 298-312.
- ~~Cinelli F. 2009. Field survey methods and mapping: 136-139. In: Relini G. (Ed.), *Marine bioconstructions, nature's architectural seascapes*. Italian Ministry of the Environment, Land and Sea Protection, Friuli Museum of Natural History, Udine. *Italian Habitats* 22, 159 p.~~
- [Çinar M.E., Féral J.-P., Arvanitidis C., David R., Taşkin E., Sini M., Dailianis T., Doğan A., Gerovasileiou V., Evcen A., Chenuil A., Dağlı E., Aysel V., Issaris Y., Bakir K., Nalmpanti M., Sartoretto S., Salomidi M., Sapouna A., Açık S., Dimitriadis C., Koutsoubas D., Katağan T., Öztürk B., Koçak F., Erdogan-Dereli D., Önen S., Özgen Ö., Türkçü N., Kirkim F., Önen M. 2020. Coralligenous assemblages along their geographical distribution: testing of concepts and implications for management. \*Aquatic Conservation: Marine and Freshwater Ecosystems\* 30, 1578-1594.](#)
- David R., Arvanitidis C., Çinar, M.E., Sartoretto S., Dogan A., Dubois S., ... Féral J.-P. 2014. CIGESMED protocols: How to implement a multidisciplinary approach on a large scale for coralligenous habitats survey. In: Bouafif C., Langar H., Ouerghi A. (Eds), *Proceedings of the second Mediterranean symposium on the conservation of coralligenous and other calcareous bio-concretions*, Portorož, Slovenia, 29-30 October 2014. UNEP/MAP-RAC/SPA, Tunis, 66-71.
- Deter J., Descamp P., Ballesta L., Boissery P., Holon F. 2012. A preliminary study toward an index based on coralligenous assemblages for the ecological status assessment of Mediterranean French coastal waters. *Ecological Indicators* 20, 345-352.
- Enrichetti F., Bo M., Morri C., Montefalcone M., Toma M., Bavestrello G., Tunesi L., Canese S., Giusti M., Salvati E., Bianchi C.N. 2019. Criteria to assess the environmental status of temperate mesophotic reefs. *Ecological Indicators* 102, 218-229.
- [Evans D., Aish A., Boon A., Condé S., Connor D., Gelabert E., Michez N., Parry M., Richard D., Salvati E., Tunesi L. 2016. Revising the marine section of the EUNIS habitat classification. Report of a workshop held at the European Topic Centre on Biological Diversity, 12-13 May 2016. ETC/BD report to the EEA.](#)

- Féral J.-P., Arvanitidis C., Chenuil A., Çinar M.E., David R., Frémaux A., ... Sartoretto S. 2014. CIGESMED: Coralligenous based indicators to evaluate and monitor the “Good Environmental Status” of the Mediterranean coastal waters, a SeasEra project. In: Bouafif C., Langar H., Ouerghi A. (Eds), Proceedings of the 2nd Mediterranean Symposium on the conservation of Coralligenous and other Calcareous Bio-Concretions (Portorož, Slovenia, 29-30 October 2014). UNEP/MAP—RAC/SPA, RAC/SPA publ., Tunis, 15-21.
- Ferdeghini F., Acunto S., Cocito S., Cinelli F. 2000. Variability at different spatial scales of a coralligenous assemblage at Giannutri Island (Tuscan Archipelago, northwestern Mediterranean). *Hydrobiologia* 440, 27-36.
- Ferrigno F., Russo G.F., Sandulli R. 2017. Coralligenous Bioconstructions Quality Index (CBQI): a synthetic indicator to assess the status of different types of coralligenous habitats. *Ecological Indicators* 82, 271-279.
- [García-Gómez J.C., González A.R., Maestre M.J., Espinosa F. 2020. Detect coastal disturbances and climate change effects in coralligenous community through sentinel stations. \*PloS One\* 15 \(5\), e0231641.](#)
- [Garrabou J., Gómez-Gras D., Ledoux J.B., Linares C., Bensoussan N., López-Sendino P., Bazairi H., Espinosa F., Ramdani M., Grimes S., Benabdi M., Ben Souissi J., Soufi E., Khamassi F., Ghanem R., Ocaña O., Ramos-Esplà A., Izquierdo A., Anton I., Rubio-Portillo E., Barbera C., Cebrian E., Marbà N., Hendriks I.E., Duarte C.M., Deudero S., Díaz D., Vázquez-Luis M., Alvarez E., Hereu B., Kersting D.K., Gori A., Viladrich N., Sartoretto S., Paireud I., Ruitton S., Pergent G., Pergent-Martini C., Rouanet E., Teixidó N., Gattuso J.P., Fraschetti S., Rivetti I., Azzurro E., Cerrano C., Ponti M., Turicchia E., Bavestrello G., Cattaneo-Vietti R., Bo M., Bertolino M., Montefalcone M., Chimienti G., Grech D., Rilov G., Tuney Kizilkaya I., Kizilkaya Z., Eda Topçu N., Gerovasileiou V., Sini M., Bakran-Petricioli T., Kipson S., Harmelin J.G. 2019. Collaborative database to track Mass Mortality Events in the Mediterranean Sea. \*Frontiers in Marine Science\* 6, 707.](#)
- Garrabou J., Perez T., Sartoretto S., Harmelin J.G. 2001. Mass mortality event in red coral (*Corallium rubrum*, Cnidaria, Anthozoa, Octocorallia) population in the Provence region (France, NW Mediterranean). *Marine Ecology Progress Series* 217, 263-272.
- 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.
- Gatti G., Bianchi C.N., Montefalcone M., Venturini S., Diviacco G., Morri C. 2017. Observational information on a temperate reef community helps understanding the marine climate and ecosystem shift of the 1980-90s. *Marine Pollution Bulletin* 114, 528-538.
- Gatti G., Bianchi C.N., Morri C., Montefalcone M., Sartoretto S. 2015a. Coralligenous reefs state along anthropized coasts: application and validation of the COARSE index, based on a Rapid Visual Assessment (RVA) approach. *Ecological Indicators* 52, 567-576.
- Gatti G., Bianchi C.N., Parravicini V., Rovere A., Peirano A., Montefalcone M., Massa F., Morri C. 2015b. Ecological change, sliding baselines and the importance of historical data: lessons from combining observational and quantitative data on a temperate reef over 70 years. ~~*PloS One*~~ *PLOS One* 10 (2), e0118581.
- Gatti G., Montefalcone M., Rovere A., Parravicini V., Morri C., Albertelli G., Bianchi C.N. 2012. Seafloor integrity down the harbour waterfront: first characterisation and quality evaluation of the coralligenous rocky shoals of Vado Ligure (NW Mediterranean Sea). *Advanced in Oceanography and Limnology* 3, 51-67.
- Gatti G., Piazzì L., Schon T., David R., Montefalcone M., Feral J.P., Sartoretto S. 2016. A comparison among coralligenous-based indices for the assessment of the marine ecological quality. The 50<sup>o</sup> European Marine Biology Symposium (EMBS), 26-30 September 2016, Rhodes, Greece.
- [Gennaro P., Piazzì L., Cecchi E., Montefalcone M., Morri C., Bianchi C.N. 2020. Monitoraggio e valutazione dello stato ecologico dell’habitat a coralligeno. Il coralligeno di parete. ISPRA,](#)

[Manuali e Linee Guida n° 191, 64 pp.](#)

Georgiadis M., Papatheodorou G., Tzanatos E., Geraga M., Ramfos A., Koutsikopoulos C., Ferentinos G. 2009. Coralligène formations in the eastern Mediterranean Sea: Morphology, distribution, mapping and relation to fisheries in the southern Aegean Sea (Greece) based on high-resolution acoustics. *Journal of Experimental Marine Biology and Ecology* 368, 44-58.

[Gerovasileiou V., Dailianis T., Panteri E., Michalakis N., Gatti G., Sini M., Dimitriadis C., Issaris Y., Salomidi M., Filiopoulou I., Doğan A., Thierry de Ville d'Avray L., David R., Cinar M., Koutsoubas D., Féral J., Arvanitidis C. 2016. CIGESMED for divers: Establishing a citizen science initiative for the mapping and monitoring of coralligenous assemblages in the Mediterranean Sea. \*Biodiversity Data Journal\* 4, e8692.](#)

Gubbay S., Sanders N., Haynes T., Janssen J.A.M., Rodwell J.R., Nieto A., ... Calix M. 2016. European Red List of habitats. Part 1. Marine habitats. Luxembourg City, European Union Publications Office, Luxembourg.

Harmelin J.G. 1990. Ichtyofaune des fonds rocheux de Méditerranée : structure du peuplement du coralligène de l'île de Port-Cros (parc national, France). *Mésogée* 50, 23-30.

Kenny A.J., Cato I., Desprez M., Fader G., Schuttenhelm R.T.E., Side J. 2003. An overview of seabed-mapping technologies in the context of marine habitat classification. *ICES Journal of Marine Science* 60 (2), 411-418.

Kipson S., Fourt M., Teixidó N., Cebrian E., Casas E., Ballesteros E., ... Garrabou J. 2011. Rapid biodiversity assessment and monitoring method for highly diverse benthic communities: A case study of Mediterranean coralligenous outcrops. *PLoS One* 6, e27103.

Kipson S., Kaleb S., Kružić P., Rajković Ž., Žuljević A., Jaklin A., ... Garrabou J. 2014. Croatian coralligenous monitoring protocol: The basic methodological approach. In: Bouafif C., Langar H., Ouerghi A. (Eds), *Proceedings of the 2nd Mediterranean Symposium on the conservation of Coralligenous and other Calcareous Bio-Concretions* (Portorož, Slovenia, 29-30 October 2014). UNEP/MAP--RAC/SPA, RAC/SPA publ., Tunis, 95-99.

Martin C.S., Giannoulaki M., De Leo F., Scardi M., Salomidi M., Knittweis L., ... Bavestrello G. 2014. Coralligenous and maërl habitats: predictive modelling to identify their spatial distributions across the Mediterranean Sea. *Scientific Reports* 4, 5073.

MATTM/ISPRA. 2016. Programmi di Monitoraggio per la Strategia Marina. Art.11, D.lgs. 190/2010. Schede Metodologiche Modulo 7 - Habitat coralligeno. Ministero dell'Ambiente e della Tutela del Territorio e del Mare, Istituto Superiore per la Protezione dell'Ambiente, Roma, Italia.

Montefalcone M., Cánovas-Molina A., Cecchi E., Guala I., Morri C., Bavestrello G., ... Piazzini L. 2014. Comparison between two methods for the assessment of ecological quality of coralligenous assemblages. *Biologia Marina Mediterranea* 21, 240-241.

Montefalcone M., Morri C., Bianchi C.N., Bavestrello G., Piazzini L. 2017. The two facets of species sensitivity: stress and disturbance on coralligenous assemblages in space and time. *Marine Pollution Bulletin* 117, 229-238.

Montefalcone M., Rovere A., Parravicini V., Albertelli G., Morri C., Bianchi C.N. 2013. Evaluating change in seagrass meadows: a time-framed comparison of Side Scan Sonar maps. *Aquatic Botany* 104, 204-212.

[Montefalcone M., Tunesi L., Ouerghi A. 2021. A review of the classification systems for marine benthic habitats and the new updated Barcelona Convention classification for the Mediterranean. \*Marine Environmental Research\*, in press.](#)

Pérès J.M., Picard J. 1964. Nouveau manuel de bionomie benthique de la Méditerranée. *Recueil des Travaux de la Station Marine d'Endoume* 3, 1-137.

Paoli C., Morten A., Bianchi C.N., Morri C., Fabiano M., Vassallo P. 2016. Capturing ecological

- complexity: OCI, a novel combination of ecological indices as applied to benthic marine habitats. *Ecological Indicators* 66, 86-102.
- Parravicini V., Ciribilli G., Morri C., Montefalcone M., Albertelli G., Bianchi C.N. 2009. Size matters more than method: visual quadrats vs photography in measuring the impact of date mussel collection on Mediterranean rocky reef communities. *Estuarine, Coastal and Shelf Science* 81, 359-367.
- Parravicini V., Micheli F., Montefalcone M., Villa E., Morri C., Bianchi C.N. 2010. Rapid assessment of benthic communities: a comparison between two visual sampling techniques. *Journal of Experimental Marine Biology and Ecology* 395, 21-29.
- Piazzì L., Bianchi C.N., Cecchi E., Gatti G., Guala I., Morri C., Sartoretto S., Serena F., Montefalcone M. 2017b. What's in an index? Comparing the ecological information provided by two indices to assess the status of coralligenous reefs in the NW Mediterranean Sea. *Aquatic Conservation: Marine and Freshwater Ecosystems* 27, 1091-1100.
- Piazzì L., Bianchi C.N., Cecchi E., Gennaro P., Marino G., Montefalcone M., Morri C., Serena F. 2018. Il coralligeno toscano: distribuzione, struttura dei popolamenti e monitoraggio mediante utilizzo di differenti indici di qualità ecologica. In: Benincasa F. (Ed.), *Seventh International Symposium "Monitoring of Mediterranean coastal areas: problems and measurement techniques, Livorno 19-21 June 2018*, 311-316.
- Piazzì L., Cecchi E., Serena F., Guala I., Cánovas-Molina A., Gatti G., ... Montefalcone M. 2014. Visual and photographic methods to estimate the quality of coralligenous reefs under different human pressures. In: Bouafif C., Langar H., Ouerghi A. (Eds), *Proceedings of the 2nd Mediterranean Symposium on the conservation of Coralligenous and other Calcareous Bio-Concretions (Portorož, Slovenia, 29-30 October 2014)*. UNEP/MAP—RAC/SPA, RAC/SPA publ., Tunis, 135-140.
- [Piazzì L., Gennaro P., Cecchi E., Bianchi C.N., Cinti F., Gatti G., Guala I., Morri C., Sartoretto F., Serena F., Montefalcone M. 2021. Ecological status of coralligenous assemblages: ten years of application of the ESCA index from local to wide scale validation. \*Ecological Indicators\* 121, 107077.](#)
- Piazzì L., Gennaro P., Cecchi E., Serena F. 2015. Improvement of the ESCA index for the evaluation of ecological quality of coralligenous habitat under the European Framework Directives. *Mediterranean Marine Science* 16, 419-426.
- Piazzì L., Gennaro P., Cecchi E., Serena F., Bianchi C.N., Morri C., Montefalcone M. 2017a. Integration of ESCA index through the use of sessile invertebrates. *Scientia Marina* 81 (2), 283-290.
- Piazzì L., Gennaro P., Montefalcone M., Bianchi C.N., Cecchi E., Morri C., Serena F. 2019a. STAR: An integrated and standardized procedure to evaluate the ecological status of coralligenous reefs. *Aquatic Conservation: Marine and Freshwater Ecosystems* 29, 189-201.
- Piazzì L., Kaleb S., Ceccherelli G., Montefalcone M., Falace A. 2019b. Deep coralligenous outcrops of the Apulian continental 1 shelf: biodiversity and spatial variability of sediment-regulated assemblages. *Continental Shelf Research*, 172, 50-56.
- Piazzì L., La Manna, G., Cecchi, E., Serena, F., & Ceccherelli, G. (2016). Protection changes the relevancy of scales of variability in coralligenous assemblages. *Estuarine, Coastal and Shelf Science*, 175, 62-69.
- Relini G. 2009. Marine bioconstructions, Nature's architectural seascapes. Italian Ministry of the Environment, Land and Sea Protection, Friuli Museum of Natural History, Udine. *Italian Habitats* 22, 159 pp.
- Relini G., Giaccone G. 2009. Gli habitat prioritari del protocollo SPA/BIO (Convenzione di Barcellona) presenti in Italia. Schede descrittive per l'identificazione / Priority habitat according to the SPA/BIO protocol (Barcelona Convention) present in Italy. Identification sheets. *Biologia Marina*

Mediterranea 16 (suppl. 1), 372 pp.

Riosmena-Rodríguez R., Nelson W., Aguirre J. (Eds). 2017. Rhodolith/maërl beds: a global perspective. Springer International Publishing, Switzerland.

Rossi V., Lo M., Legrand T., Ser-Giacomi E., de Jode A., de Ville d'Avray L.T., ... Chenuil A. 2021. Small-scale connectivity of coralligenous habitats: insights from a modelling approach within a semi-opened Mediterranean bay. Vie et Milieu/Life & Environment, Observatoire Océanologique-Laboratoire Arago, in press.

Ruitton S., Personnic S., Ballesteros E., Bellan-Santini D., Boudouresque C.F., Chevaldonné P., ... Verlaque M. 2014. An ecosystem-based approach to evaluate the status of the Mediterranean coralligenous habitat. In: Bouafif C., Langar H., Ouerghi A. (Eds), Proceedings of the 2nd Mediterranean Symposium on the conservation of Coralligenous and other Calcareous Bio-Concretions (Portorož, Slovenia, 29-30 October 2014). UNEP/MAP-RAC/SPA, RAC/SPA publ., Tunis, 153-158.

Sartoretto S., Schohn T., Bianchi C.N., Morri C., Garrabou J., Ballesteros E., ... Gatti G. 2017. An integrated method to evaluate and monitor the conservation state of coralligenous habitats: the INDEX-COR approach. Marine Pollution Bulletin 120, 222-231.

Savini A., Basso D., Alice Bracchi V., Corselli C., Pennetta M. 2012. Maërl-bed mapping and carbonate quantification on submerged terraces offshore the Cilento peninsula (Tyrrhenian Sea, Italy). Geodiversitas 34, 77-98.

SPA/RAC-UN Environment/MAP, OCEANA, 2017. Guidelines for inventorying and monitoring of dark habitats in the Mediterranean Sea. Gerovasileiou V., Aguilar R., Marín P. (Eds), SPA/RAC-Deep Sea Lebanon Project. UNEP/MAP-SPA/RAC publ., Tunis, 40 pp + Annexes.

SPA/RAC-UN Environment/MAP. 2019a. Updated classification of benthic marine habitat types for the Mediterranean Region. UNEP/MAP-SPA/RAC publ., Tunis, 23 pp.

SPA/RAC-UN Environment/MAP. 2019b. Updated reference list of marine habitat types for the selection of sites to be included in the national inventories of natural sites of conservation interest in the Mediterranean. UNEP/MAP-SPA/RAC publ., Tunis, 20 pp.

Teixidó N., Casas E., Cebrian E., Linares C., Garrabou J. 2013. Impacts on coralligenous outcrop biodiversity of a dramatic coastal storm. PloS One ~~PLoS ONE~~ 8, e53742.

Tetzaff K., Thorsen E. 2005. Breathing at depth: physiological and clinical aspects of diving when breathing compressed air. Clinics in Chest Medicine 26, 355-380.

UNEP/MAP. 2008. Decision IG.17/06: Implementation of the ecosystem approach to the management of human activities that may affect the Mediterranean marine and coastal environment. UNEP(DEPI)/MED IG.17/10. 15th Ordinary Meeting of the Contracting Parties to the Convention for the Protection of the Marine Environment and the Coastal Region of the Mediterranean and its Protocols.

UNEP/MAP-RAC/SPA. 2009. Proceedings of the 1st Mediterranean symposium on the conservation of the coralligenous and other calcareous bio-concretions. Pergent-Martini C., Bricchet M. (Eds), Tabarka, 15-16 January 2009.

UNEP/MAP-RAC/SPA. 2015. Standard methods for inventorying and monitoring coralligenous and rhodoliths assemblages. Pergent G., Agnesi S., Antonioli P.A., Babbini L., Belbacha S., Ben Mustapha K., Bianchi C.N., Bitar G., Cocito S., Deter J., Garrabou J., Harmelin J.-G., Hollon F., Mo G., Montefalcone M., Morri C., Parravicini V., Peirano A., Ramos-Espla A., Relini G., Sartoretto S., Semroud R., Tunesi L., Verlaque M. (Eds), RAC/SPA publ., Tunis, 20 pp. + Annex.

- UNEP/MAP-SPA/RAC. 2017. Action plan for the conservation of the coralligenous and other calcareous bio-concretions in the Mediterranean Sea., [SPA/RAC publ.](#), Tunis, 21 pp.
- ~~UNEP/MAP-RAC/SPA. 2009. Proceedings of the 1st Mediterranean symposium on the conservation of the coralligenous and other calcareous bio-concretions. Pergent-Martini C., Bricchet M. (Eds), Tabarka, 15-16 January 2009.~~
- ~~UNEP/MAP-RAC/SPA. 2015. Standard methods for inventorying and monitoring coralligenous and rhodoliths assemblages. Pergent G., Agnesi S., Antonioli P.A., Babbini L., Belbacha S., Ben Mustapha K., Bianchi C.N., Bitar G., Cocito S., Deter J., Garrabou J., Harmelin J.-G., Hollon F., Mo G., Montefalcone M., Morri C., Parravicini V., Peirano A., Ramos Espla A., Relini G., Sartoretto S., Semroud R., Tunesi L., Verlaque M. (Eds), RAC/SPA publ., Tunis, 20 p. + Annex.~~
- UNEP/MAP-SPA/RAC. 2019. Report of the meeting of experts on the finalization of the classification of benthic marine habitat types for the Mediterranean region and the reference list of marine and coastal habitat types in the Mediterranean. SPA/RAC publ., Tunis, 49 pp.
- Vassallo P., Bianchi C.N, Paoli C., Holon F., Navone A., Bavestrello G., Cattaneo Vietti R., Morri C. 2018. A predictive approach to benthic marine habitat mapping: efficacy and management implications. *Marine Pollution Bulletin* 131, 218-232.
- [Viala C., Lamouret M., Abadie A. 2021. Seafloor classification using a multibeam echosounder: A new rugosity index coupled with a pixel-based process to map Mediterranean marine habitats. \*Applied Acoustics\* 179, 108067.](#)
- Zapata-Ramírez P.A., Huete-Stauffer C., Scaradozzi D., Marconi M., Cerrano C. 2016. Testing methods to support management decisions in coralligenous and cave environments. A case study at Portofino MPA. *Marine Environmental Research* 118, 45-56.
- Zapata-Ramírez P.A., Scaradozzi D., Sorbi L., Palma M., Pantaleo U., Ponti M., Cerrano, C. 2013. Innovative study methods for the Mediterranean coralligenous habitats. *Advances in Oceanography and Limnology* 4, 102-119.

## Annex 2.1

List of the main species to be considered in the inventorying and monitoring of coralligenous and rhodoliths habitats (from UNEP/MAP-RAC/SPA, 2015). Each Contracting Party can regularly improve these lists and chose the most appropriate species according to its geographical situation.

### Coralligenous

(\*invasive; \*\*disturbed or stressed environments, when abundant; \*\*\* protected species)

#### Builders

##### Algal builders

*Lithophyllum cabiochae* (Boudouresque & Verlaque) Athanasiadis, 1999

*Lithophyllum ~~stictiforme~~ ~~stictaeforme~~* (J.E. Areschoug) Hauck, 1877

*Lithothamnion sonderi* Hauck, 1883

*Lithothamnion philippii* Foslie, 1897

*Mesophyllum alternans* (Foslie) Cabioch & M.L. Mendoza, 1998

*Mesophyllum expansum* (Philippi) Cabioch & M.L. Mendoza, 2003

*Mesophyllum macedonis* Athanasiadis, 1999

*Mesophyllum macroblastum* (Foslie) W.H. Adey, 1970

*Neogoniolithon mamillosum* (Hauck) Setchell & L.R. Mason, 1943

*Peyssonnelia rosa-marina* Boudouresque & Denizot, 1973

*Peyssonnelia polymorpha* (Zanardini) F. Schmitz, 1879

*Sporolithon ptychoides* Heydrich, 1897

##### Animal builders

###### Foraminifera

*Miniacina miniacea* Pallas, 1766

###### Bryozoans

*Adeonella* spp. Canu & Bassler, 1930

*Myriapora truncata* Pallas, 1766

*Pentapora fascialis* Pallas, 1766

*Rhynchozoon neapolitanum* Gautier, 1962

*Schizomavella* spp.

*Schizoretepora serratimargo* (Hincks, 1886)

*Smittina cervicornis* Pallas, 1766

~~*Turbicellepora* spp.~~

*Adeonella calveti* Canu & Bassler, 1930

*Smittina cervicornis* Pallas, 1766

~~*Pentapora fascialis* Pallas, 1766~~

~~*Schizoretepora serratimargo* (Hincks, 1886)~~

~~*Rhynchozoon neapolitanum* Gautier, 1962~~

~~*Turbicellepora* spp.~~

###### Polychaeta

~~*Serpula* spp.~~

*Protula tubularia* (Montagu, 1803)

*Spirobranchus polytrema* Philippi, 1844

~~*Serpula* spp.~~

*Spirorbis* sp.

~~*Spirobranchus polytrema* Philippi, 1844~~

###### Cnidaria

*Caryophyllia* (*Caryophyllia*) *inornata* (Duncan, 1878)

*Caryophyllia* (*Caryophyllia*) *smithii* Stokes & Broderip, 1828

~~*Cladocora caespitosa* Linnaeus, 1767~~

~~*Dendrophyllia ramea* Linnaeus, 1758~~

~~*Dendrophyllia cornigera* Lamarck, 1816~~

~~*Hoplangia durotrix* Gosse, 1860~~

~~*Leptopsammia pruvoti* Lacaze-Duthiers, 1897~~

~~*Hoplangia durotrix* Gosse, 1860~~

~~*Madracis pharensis* (Heller, 1868)~~

~~*Polycyathus muelleriae* Abel, 1959~~

~~*Cladocora caespitosa* Linnaeus, 1767~~

~~*Phyllangia americana mouchezii* Lacaze-Duthiers, 1897~~

~~*Dendrophyllia ramea* Linnaeus, 1758~~

~~*Dendrophyllia cornigera* Lamarck, 1816~~

###### Bioeroders

###### Sponges

Clionidae (*Cliona*, Pione)

###### Echinoids

*Echinus melo* Lamarck, 1816

*Sphaerechinus granularis* (Lamarck, 1816)

###### Molluscs

~~*Rocellaria dubia* (Pennant, 1777)~~

*Hiatella arctica* Linnaeus, 1767

*Lithophaga lithophaga* Linnaeus, 1758\*\*\*

*Petricola lithophaga* (Retzius, 1788)

~~*Rocellaria dubia* (Pennant, 1777)~~

###### Polychaetes

~~*Polydora* spp.~~

*Dipolydora* spp.

*Dodecaceria concharum* Örsted, 1843

~~*Polydora* spp.~~

###### Sipunculids

*Aspidosiphon (Aspidosiphon) muelleri muelleri*  
Diesing, 1851  
*Phascolosoma (Phascolosoma) stephensoni*  
Stephen, 1942

### **Other relevant species**

**~~(\*invasive; \*\*disturbed or stressed environments- usually, when abundant)~~**

#### **Algae**

##### **Green algae**

~~*Caulerpa cylindracea* Sonder, 1845\*~~  
~~*Caulerpa taxifolia* (M. Vahl) C. Agardh, 1817\*~~  
~~*Codium bursa* (Olivi) C. Agardh, 1817\*\*~~  
~~*Codium fragile* (Suringar) Hariot, 1889\*~~  
~~*Codium vermilara* (Olivi) Chiaje, 1829\*\*~~  
*Flabellia petiolata* (Turra) Nizamuddin, 1987  
*Halimeda tuna* (J. Ellis & Solander) J.V.  
Lamouroux, 1816  
*Palmophyllum crassum* (Naccari) Rabenhorst, 1868  
~~*Caulerpa cylindracea* Sonder, 1845~~  
~~*Caulerpa taxifolia* (M. Vahl) C. Agardh, 1817\*~~  
~~*Codium bursa* (Olivi) C. Agardh, 1817\*\*~~  
~~*Codium fragile* (Suringar) Hariot, 1889\*~~  
~~*Codium vermilara* (Olivi) Chiaje, 1829\*\*~~

##### **Brown algae**

~~*Acinetospora crinita* (Carmichael) Sauvageau,  
1899\*\*~~  
~~*Cystoseira dubia* -Valiante, 1883\*\*\*~~  
~~*Cystoseira montagnei* var. *compressa* (Eregeovic)  
M. Verlaque, A. Blanfuné, C.F. Boudouresque,  
T. Thibaut & L.N. Sellam, 2017~~  
~~*Cystoseira zosteroides* (Turner) C. Agardh, 1821\*\*\*~~  
~~*Dictyopteris lucida* M.A. Ribera Siguán, A. Gómez  
Garreta, Pérez Ruzafa, Barceló Martí & Rull Lluch,  
2005\*\*~~  
~~*Dictyota* spp.\*\*~~  
~~*Halopteris filicina* (Grateloup) Kützing, 1843~~  
~~*Cystoseira montagnei* var. *compressa* (Eregeovic)  
M. Verlaque, A. Blanfuné, C.F. Boudouresque,  
T. Thibaut & L.N. Sellam, 2017~~  
~~*Laminaria rodriguezii* Bornet, 1888\*\*\*~~  
~~*Halopteris filicina* (Grateloup) Kützing, 1843~~  
~~*Phyllariopsis brevipes* (C. Agardh) E.C. Henry &  
G.R. South, 1987~~  
~~*Stictyosiphon adriaticus* Kützing, 1843\*\*~~  
~~*Stilophora tenella* (Esper) P.C. Silva in P.C. Silva,  
Basson & Moe, 1996\*\*~~  
~~*Stictyosiphon adriaticus* Kützing, 1843\*\*~~  
~~*Dictyopteris lucida* M.A. Ribera Siguán, A. Gómez  
Garreta, Pérez Ruzafa, Barceló Martí & Rull Lluch,  
2005\*\*~~  
~~*Dictyota* spp.\*\*~~

~~*Styopodium schimperi* (Kützing) M. Verlaque &  
Boudouresque, 1991\*~~

~~*Acinetospora crinita* (Carmichael) Sauvageau,  
1899\*\*~~

~~*Stilophora tenella* (Esper) P.C. Silva in P.C. Silva,  
Basson & Moe, 1996\*\*~~

~~*Stictyosiphon adriaticus* Kützing, 1843\*\*~~

**“Yellow” algae (Pelagophyceae)**

~~*Nematochryopsis marina* (J. Feldmann) C. Billard,  
2000\*\*~~

##### **Red algae**

~~*Acrothamnion preissii* (Sonder) E.M. Wollaston,  
1968\*~~

~~*Asparagopsis taxiformis* (Delile) Trevisan de Saint-  
Léon, 1845\*~~

~~*Cryptonemia lomation* (Bertoloni) J. Agardh, 1851~~

~~*Gloiocladia* spp.~~

~~*Halymenia* spp.~~

~~*Kallymenia* spp.~~

~~*Gloiocladia* spp.~~

~~*Leptofaucha coralligena* Rodríguez-Prieto & De  
Clerck, 2009~~

~~*Lophocladia lallemandii* (Montagne) F. Schmitz,  
1893\*~~

~~*Osmundaria volubilis* (Linnaeus) R.E. Norris, 1991~~

~~*Peyssonnelia* spp. (non calcareous)~~

~~*Phyllophora crispa* (Hudson) P.S. Dixon, 1964~~

~~*Ptilophora mediterranea* (H.Huvé) R.E. Norris,  
1987~~

~~*Rodriguezella* spp.~~

~~*Ptilophora mediterranea* (H.Huvé) R.E. Norris,  
1987~~

~~*Kallymenia* spp.~~

~~*Halymenia* spp.~~

~~*Sebdenia* spp.~~

~~*Peyssonnelia* spp. (non calcareous)~~

~~*Phyllophora crispa* (Hudson) P.S. Dixon, 1964~~

~~*Gloiocladia* spp.~~

~~*Leptofaucha coralligena* Rodríguez-Prieto & De  
Clerck, 2009~~

~~*Acrothamnion preissii* (Sonder) E.M. Wollaston,  
1968\*~~

~~*Lophocladia lallemandii* (Montagne) F. Schmitz,  
1893\*~~

~~*Asparagopsis taxiformis* (Delile) Trevisan de Saint-  
Léon, 1845\*~~

~~*Womersleyella setacea* (Hollenberg) R.E. Norris,  
1992\*~~

#### **Animals**

Sponges

*Acanthella acuta* Schmidt, 1862  
*Agelas oroides* Schmidt, 1864  
*Aplysina aerophoba* Nardo, 1843\*\*\*  
*Aplysina cavernicola* Vacelet, 1959\*\*\*  
*Axinella* spp.\*\*\*  
*Calyx nicaeensis* (Risso, 1827)  
*Chondrosia reniformis* Nardo, 1847  
*Clathrina clathrus* Schmidt, 1864  
*Cliona viridis* (Schmidt, 1862)  
*Crambe crambe* (Schmidt, 1862)  
*Dysidea* spp.  
*Fasciospongia cavernosa* (Schmidt, 1862)  
*Haliclona* (*Reniera*) *mediterranea* Griessinger, 1971  
*Haliclona* (*Soestella*) *mucosa* Griessinger, 1971  
*Haliclona* (*Halichoelona*) *fulva* (Topsent, 1893)  
*Hemimyscale columella* Bowerbank, 1874  
*Ircinia oros* Schmidt, 1864  
*Ircinia variabilis* Schmidt, 1862  
*Oscarella* spp.  
*Petrosia* (*Petrosia*) *ficiformis* (Poiret, 1789)  
*Phorbas tenacior* Topsent, 1925  
*Sarcotragus foetidus* Schmidt,  
 1862 *fasciculatus* (Pallas, 1766)  
~~*Sarcotragus spinosulus* -Schmidt, 1862~~  
*Spirastrella cunctatrix* Schmidt, 1868  
*Spongia* (*Spongia*) *officinalis* Linnaeus, 1759\*\*\*  
*Spongia* (*Spongia*) *lamella* Schulze, 1879\*\*\*

Cnidaria

*Aglaophenia kirchenpaueri* (Heller, 1868)  
*Alcyonium acaule* Marion, 1878  
*Alcyonium palmatum* Pallas, 1766  
~~*Antipathes* spp.\*\*\*~~  
~~*Callogorgia verticillata* Pallas, 1766~~  
~~*Cerianthus lloydii* Gosse, 1859~~  
~~*Cerianthus membranaceus* (Gmelin, 1791)~~  
~~*Corallium rubrum* Linnaeus, 1758\*\*\*~~  
~~*Desmophyllum dianthus* (Esper, 1794)~~  
~~*Ellisella paraplexauroides* Stiasny, 1936~~  
~~*Eunicella* spp.~~  
~~*Leptogorgia sarmentosa* Esper, 1789~~  
~~*Madracis pharensis* (Heller, 1868)~~  
~~*Paramuricea clavata* Risso, 1826~~  
~~*Eunicella* spp.~~  
~~*Leptogorgia sarmentosa* Esper, 1789~~  
~~*Madracis pharensis* (Heller, 1868)~~  
~~*Ellisella paraplexauroides* Stiasny, 1936~~  
~~*Antipathes* spp.~~  
*Parazoanthus axinellae* Schmidt, 1862  
*Savalia savaglia* Bertoloni, 1819\*\*\*  
~~*Callogorgia verticillata* Pallas, 1766~~

Polychaeta

*Filograna implexa* Berkeley, 1835  
*Sabella spallanzanii* Gmelin, 1791  
~~*Filograna implexa* Berkeley, 1835~~  
*Salmacina dysteri* Huxley, 1855  
*Protula* spp.

Bryozoans

*Chartella tenella* Hincks, 1887  
*Hornera frondiculata* (Lamarck, 1816)\*\*\*  
*Margaretta cereoides* Ellis & Solander, 1786  
~~*Hornera frondiculata* (Lamarck, 1816)\*\*\*~~

Tunicates

*Aplidium* spp.  
~~*Pseudodistoma cyrnusense* Pérès, 1952~~  
~~*Aplidium* spp. *Cystodytes dellechiaiei* (Della Valle, 1877)~~  
~~*Halocynthia papillosa* Linnaeus, 1767~~  
~~*Herdmania momus* (Savigny, 1816)~~  
~~*Microcosmus sabatieri* Roule, 1885~~  
~~*Pseudodistoma cyrnusense* Pérès, 1952~~  
~~*Halocynthia papillosa* Linnaeus, 1767~~

Molluscs

~~*Cerithium scabridum* Philippi, 1848\*~~  
~~*Charonia lampas* Linnaeus, 1758\*\*\*~~  
~~*Charonia variegata* Lamarck, 1816~~  
~~*Pinna rudis* Linnaeus, 1758\*\*\*~~  
~~*Naria spurca* (Linnaeus, 1758)~~  
~~*Cerithium scabridum* Philippi, 1848\*~~  
~~*Luria lurida* Linnaeus, 1758\*\*\*~~  
~~*Naria spurca* (Linnaeus, 1758)~~  
~~*Pinna rudis* Linnaeus, 1758\*\*\*~~

Decapoda

~~*Dardanus arrosor* (Herbst, 1796)~~  
~~*Maja squinado* Herbst, 1788\*\*\*~~  
~~*Palinurus elephas* Fabricius, 1787\*\*\*~~  
~~*Pilumnus hirtellus* (Linnaeus, 1761)~~  
~~*Scyllarides latus* Latreille, 1803\*\*\*~~  
~~*Maja squinado* Herbst, 1788\*\*\*~~

Echinodermata

*Antedon mediterranea* Lamarck, 1816  
~~*Hacelia attenuata* Gray, 1840~~  
~~*Centrostephanus longispinus* Philippi, 1845\*\*\*~~  
~~*Diadema setosum* (Leske, 1778)\*~~  
~~*Echinaster* (*Echinaster*) *sepositus* (Retzius, 1783)~~  
~~*Hacelia attenuata* Gray, 1840~~  
*Holothuria* (*Panningothuria*) *forskali* Delle Chiaje,  
 1823

*Holothuria (Platyperona) sanctori* Delle Chiaje,  
1823

*Synaptula reciprocans* (Forsskål, 1775)

Pisces

*Anthias anthias* (Linnaeus, 1758)

*Coris julis* (Linnaeus, 1758)

*Chromis chromis* (Linnaeus, 1758)

*Epinephelus* spp.\*\*\*

*Mycteroperca rubra* Bloch, 1793

*Pterois miles* (Bennett, 1828)\*

*Sargocentron rubrum* (Forsskål, 1775)\*

*Seriola dumerili* (Risso, 1810)

*Siganus luridus* (Rüppell, 1829)\*

*Siganus rivulatus* Forsskål & Niebuhr, 1775\*

*Sparisoma cretense* (Linnaeus, 1758)

*Sciaena umbra* Linnaeus, 1758\*\*\*

*Scorpaena scrofa* Linnaeus, 1758

*Raja* spp.\*\*\*

*Torpedo* spp.

*Mustelus* spp.

*Phycis phycis* Linnaeus, 1766

*Serranus cabrilla* Linnaeus, 1758

*Scyliorhinus canicula* Linnaeus, 1758

## Rhodoliths

~~(\*invasive; \*\*disturbed or stressed environments, when abundant; \*\*\* protected species(\*invasive; \*\*disturbed or stressed environments usually, when abundant). Species that can be dominant or abundant are preceded by #)~~

## Algae

### Red algae (calcareous)

~~*Lithophyllum cabiochae* (Boudouresque et Verlaque) Athanasiadis~~

~~*Lithophyllum stictiforme* (J.E. Areschoug) Hauck, 1877~~

~~*Lithothamnion minervae* Basso, 1995~~

~~#*Lithophyllum racemus* (Lamarck) Foslie, 1901~~

~~*Lithophyllum stictiforme* (J.E. Areschoug) Hauck, 1877~~

~~#*Lithothamnion corallioides* (P.L. Crouan & H.M. Crouan) P.L. Crouan & H.M. Crouan, 1867\*\*\*~~

~~*Lithothamnion minervae* Basso, 1995~~

~~#*Lithothamnion valens* Foslie, 1909~~

~~#*Peyssonnelia crispata* Boudouresque & Denizot, 1975~~

~~#*Peyssonnelia rosa marina* Boudouresque & Denizot, 1973~~

~~#*Phymatolithon calcareum* (Pallas) W.H. Adey & D.L. McKibbin ex Woelkerling & L.M. Irvine, 1986~~

~~#*Spongites fruticulosa* Kützing, 1841~~

~~#*Tricleocarpa cylindrica* (J. Ellis & Solander) Huisman & Borowitzka, 1990~~

~~*Lithophyllum cabiochae* (Boudouresque et Verlaque) Athanasiadis~~

~~*Lithophyllum stictiforme* (J.E. Areschoug) Hauck, 1877~~

~~*Lithothamnion minervae* Basso, 1995~~

*Mesophyllum alternans* (Foslie) Cabioch & Mendoza, 1998

*Mesophyllum expansum* (Philippi) Cabioch & Mendoza, 2003

*Mesophyllum philippii* (Foslie) W.H. Adey, 1970

*Neogoniolithon brassica-florida* (Harvey) Setchell & L.R. Mason, 1943

*Neogoniolithon mammosum* (Hauck) Setchell & L.R. Mason, 1943

~~#*Peyssonnelia crispata* Boudouresque & Denizot, 1975~~

~~*Peyssonnelia heteromorpha* (Zanardini) Athanasiadis, 2016~~

~~#*Peyssonnelia rosa-marina* Boudouresque & Denizot, 1973~~

~~#*Phymatolithon calcareum* (Pallas) W.H. Adey & D.L. McKibbin ex Woelkerling & L.M. Irvine, 1986\*\*\*~~

~~#*Spongites fruticulosa* Kützing, 1841~~

~~*Sporolithon ptychoides* Heydrich, 1897~~

~~#*Tricleocarpa cylindrica* (J. Ellis & Solander) Huisman & Borowitzka, 1990~~

~~*Peyssonnelia heteromorpha* (Zanardini) Athanasiadis, 2016~~

~~*Sporolithon ptychoides* Heydrich, 1897~~

### Red algae (non-buildersnon-builders)

~~#*Osmundaria volubilis* (Linnaeus) R.E. Norris, 1991~~

~~#*Phyllophora crispa* (Hudson) P.S. Dixon, 1964~~

~~#*Peyssonnelia* spp. (non-calcareous)~~

*Acrothamnion preissii* (Sonder) E.M. Wollaston, 1968\*

*Alsidium corallinum* C. Agardh, 1827

*Cryptonemia* spp.

*Felicinia marginata* (Roussel) Manghisi, Le Gall, Ribera, Gargiulo & M. Morabito, 2014

*Gloiocladia microspora* (Bornet ex Bornet ex Rodríguez y Femenías) N. Sánchez & C. Rodríguez-Prieto ex Bercibar, M.J. Wynne, Barbara & R. Santos, 2009

*Gloiocladia repens* (C. Agardh) Sánchez & Rodríguez-Prieto, 2007

*Gracilaria* spp.

*Halymenia* spp.

*Kallymenia* spp.

- Leptofaucha coralligena* Rodríguez-Prieto & De Clerck, 2009  
*Nitophyllum tristromaticum* J.J. Rodríguez y Femenías ex Mazza, 1903  
*Osmundea pelagosae* (Schiffner) K.W. Nam, 1994  
[#\*Osmundaria volubilis\* \(Linnaeus\) R.E. Norris, 1991](#)  
[# \*Peyssonnelia\* spp. \(non-calcareous\)](#)  
[#\*Phyllophora crispa\* \(Hudson\) P.S. Dixon, 1964](#)  
*Phyllophora heredia* (Clemente) J. Agardh, 1842  
*Rhodophyllis divaricata* (Stackhouse) Papenfuss, 1950  
*Rytiphlaea tinctoria* (Clemente) C. Agardh, 1824  
*Sebdenia* spp.  
*Vertebrata byssoides* (Goodenough & Woodward) Kuntze, 1891  
*Vertebrata subulifera* (C. Agardh) Kuntze, 1891  
*Womersleyella setacea* (Hollenberg) R.E. Norris, 1992\*

Green algae

- ~~# *Flabellia petiolata* (Turra) Nizamuddin, 1987~~  
*Caulerpa cylindracea* Sonder, 1845\*  
*Caulerpa taxifolia* (M. Vahl) C. Agardh, 1817\*  
*Codium bursa* (Olivi) C. Agardh, 1817  
[# \*Flabellia petiolata\* \(Turra\) Nizamuddin, 1987](#)  
*Microdictyon umbilicatum* (Velle) Zanardini, 1862  
*Palmophyllum crassum* (Naccari) Rabenhorst, 1868  
*Umbraulva dangeardii* M.J. Wynne & G. Furnari, 2014

Brown algae

- # *Arthrocladia villosa* (Hudson) Duby, 1830  
~~# *Laminaria rodriguezii* Bornet, 1888~~  
~~# *Sporochnus pedunculatus* (Hudson) C. Agardh, 1817~~  
*Acinetospora crinita* (Carmichael) Sauvageau, 1899\*\*  
*Carpomitra costata* (Stackhouse) Batters, 1902  
*Cystoseira abies-marina* (S.G. Gmelin) C. Agardh, 1820  
*Cystoseira foeniculacea* (Linnaeus) Greville, 1830  
*Cystoseira foeniculacea* f. *latiramosa* (Ercegovic?) A. Gómez Garreta, M.C. Barceló, M.A. Ribera & J.R. Lluç, 2001  
*Cystoseira montagnei* var. *compressa* (Ercegovic) M. Verlaque, A. Blanfuné, C.F. Boudouresque, T. Thibaut & L.N. Sellam, 2017  
*Cystoseira zosteroides* (Turner) C. Agardh, 1821\*\*\*  
*Dictyopteris lucida* M.A. Ribera Siguán, A. Gómez Garreta, Pérez Ruzafa, Barceló Martí & Rull Lluç, 2005  
*Dictyota* spp.  
*Halopteris filicina* (Grateloup) Kützing, 1843  
~~# *Laminaria rodriguezii* Bornet, 1888\*\*\*~~  
[# \*Lobophora variegata\* \(J.V. Lamouroux\) Womersley ex E.C.Oliveira, 1977](#)

- Nereia filiformis* (J. Agardh) Zanardini, 1846  
*Phyllariopsis brevipes* (C. Agardh) E.C. Henry & G.R. South, 1987  
*Spermatochnus paradoxus* (Roth) Kützing, 1843  
[# \*Sporochnus pedunculatus\* \(Hudson\) C. Agardh, 1817](#)  
*Stictyosiphon adriaticus* Kützing, 1843  
*Stilophora tenella* (Esper) P.C. Silva, 1996  
*Zanardinia typus* (Nardo) P.C. Silva, 2000

**Animals**

Sponges

- Aplysina* spp.\*\*\*

Axinella\_spp.\*\*\*

*Cliona viridis* Schmidt, 1862  
*Dysidea* spp.  
*Haliclona* spp.  
*Hemimycale columella* Bowerbank, 1874  
*Oscarella* spp.  
*Phorbas tenacior* Topsent, 1925  
*Spongia (Spongia) officinalis* Linnaeus, 1759\*\*\*  
*Spongia (Spongia) lamella* Schulze, 1879\*\*\*

Cnidaria

*Adamsia palliata* (Müller, 1776)  
# *Alcyonium palmatum* Pallas, 1766  
~~# *Eunicella verrucosa* Pallas, 1766~~  
# *Paramuricea macrospina* Koch, 1882  
# *Aglaophenia* spp.  
~~*Adamsia palliata* (Müller, 1776)~~  
*Calliactis parasitica* Couch, 1838  
*Cereus pedunculatus* Pennant 1777  
*Cerianthus membranaceus* (Gmelin, 1791)  
# *Eunicella verrucosa* Pallas, 1766  
*Funiculina quadrangularis* Pallas, 1766  
*Leptogorgia sarmentosa* Esper, 1789  
*Nemertesia antennina* Linnaeus, 1758  
# *Paramuricea macrospina* Koch, 1882  
*Pennatula* spp.  
*Veretillum cynomorium* Pallas, 1766  
*Virgularia mirabilis* Müller, 1776

Polychaetes

*Aphrodita aculeata* Linnaeus, 1758  
*Sabella pavonina* Savigny, 1822  
*Sabella spallanzanii* Gmelin, 1791

Bryozoans

*Cellaria fistulosa* Linnaeus, 1758  
*Hornera frondiculata* (Lamarck, 1816)  
*Pentapora fascialis* Pallas, 1766  
*Turbicellepora* spp.

Tunicates

# *Aplidium* spp.  
*Ascidia mentula* Müller, 1776  
*Diazona violacea* Savigny, 1816  
*Halocynthia papillosa* Linnaeus, 1767  
*Microcosmus* spp.  
*Phallusia mammillata* Cuvier, 1815  
*Polycarpa* spp.  
*Pseudodistoma crucigaster* Gaill, 1972  
*Pyura dura* Heller, 1877  
*Rhopalaea neapolitana* Philippi, 1843  
*Synoicum blochmanni* Heiden, 1894

Echinodermata

*Astropecten irregularis* Pennant, 1777

*Chaetaster longipes* (Bruzellius, 1805)  
*Echinaster (Echinaster) sepositus* Retzius, 1783  
*Hacelia attenuata* Gray, 1840  
*Holothuria (Panningothuria) forskali* Delle Chiaje, 1823  
*Leptometra phalangium* Müller, 1841  
*Luidia ciliaris* Philippi, 1837  
*Ophiocomina nigra* Abildgaard in O.F. Müller, 1789  
*Parastichopus regalis* Cuvier, 1817  
*Spatangus purpureus* O.F. Müller 1776  
*Sphaerechinus granularis* Lamarck, 1816  
*Stylocidaris affinis* Philippi, 1845

Pisces

*Mustelus* spp.  
*Pagellus acarne* (Risso, 1827)  
*Pagellus erythrinus* (Linnaeus, 1758)  
*Raja undulata* Lacepède, 1802  
*Scyliorhinus canicula* (Linnaeus, 1758)  
*Squatina* spp.\*\*\*  
*Trachinus radiatus* Cuvier, 1829