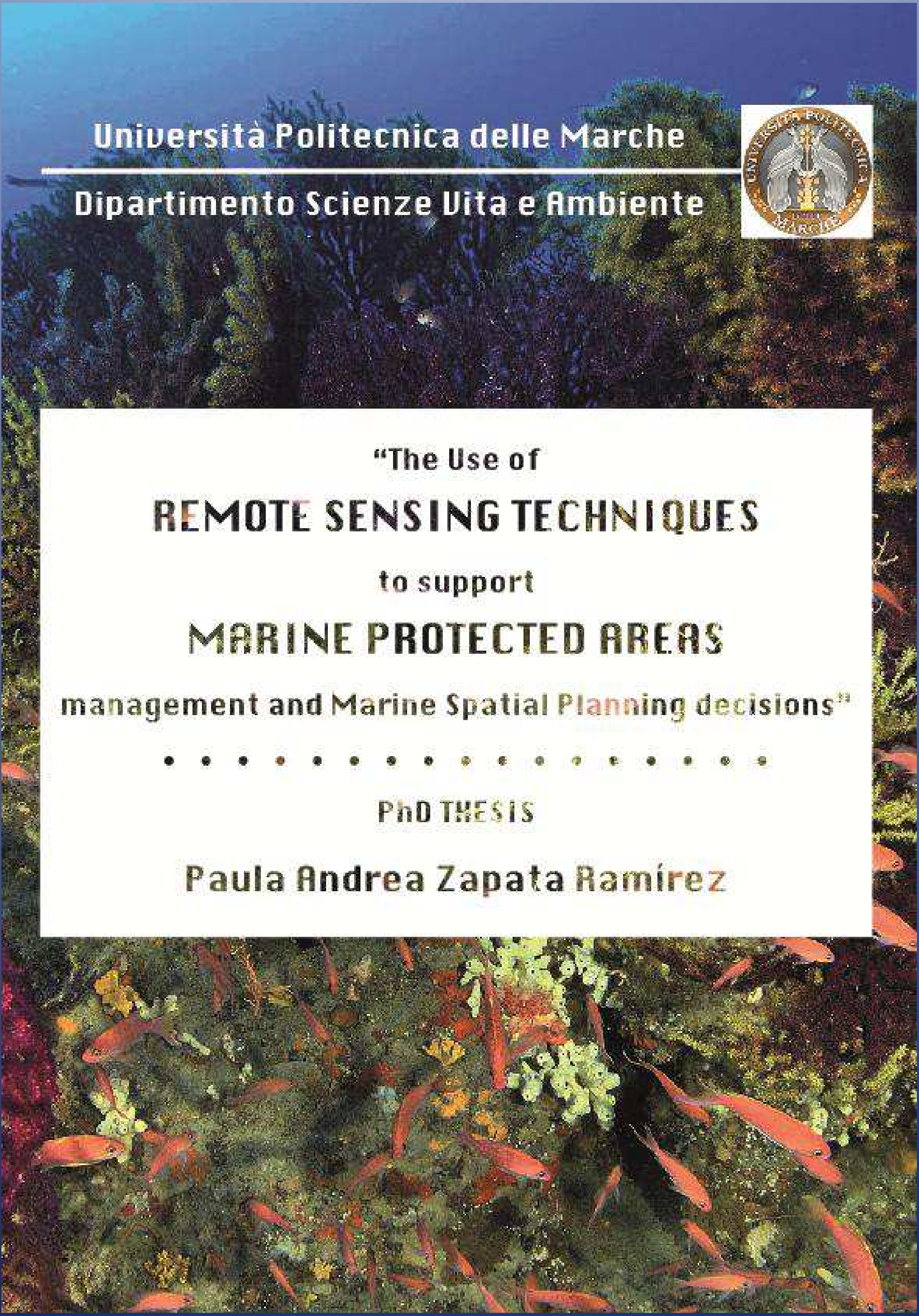

Università Politecnica delle Marche

Dipartimento Scienze Vita e Ambiente

“The Use of
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to support
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management and Marine Spatial Planning decisions”

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PhD THESIS

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PhD Thesis

Paula Andrea Zapata Ramírez

PhD Program in Marine Biology and Ecology

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Contents

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Abstract

The present doctoral degree thesis is based on the implementation of remote sensing (RS) methods habitat mapping and distribution modelling (DMs) techniques as management tools to assess the status of benthic habitats and to support Marine Spatial Planning (MSP) decisions.

A Geographic Information System (GIS) was used to model the spatial boundaries of the physical and biological datasets, as well to assess the proximity of anthropogenic pressures. Through spatial examination, image analysis and underwater video, the biological patterns of habitats/species were related to the variation in geomorphology based on geophysical substrate properties gathered through RS techniques in combination with optical data, collected during the ground truthing sampling. In addition, DMs and classification approaches were applied and their accuracy tested. Finally, a methodological framework was suggested as guideline to inform and provide recommendations to managers and policymakers about how to accurately locate and best protect benthic habitats and its resources, how to evidence possible different sensitivities between habitats in relation to geomorphology, create or redefine different zones or levels of protections at Marine Protected Areas and how to forecast future changes due to global warming and/or anthropogenic activities.

General results demonstrate that the produced maps provide information about where the habitats/species could be present and how they are related to the geomorphological context and/or the anthropogenic pressures. Results emphasize the role of critical expert evaluation of spatial predictions before they are used to guide policy. We conclude that RS and DMs could be very useful tools for understanding the distribution of species–habitat associations and to help resources managers make informed and ecologically relevant decisions.

Sommario

La presente tesi di dottorato prende in considerazione tecniche di rilevamento acustiche (Remote sensing, RS) e ottiche per lo sviluppo di modelli di distribuzione e mappatura (Distribution and mapping modelling, DMS) come strumenti di gestione per valutare lo stato degli habitat bentonici e per supportare decisioni relative alla pianificazione dello spazio marittimo (Marine Spatial Planning). Modelli di distribuzione di habitat e specie sono stati analizzati congiuntamente ad analisi spaziali e analisi di immagine da video subacquei, e messi in relazione alle caratteristiche geomorfologiche del substrato, raccolte tramite RS e validate tramite immersioni di controllo. L'impiego del Sistema Informativo Geografico (GIS) ha permesso di disegnare spazialmente la distribuzione e l'estensione degli habitat così come la distribuzione e l'intensità delle pressioni antropiche, creando quindi un dataset utile a sostenere adeguate scelte gestionali. L'accuratezza dei modelli è stata testata e confrontata. I risultati hanno permesso di definire un quadro metodologico che potrebbe essere facilmente recepito a fini gestionali. Sono infatti state sviluppate delle linee guida da distribuire ai gestori di Aree Marine Protette e ai manger interessati alla gestione della fascia costiera, utili ad invidaure le aree prioritarie in termini di conservazione, sulla base di modelli predittivi che potrebbero suggerire anche eventuali azioni di recupero ambientale. I risultati ottenuti dal presente lavoro mettono quindi in relazione complessità geomorfologica e habitats, permettendo di sviluppare piani di gestione che prendono in considerazione la distribuzione e l'intensità degli impatti antropici.

Introduction

Governmental bodies are increasingly obliged to manage the marine environment under a suite of legislative packages to ensure appropriate and sustainable management of marine ecosystems. In specific, the European Union Marine Strategy Framework Directive (MSFD) requires the Good Environmental Status of marine environments (GES) in Europe's regional seas (Borja et al., 2013; 2014). Faced with the challenge of implementing MSDF conservation goals, policymakers are tackled with the problem of 'the need to know versus the need to act'. In recent years, marine spatial planning (MPS) has gained considerable importance toward to a more knowledgeable of an integrated ecosystem based management of marine areas (Douvere, 2011) with which to address and achieve conservation goals. The concept has emerged as a highly promoted approach to implementing integrated management of coastal and ocean areas. MSP is directly linked to ecosystem based management (EBM), the ecosystem approach to fisheries (EAF), geographic information systems (GIS), marine protected areas (MPAs) among others. As a result, MSP is a promising way to achieve simultaneously social, economic, and ecological objectives by means of a more rational and scientifically-based organization of the use of ocean space (Gilbert et al., 2015).

Effective implementation of ecosystem management and marine spatial planning (MSP) relies on a comprehensive geospatial framework with which to understand the process that determine the observed distribution patterns of species in marine ecosystems as a starting point. In particular, biological, geological and physical information and the mapping of the ecosystem is the first step of MSP and the base for the whole planning and proxies, such as suitable environmental conditions, for any given feature may be needed. This information should contains spatially continuous and broad scale data on the distribution and their interaction, with which to make informed and ecologically relevant decisions. In addition, information about the influence of the location of the human activities on the marine ecosystem combined with detailed spatial data, is required to ensure adequate protection and management of the ecosystems itself. In particular, the MSFD states that “the structure and function of seafloor ecosystems must be safeguarded against harm from human activities”. To achieve this, the MSFD also requires each EU Member State to monitor pressures on the ecosystems and take actions which lead to a ‘good environmental status’ by 2020. Therefore, MSFD offers a crucial opportunity to Member States to build and standardise novel innovative methodological assessments and to incorporate today's state-of-the-art technological developments into current monitoring practices and with which to develop programs of measures designed to achieve or maintain a Good Environmental Status (GES) by 2020.

Remote sensing, habitat mapping and distribution models as tools to support MSP and MPAs management decisions

The use of Remote Sensing (RS) techniques for the production of benthic habitats maps is an essential tool for seabed management and assessing human impacts on marine benthic ecosystems (Harris and Baker, 2012). Maps derivate from remote sensing (RS) techniques have proved to be a cost-effective and productive endeavour to achieve MSFD goals (e.g Connor, 2005; Galparsoro et al., 2013; García-Alegre et al., 2014; Buhl-Mortensen et al.,2015). The resulting maps have the potential to provide a broad-scale synoptic view of benthic environments and species providing temporal data that may be used to assess events in community dynamics (Zapata-Ramirez et al., 2013a) and in long term monitoring practices. As a result, these techniques have proved to be a cost-effective and productive endeavour to achieve management objectives, but until recently, the lack of high-resolution environmental datasets has been a major restriction in the marine realm, in particular below the mesophotic depths. In addition, direct inventories and surveys on these areas are expensive and time-consuming and are therefore impractical to conduct over extensive seascapes (Zapata-Ramirez et al., 2013a and reference therein). However, recent developments in the last couple of decades on new state-of-the-art technology is now available for the visualisation and investigation of sea bed structures and biological communities-species, and for precision sampling in rugged terrain. While deeper areas are still considered a difficult environment to work in, the advantage of sophisticated acoustic mapping (e.g. multibeam sonars) and submersibles with high-resolution video and sampling capabilities has revolutionised our ability to accurately geo-referenced and describe different benthic habitats in challenging zones. Additionally, the implementation of distribution models (DM) procedures have resulted in an increased availability of environmental data (Dutertre et al., 2013; Giusti et al., 2014; Gormley et al., 2013; Greathead et al., 2014) with which to explore the relationships between abiotic and biotic patterns. Furthermore, DMs relate the presence of habitats/species in a location to a set of environmental variables, which then allows predicted distributions to be mapped across an entire region (Reiss et al., 2015). In this context, DMs based on habitat-species/environment relationships provides a potentially useful way to synthesise information from scattered samples into coherent maps of distributions of species and habitats, ecological goods, and services (Reiss et al., 2015). More specifically these tools can be applied (i) to explore the possible effects of climate change on benthic species distribution patterns (Elith et al., 2011), (ii) to assess habitat distributions in areas that, due to their complexity, are difficult to study and therefore have limited data availability (Fourcade et al., 2014), (iii) to estimate the most suitable areas for a species and infer probability of presence in regions where no systematic surveys are available (Martin et al., 2014), (iv) to illustrate how human impacts interact with their distribution (Bandelj et al., 2009; Martinez et al., 2012) and (v) to identify optimal sites for restoration initiatives (Elsäßer et al., 2013; Valle et al., 2015).

The integration of habitat mapping techniques and DM approaches will allow the development and application of appropriate management strategies providing benefits in terms of scale, consistency, and volume of data collected; potentially providing a means to address some of the key questions inhibiting wider use of these models in MSP and the assessment of species vulnerability to climate change (Piroddi et al., 2015; Reiss et al., 2015). As a result, if the distribution of marine habitats is known, then the spatial distribution of the potential environmental or anthropogenic risks of impact can be estimated, thereby helping to identify the most efficient management (Stelzenmüller et al., 2010) and monitoring solutions.

OBJECTIVE AND STRUCTURE OF THE THESIS

In specific, the present study is concerned with the application of RS techniques and biological data to map and model marine benthic habitats in MPAs that could support MSP activities. In particular, the study focus on two important temperate reefs at Portofino's MPA: i) Coralligenous habitats and ii) Rocky shore indicator species located at Portofino MPA as case study.

i) Coralligenous habitats

Coralligenous habitats provide several essential ecological, economic and cultural services. While scientific knowledge about their structure, functioning and responses to stressors has increased exponentially over the past decade, the state of this habitats has declined during this period, at a comparable rate in many places (Zapata-Ramirez et al., 2013b). Their importance have been recognised under different international, European and national conservation frameworks (e.g. Habitats Directive; European Water Framework Directive) and as protected habitats in the EC Regulation No. 1967/2006 concerning management measures for the sustainable exploitation of fishery resources (European Commission, 2006).

Their habitats are of special interest in the Mediterranean sea because they represent one of the "hot-spots" of biodiversity importance, around 20% of Mediterranean species, and have great structural and functional complexity (Ballesteros 2006). Furthermore, these environments are considered of great significance for fisheries and CO_2 regulation (Zapata-Ramirez et al., submitted and references therein). The species that dominate coralligenous seascapes are encrusting calcareous algae, sponges, cnidarians, bryozoans and tunicates (Ballesteros 2006; Kipson et al., 2011). Some of these species have a slow structural dynamics and high longevity (Ballesteros 2006; Teixidó et al. 2011). Therefore the low vitality of this community involves a vulnerability to various disturbances such as destructive fishing practices, pollution, invasive species or mass mortality outbreaks (Cerrano et al. 2000, Coma et al., 2004, UNEP-MAP-RAC/SPA, 2008, Garrabou et al., 2009).

Fishing activities, have been shown to damage or destroy long-lived emergent epifaunal animals such as corals and sponges, harming the three-dimensional complexity of the seabed, and subsequently reducing species diversity and faunal biomass (Zapata-Ramirez et al., 2013a). Thus, these habitats are in urgent need of efficient monitoring and management programs to sustain their biological, economic and cultural values for the global community. The first step in managing any threat is to understand it, a barrier to develop management plans in coralligenous environments is that they distribution remain poorly characterized because of the difficulties associated with its exploration and therefore they have not been mapped with sufficient accuracy and at spatial resolutions high enough to support their efficient management and conservation (Agnesi et al., 2008; Pergent, 2011). Furthermore, there is a missing consensual methodology for its monitoring and no environmental or ecological quality indexes have been established (UNEP-MAP-RAC/SPA, 2011; EUROPEAN COMMISSION: SEC, 2011). Knowledge on the distribution, biodiversity and its relation with functioning is therefore crucial for providing information relevant to the identification and implementation of technical options for their conservation and sustainable use (EUROPEAN COMMISSION: SEC, 2011). In order to improve our knowledge about this environments and to set up effective management and protection schemes, high quality benthic/habitat maps are essential, both at a large scale, indicating assemblages occurrence within the Mediterranean basin (e.g. Martin et al., 2014), and at a more local scale (e.g. Agnesi et al., 2008) detailing the spatial distribution of coralligenous vitality and status (pristine vs. damaged). Further development of predictive habitat mapping techniques is also necessary to guide the exploration for the known and the unknown coralligenous areas around the Mediterranean basin. In addition, as management schemes become established, it will become important to follow-up the coralligenous status and recovery with repeated surveys (e.g monitoring) and habitat mapping efforts (EUROPEAN COMMISSION: SEC, 2011).

ii) Rocky shore indicator species

Similar tendencies are currently occurring at rocky shore species. In particular, loss of forests of *Cystoseira amentacea* (a protected species) has been observed in many coastal areas. Coastal urbanization, marine pollution and outbreak of herbivores (i.e. sea urchins and herbivorous fish) are some of the most important factors affecting marine forests (for a review see Mineur et al., 2015). *Cystoseira* species are listed in two European Conventions (Barcelona Convention, 1976 and Bern Convention, 1979), but very few tangible focussed actions have been carried out so far for their conservation, monitoring and management, especially as concern the assessment of indicator species distribution or the establishment of marine protected areas (MPAs). An exception is the cartography of *Cystoseira* belts in the infra-littoral fringe performed to assess the ecological status of coastal waters using the CARLIT index, under the Water Framework Directive (WFD) 2000/60/EU (Ballesteros et al., 2007, Mangialajo et al., 2007). However, this index is often performed only on limited stretches of the rocky coastlines hampering the assessment and monitoring at more large scales. Therefore, it is extremely important to increase our knowledge on rocky shore indicator species, updating maps on their distribution at more large scales, following their evolution over time and, if necessary, considering restoration (Gianni et al., 2013) in the case of important engineering species like *Cystoseira amentacea.*

In agreement with MSFD (2008/56/EC) and in line with Directive 2007/2/EC of the European Parliament, it is necessary and appropriate to provide the development of criteria and specifications for methodological standards to guarantee consistency and to allow for comparison between marine regions or sub-regions of the extent to which good environmental status (GES) is being achieved (Piha and Zampoukas, 2011). **Consequently, the main objectives of this thesis are**:

i) Test the potential of the remote sensing, habitat mapping and distribution modelling techniques to detect the importance of different environmental variables (EVs), that define the distribution of temperate reefs (coralligenous assemblages and rocky shore species)at Portofino's MPA, that can contribute to the baseline information regarding presence and distribution of the Specially Protected Areas of Mediterranean Importance (SPAMI), and regarding processes/functions that characterized the habitats.

ii) Develop, test and validate a rapid and cost-effective standardized monitoring tools to improve our understanding of ecosystem and biodiversity changes, for integration into a unique and holistic assessment that can be applicable to a wide array of Mediterranean MPAs.

iii) Assess the resulting maps as potential tools in management strategies that could contribute to the MSDF requirements.

iv) Provide an easy and understandable guideline to inform and provide recommendations to managers and policymakers about how to best protect coralligenous resources, how to create or redefine different zones or levels of protections at Marine Protected Areas (MPA's) and how to forecast future changes due to global warming and/or anthropogenic activities.

The thesis is divided in six chapters:

Chapter 1- Innovative study methods for the Mediterranean coralligenous habitats.

This chapter described the state of the art of the different methodologies currently applied on benthic habitats, in particular focused on diverse assessments currently used in "reef" environments The study identified still photographs and video mosaics as the most suitable in situ data collection method for benthic habitats. Optical-based methods (i.e. video and stills cameras) are becoming more commonly used in research because they collect data quickly reducing the time spent underwater, provide high-resolution images of the organisms and cover large areas quickly (Van Rein et al., 2011; McKinnon et al., 2011). In addition, they generate permanent survey records, achieve greater sampling objectivity than traditional diver observations and have a low environmental impact in sensitive areas of conservation importance (Lirman et al., 2007; He et al., 2012).

Chapter 2 – Innovative strategy and process for underwater data gathering and results elaboration.

This chapter is focused in the application of in situ optical techniques and their process. In order to investigate the monitoring potential of the still photographs and video mosaics method to collect in situ data, we randomly sampled different zones at Portofino MPA. All field activities were conducted using conventional SCUBA. Two calibrated Go-pro Hero2 video camera and one Go-Pro Hero 2 to collect pictures were used to gather the in situ optical information. In collaboration of the engineering team of the Dipartimento di Ingegneria dell'Informazione, of Università Politecnica delle Marche the chapter describes the design and realization of a device, called DiRAMa, and the relative architecture for data gathering in underwater environments. The device is planned to make the image and data acquisition easy, and let the user upload all the information on an appropriate Web Server as soon as an Internet connection is available. As a result of DiRAMa implementation we obtained mosaics with a ground resolution of 1–2 mm per pixel with which identify coral colonies and/or other benthic components (e.g corals, sponges) useful to detect changes in species composition at very high resolution.

Chapter 3- A multi approach to map and model the distribution of coralligenous and cave environments. A case study at Portofino Marine Protected Area (Ligurian Sea, Italy).

This chapter focused in the methodological assessment applied to map and model the distribution of coralligenous and cave habitats. Data collected with a Multibeam Echosounder System (MBES) in combination with optical data, collected during the ground truthing sampling, and following the methodology proposed by the in situ optical techniques previously described in chapter 2 were used. The chapter tackled the difficulties to accurately map and explore Coralligenous, Caves and Overhangs on the case study. We show how MBES were used in combination with optical data, to map these bioconcretions with acceptable accuracy and discriminate the main habitat types. Nevertheless, in areas where large changes in the geomorphology over short distances happened, especially near the notches, caves and overhangs some misclassification as well as an increase in the prediction error of the classification occurred, probably due to the standard deployment of the MBES's orientation. However, and despite these limitations, the results demonstrate that the produced habitat map and the DM technique provide critical information about where the habitats could be present and how they are related to the geomorphological context.

Chapter 4- Using Maxent to understand and predict the distribution of coralligenous environments

This chapter describes a conference paper presented at the 2nd Mediterranean Symposium on the conservation of Coralligenous & other Calcareous Bio-Concretions (Portorož, Slovenia, 29-30 October 2014), pp 183-188". The paper evaluate the potential of the Machine Learning Technique MaxEnt to evaluate the distribution of coralligenous environments at Portofino MPA. The model was selected because it provides a straightforward mathematical formulation to model the distribution of species based on presence only data and available habitat variables. The reason behind this selection at first glance was based on the associated difficulties to collect absence data due to the depth constraints of coralligenous habitats (-30 to -150m), which therefore make the field campaign expensive to gather absence data. Results show that the method is simple and cost-effective becoming an optimal solution for extended monitoring by the combination of innovative and new tech tools.

Chapter 5- Modelling the distribution of rocky shore indicator species and its relation to the geomorphology and anthropogenic pressures at Portofino MPA

In collaboration with colleagues from Université Nice-Sophia Antipolis this chapter is focused on the performance of DM to map the distribution of rocky shore indicator species at Portofino MPA. Similar methodological assessments previously described in chapter 3 were used in combination with data collected by the CARLIT method and adding anthropogenic variables that could also contribute with the distribution patterns of the indicator species. Results indicated that slope, rugosity and depth are the most contributing variables for Cystoseira amentacea distribution. While sites close to anthropogenic stressors are favourable for more competitive species (e.g: Ulva lactuca and Mytilus galloprovincialis). Results also shown that the species selected as indicators have proved to be appropriate for the type of pressure tackled.

Chapter 6- Guidelines for monitoring measures of coralligenous assemblages within a Management context

This chapter provided a methodological framework for the implementation of monitoring measures for coralligenous assemblages. The guideline offers a summary of the PhD document in easy and understandable steps. The aim is to inform and provide recommendations to managers and policymakers about how to best protect coralligenous resources, how to create or redefine different zones or levels of protections at Marine Protected Areas (MPAs) and how to forecast future changes due to global warming and/or anthropogenic activities. The application of the standardized methodological framework could strength management efficiency and will help to make the best decision a local scale that also take into consideration the broader regional contacts and in that way, help to achieve or maintain a GES for 2020.

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Chapter 1

Innovative study methods for the Mediterranean coralligenous habitats

Abstract

Coralligenous habitats are of special interest in the Mediterranean Sea because they represent one of the most important biodiversity 'hot-spots' and are considered of great relevance for fisheries activities in the region. Despite their importance, however, there are missing consensual methodologies for their monitoring and, despite some attempts, no environmental or ecological quality indices have been established yet. This situation could be related to the difficulties associated with their exploration and their spatial heterogeneity. These habitats are in urgent need of efficient standard monitoring and management protocols programmes to develop an effective network for their conservation. Here we reviewed the available methodologies and robotics tools used to evaluate and monitor benthic habitats, highlighting the importance of defining rapid cost-effective sampling and analyses approaches and architectures for future monitoring of changes in coralligenous habitats based on current technological developments. We identified still images acquisitions as the most effective data gathering system. Stereo photogrammetry, photomosaic elaboration and three-dimensional (3D) modelling may largely improve the data analysis and therefore the quality status assessment of the coralligenous habitats. The advantage and efficiency of different approaches and methods, and whether they should be applied and standardised for further monitoring activities, were discussed.

Keywords: quality status; underwater mapping; impact assessment; Mediterranean.

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1. Introduction

The Mediterranean Sea is an attractive region with 70 million inhabitants concentrated in its coastal cities with an additional 175 million tourists visiting every year as a holiday destination. This crowd generates important financial gains, but also places drastic pressure on marine ecosystems. The 46,000 km of coastline of the basin hosts key habitats such as meadows of Posidonia oceanica, down to 40–50 m in depth, mainly on sandy bottoms, and coralligenous assemblages, which form biogenic rims and banks down to 130 m depth [1]. In particular, coralligenous habitats are of special interest in the Mediterranean Sea because they represent a key spot of biodiversity, hosting around 20% of the Mediterranean species, and having great structural and functional complexity [1]. These habitats are also considered of high relevance for fisheries activities in the region. They result from a multi-stratified accretion, made of macroalgae and invertebrates' mineral skeletons, under a dynamic equilibrium between builders (i.e. rhodophythes, scleractinians, bryozoans, serpulids, etc.) and borers, represented mainly by clionaids and allied sponges [2,3]. Whenever either of these actions prevails, it favours the accretion or the erosion of these bioconstructions respectively.

Radiocarbon analyses allowed the initial formation of these bioconstructions to be dated back to the early Holocene or to the late Pleistocene periods. They seem to appear during the last great transgression, caused by the general increase in temperature at the end of the warm period [4]. The species that dominate coralligenous seascapes are encrusting calcareous algae, sponges, cnidarians, bryozoans and tunicates [1,5]. Some of these species are slow growing (e.g. red coral 0.006–0.83 mm year 1) with high longevity [1,6,7] and they give high stability to the whole assemblage, especially regarding edaphic conditions. Therefore the complexity of this community involves a vulnerability to various disturbances such as destructive fishing practices, pollution, diving, storm impacts associated with climate change, invasive species, ocean acidification or mass mortality outbreaks [8–13]. Bottom trawling and artisanal fishery, in particular, have been shown to damage or destroy long-lived erected invertebrates such as corals and sponges, harming the three-dimensional complexity of the seabed, and subsequently reducing species diversity and faunal biomass [14–15]. The disturbance due to mass mortality outbreaks has become more frequent since 1999, affecting more than 30 benthic species (mainly filter feeders) over hundreds of kilometres of the NW Mediterranean coast [8,11,16]. There are different studies that have provided information on the effects of these impacts [7,9,11,17–22]. However, there is little quantitative information of the mortality rates of these groups, and changes in the community regarding the coralligenous composition and coverage of different species. Clearly, there is an urgent need to improve the scientific background that will underpin policy decisions concerning the sustainable management of coralligenous habitats. The Mediterranean basin requires such decisions to be taken in line with its strategic objective of sustainable development (e.g. European Habitat Directive, 92/43/EEC; Barcelona 2000; Water Framework Directive, 2000/60/EC, Marine Strategy Framework Directive, 2008/56/EC), and its global commitments to the Convention of Biological Diversity (Rio, 1992). These initiatives have to meet the challenges of efficient monitoring and management programmes to sustain their biological, economic and cultural values for the global community. An action plan for the conservation of the coralligenous and other calcareous bioconcretions in the Mediterranean Sea was established in the framework of the Barcelona Convention [10]. The first step in managing any threat is to understand it. A barrier to development of management plans in coralligenous habitats is that their distribution remains poorly characterised because they have not been mapped with sufficient accuracy and with spatial resolutions high enough to support their efficient management and conservation [23–25]. Even if we have an overall knowledge about the composition of the Mediterranean coralligenous assemblages [1,24,26], the absence of cartographical data and associated species on the overall distribution of these assemblages is one of the greatest lacunae from the conservation point of view [23,27]. Most of the cartographic information is based on surveys carried out in the north-western Mediterranean Sea [e.g. 25,28] and there is an evident lack of data and a poor representation of these habitats in the southern and eastern Mediterranean Sea

[29]. This situation could be related to the difficulties associated with their exploration, their spatial heterogeneity and with the limited means of investigation. Current research on coralligenous habitats often lacks coordination, consensual monitoring and effective environmental or ecological quality indices [5,25,30–32]. Furthermore, the fragmented geopolitical scenario characterising the Mediterranean basin still leads to weak, uncoordinated, conflicting approaches, and there are not existent regulatory frameworks, policy mechanisms and enforcement [27].

Knowledge of the distribution, biodiversity and its relation with functioning of the coralligenous habitats is therefore crucial for providing information relevant to the identification and implementation of technical options and for their conservation and sustainable use [31]. In order to address this management requirement and to set up effective management and protection schemes, there is an urgent need to develop robust methods for mapping these habitats and to establish their geographical location, extent, and condition. High quality benthic/habitat maps, both at a regional scale [e.g. 23], indicating assemblage occurrence within the Mediterranean basin, and at a more local scale [e.g. 33] detailing the spatial distribution of coralligenous vitality and status (pristine vs. damaged) are essential. Further development of predictive habitat mapping techniques is also necessary to guide the exploration for the known and the unknown coralligenous areas around the Mediterranean basin. In addition, as management schemes become established, it will become important to follow-up the coralligenous status and recovery with repeated surveys (e.g. monitoring) and habitat mapping efforts [31]. The results of the mapping efforts in these environments would provide clarity and coordination among plans to better inform decision makers. Thereby, the review attempts to evaluate the advantages and efficiency of different approaches and methods used to map and monitor benthic habitats and whether they should be applied and standardised for further coralligenous monitoring activities

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2. Classic survey methods

Ever more sophisticated methods have been used to study and map the benthic environments (eg. [30, 34]). Classic survey methods in marine hard bottoms include visual transect (using chain or measure tape) or quadrats (e.g. [35]). In coralligenous habitat they have been mainly used to estimate species diversity and assemblages structure (e.g. [6]), demographic parameters and to study the short and long term changes in gorgonian populations (e.g. [9, 36, 37]). These studies recommended a quarter to one square meter frames to monitor abundant large-sized organisms growing at the coralligenous outcrops. Technical information regarding these survey methods and comparisons between them has been reviewed adequately and at length elsewhere (see: [38-44]). As well, information regarding their cost, time required, accuracy, precision and statistical power has been also evaluated in detail [39]. In general, these visual methods provide a high taxonomic accuracy, yield a good estimate for small or rare species, are easy to implement and have a low cost. However, limitation of the methods has been also addressed, such as the need of very well trained observers, small investigated area and the limited operative depth due to divers safety reasons. Moreover these methods cannot be used to measure three-dimensional complexity, since they are not well suited to characterise the holistic features of natural landscapes, and measurements are prone to dramatic variation with minor changes on the adopted tools placement [45].

According to Van Rein et al. [34] more research in standardising methodologies has been conducted within tropical latitudes than in temperate latitudes, largely due to differences in survey environments, target communities and operational budgets. However, this accumulated wealth of knowledge in the tropics in some cases may be transferred to temperate areas. For instance, as happen for tropical coral reefs, despite the well-known and obvious differences between those environments, both coralligenous and coral reefs accretions are characterised by a photosynthetic growing side and by a shaded side, colonized mainly by heterotrophic filter feeders, among which several bioeroders (e.g. sponges and bivalves). In case of healthy conditions of the biogenic structures, a high spatial complexity can be reported, otherwise, in case of damaged conditions, complexity decrease shifting towards a more trivialised system. In damaged coral reefs, physical and biological processes of erosion overcome bioconstruction and the percentage covered by coral rubble and sediment increase [46]. In temperate coralligenous systems, the rugosity of the coralligenous concretions enhances sediment deposition [47]. For coral reefs, high sedimentation rates can smother the living organisms, compromise the reef accretion [48]) and limit the community renewing by new settlers [48]. In coralligenous habitats the mechanical disturbance [9], sedimentation increase [49], species invasion [50], temperature increase and water degradation [51] have all negative effects on species assemblages. However, coral rubble and limited sediment deposition may contribute in the following building up of the new frameworks through complex processes of lithification [52].

3. Underwater Mapping: state of the art

During the seventies conventional coral reef maps were based on field data obtained by planimetric surveys and visual observations [53]. Rapid development of remote sensing techniques has opened a new avenue for seamless mapping of biodiversity at different scales. Remotely sensed data has the potential to provide a broad-scale synoptic view of benthic environments and provide temporal data that may be used to assess events in community dynamics [54,55]. In addition to these advantages, using remote sensing techniques, the data are collected from a sensor without really impacting or creating disturbances on the seabed [56–58]. These advances have led to the development of new approaches to biodiversity measurements, including the use of indirect abiotic proxies, statistical modelling, remote sensing and a combination of these [59].

3.1 Acoustic sensors

Acoustic technologies are increasingly being used for monitoring benthic habitats. The data have been analysed with means of dedicated software and geographic information systems (GIS) to extract different acoustic classes, which in turn have been applied to the identification of seafloor habitats [34,57,60]. In the case of coralligenous habitats, the acoustic technologies normally include side-scan sonars and multibeam sonars (e.g. [61,62]), eventually coupled with observations by scientific divers and/or remote-operated vehicles. For instance, Barber_a et al. [28] describe the benthic habitats located at the Menorca channel. The study was carried out with side-scan sonar, a remote-operated vehicle and an underwater drop camera. The techniques were used to map the habitat distribution between 50 and 100 m depth, to make an inventory and describe the spatial patterns of both the specific and functional diversity in the area. Results obtained with this research show evidence that trawling intensity affects coralligenous environments in the study area. Gordini et al. [61] used side-scan sonar, and multibeam technologies to characterise a set of submarine rock outcrops in the Northern Adriatic Sea. By means of these technologies, the authors reported coralligenous concretions in the area and highlighted the importance of these habitats in the origin of the rock outcrops. Bonacorsi et al. [62] collected side-scan sonar and multibeam data in the Western Mediterranean Sea. The authors discovered a new coralligenous morphotype ('coralligenous atolls') with the data obtained from the side-scan sonar. Finally, the study leaves open the hypothesis that the origin of these 'atolls' could be related to gaseous emissions in the region. However, despite the advantages of the acoustic technologies in marine ecosystems, these methods are unable to discriminate benthic communities based on pigmentation [57] and do not provide any photometric information to obtain three-dimensional (3D) textured visual maps [63]. In addition, these methods cannot resolve fine scale structure due to the resolution of the survey data [45] and often the acoustic records require interpolation methods for mapping the area of interest. Another important disadvantage is the price of the implementation, still very high, although these technologies become accurate, light, easy and cheap day by day. Reducing the cost for acquisition of data is a key priority in order to implement European Union (EU) legislations such as the Marine Strategy Framework Directive.

3.2 *In situ* optical methods

Despite the advantages of remote sensing in marine ecosystems, in situ measurements remain the most important and reliable source of information on biodiversity [59]. There has been a sharp increase in recent years in the use of digital devices in marine benthic environments [39]. Optical-based methods (i.e. digital video and stills cameras) are becoming more commonly used in research because they collect data quickly reducing the time spent underwater, provide high-resolution images of the organisms, and cover large areas quickly [44,64,65]. In addition, they generate permanent survey records, achieve greater sampling objectivity than traditional diver observations and have a low environmental impact in sensitive areas of conservation importance [64,66,67]. Photographic methods have been applied in coralligenous environments at regular time intervals in fixed sites in order to measure individual growth, mortalities, disease development and recovering processes [68]. Moreover, images of benthic assemblages can provide information on species abundances and species diversity, by means of dedicated image analysis software [e.g. 69,70]. Ferdeghini et al. [71] used a visual estimate approach with a multi-factorial sampling design to assess patterns of vertical distribution on coralligenous environments at the Giannutri Island (Tuscan Archipelago, Northwest Mediterranean).

The study found a high heterogeneity in the distribution and abundance of the analysed taxa. The authors attribute these results to the smallest spatial scale investigated (10's of m). Certainly, Prada et al. [72] stated that the scale at which ecological processes operate, and the scale at which organisms perceive (or respond to) the heterogeneity of the 'seascape' are often determining factors in choosing the resolution at which a habitat should be mapped. Therefore, under-sampling can cause information loss in a spatial domain, especially when there is a discontinuous distribution of elements or when the sample frequency is too low to capture the fundamental signal pattern [73]. Recently, Deter et al. [69] addressed this disadvantage proposing a rapid photographic method to estimate the percentage cover of sessile organisms. The authors identified that 64 photographic quadrats on stratified random points (RQ) and at different depths is a good method to estimate abundance in coralligenous environments. For the photographic analysis, the study used and adapted the CPCe (Coral Point Count with Excel extensions) software to be used in coralligenous environments (CPCe 4.1 ‘coralligenous assemblage version’). The software reduces the time spent (image preparation and analysis) for RQ by grouping in a unique interface picture enhancement, point distribution and identification. Nevertheless, the authors stated that the method should be avoided when a total species inventory is necessary or when species richness is the variable of interest because species that cover less than 4% could be missed. In addition to this disadvantage, the precision of this method depends on the sampling frequency during the monitoring plan and the ability to take photos from exactly the same spot. Kipson et al. [5] attempt to provide guidelines for the application of a rapid, non-destructive protocol for biodiversity assessment and monitoring coralligenous environments. The method searches for a way to assess the natural spatio-temporal variability of coralligenous outcrops. To achieve that aim the authors propose a photographic sampling method based on the determination of the presence/absence of macrobenthic species. However, and taking in account the recommendations of [25], the monitoring methods should not be based on presence/absence or restricted number of target species. Another limitation of these methods is the impossibility to identify changes at a landscape level with which to determine the impacts of coralligenous stressors at these scales. In addition to these constraints, Reid et al. [74] found that when using the photo-quadrats method for mapping activities, the repeatability (tracking changes over time) requires that several permanent markers be deployed per image during the post processing step, which is tedious to set up and easily disturbed.

4. Photo and video mosaicing technologies

Several studies have demonstrated the value of using photographic or video techniques to evaluate benthic habitat conditions; nevertheless these types of surveys allow studying limited benthic areas and are affected by visibility and lighting factors [75]. As a result, these surveys are spatially and temporally sparse [66,76]. Accordingly, these disadvantages restrict our understanding of the mechanistic processes occurring at different scales in benthic environments. Photo – video mosaicing presents itself as a suitable technique to overcome these limitations [66,67,75,76]. Basically, photo – video mosaicing is defined as the process that merges several images of the same scene into a single and larger composite [75,77]. In the case of the marine environment, either divers deploy underwater cameras or underwater vehicles acquire images of the area of interest [63]. According to Van Rein et al. [65] the potential of the method lies with being able to create images of the seabed while maintaining high image resolution. The images can provide information in both, landscape level (metre-scale) maps and high-resolution (sub-millimetre) images of individual colonial organisms [74]. In addition and due to the recent advances in optical imaging systems coupled with precision navigation [78–80], the mosaics can be easily georeferenced providing a precise positioning of the environment, allowing mapping and monitoring activities [e.g. 67,81,82]. They can be integrated with other data sets using GIS such as those obtained by acoustic technologies. Therefore, the integration of the whole set of data allows the assessment of the relationships between seafloor depth, morphology and organism distributions [83]. This information can then be used to test hypotheses related to the distribution of benthic habitats that could also inform further surveys and sampling activities [79].

4.1 2D mosaicing reconstructions

First-generation mosaics (resolution in the order of 3–5 mm pixel $^{-1}$) were developed by Lirman et al. [67] to construct two-dimensional (2D), spatially accurate, high-resolution mosaics of the reef benthos in Florida. The mosaicing method was able to discern broad benthic taxonomic categories such as stony corals, octocorals, algae, sponges, and sand. The two dimensional images were analysed by the author with the same methods commonly used by divers to estimate in situ the percentage of cover (point intercept method). Despite these advances, first-generation mosaic products were insufficient for species level identification of many benthic taxa, thereby limiting the survey potential of the technique [82]. As a result and to overcome this limitation a second-generation mosaicing was designed. The method employed two cameras to generate multi-layer datasets [82]. The improvement in the technology allowed species identification of coral colonies (as small as 3 cm) and macroalgal genera, covering areas of up to 400 m^2 with sub-millimetre pixel resolution [74]. Subsequently, Gintert et al. [84] released a third-generation underwater landscape mosaic, using just one still camera for the mosaic creation and reporting up to 3x greater benthic spatial resolution than second-generation mosaics.

The study also assesses the mosaicing method by comparing community data collected from the corresponding stills cameras and high definition video. To carry out these comparisons the authors tested several camera and video devices, finding that low-cost cameras such as Go-Pro™ provided high resolution for mosaic creation. Finally, the study found that still cameras performed better than high definition video (15 pixels cm ^{1} vs. 11 pixels cm ^{1} respectively). Similar results were also found for Van Rein et al. [65] and Morrison et al. [85]. Both studies identified that still imagery offered additional advantages over high-definition video, including increased consistency in the number of frames acquired per transect, decreased costs, and reduced processing time. In addition, still images enabled identification of more species and less-conspicuous benthic categories. The authors also stated that the frequency of motion blur in still images is greatly diminished (especially in low light) because the camera is stationary when the images are captured.

4.2 3D mosaicing reconstructions

Despite the potential of the 2D mosaics, there are cases in which this information is not sufficient for a comprehensive understanding of the area of interest. One of the weaknesses of the 2D mosaics is that they are not geometrically accurate due to the ignorance of the 3D structure of the scene [66] and therefore can produce strong distortions in the presence of steep slopes and cliffs, as often happens in the coralligenous habitats [79]. Three-dimensional structure, represented as topographic structural complexity, has been strongly correlated to biodiversity in marine environments affecting community structure, and is therefore integral in determining ecological processes. In general, ecologists use indices, such as rugosity, slope and aspect to describe habitat complexity [45,76,86]. For instance, seabed topography has been suggested to control coral distribution indirectly by governing the local current regimes [45,76,86], and more recently, rugosity has become a metric to examine the structural changes that benthic habitats undergo as the framework of engineering species die (e.g. corals). Rates of bioerosion overtake accretion, and the habitat eventually becomes flat [87], subsequently reducing species diversity and faunal biomass. In order to surpass the limitations of the 2D mosaics, computer vision offers promising technologies to build 3D models of different benthic environments. Thanks to these advances there have been significant improvements in the mosaicing technology and full 3D reconstruction in the last decade and several studies such as coral reefs in biology and ecology, hydrothermal vents and lava formations in geology or underwater archaeological sites, among others, have benefited from three-dimensional maps [77,88]. Recently different authors have assessed several methods and algorithms to convert optical imagery into 3D representations of the benthic environments, see for instance [44,63,76,78,79]. As well, different studies show that there are a variety of optical approaches to obtain 3D representations, ranging from the used of multiple calibrated cameras, stereovision or by a single moving camera [44,45,63,66,80,86]. Nicosevici et al. [63] identified the problem of using a single camera in mosaicing construction and addressed the difficulties in determining the 3D camera motion for each frame. The authors proposed a more flexible approach using multiple calibrated cameras or stereo cameras and moving towards a calibrated method for visual motion estimation (Structure-from-motion/Visual Odometry, VO). The study presents different algorithms that can be applied to monocular or stereo imaging systems for applications ranging from autonomous robot navigation to aerial imagery. The results show that the application of these algorithms results in accurate information for both camera pose and scene model estimations. Finally the authors developed a blending image texture method, using 3D geometric information and photometric differences between registered textures. The method allowed high-quality mosaics over 3D surfaces, by reducing the effects of the distortions induced by camera viewpoint and illumination changes. Williams et al. [89] surveyed the drowned reefs along the shelf edge of the Great Barrier Reef, Australia. The study used high-resolution optical images to validate the interpretations of the seabed based on acoustic data. In addition, the 2-Hz stereo imagery data were used to assess the substrate types and character of the modern epibenthic assemblages associated with shelf edge reefs. The paper presents the methodological techniques used to recover detailed seafloor maps based on the stereo imagery and navigation data available. The study demonstrated how simultaneous localisation and mapping (SLAM) could be used to generate a consistent, georeferenced navigation solution suitable for creating detailed 3D models of the seafloor. According to the authors, this information could be useful to investigate the relationship between fine-scale seabed structure and the benthic organisms they support. Finally the study described the automated classification technique of the imagery with which to improve the volume of the data management. Friedman et al. [76] showed how rugosity, slope and aspect could be derived from fine-scale bathymetric reconstructions using georeferenced stereo imagery collected by an autonomous underwater vehicle (AUV). The method can generate fine-scale bathymetric reconstructions with a centimetre of resolution in the form of irregular 3D triangular meshes. Later, Friedman et al. [45] evaluated the accuracy of the method comparing their results with the conventional in situ chain-tape measurement method. The study shows that performing calculations over a digital terrain reconstruction is more robust, flexible and easily repeatable with the use of these devices. Finally the study highlights the potential of stereovision to provide 3D structure complexity and visual appearance, which can be used later for, automated classification. In the same direction, Schmidt and Rzhanov [90] used a GoProTM stereo camera pair to measure the 3D topography (bathymetry). The paper shows preliminary results of rugosity measurements of the seafloor at scales comparable to those that affect acoustic backscatter from commonly used bathymetric sonar systems. The study resolved seafloor features less than 1 cm in amplitude. Elibol et al. [91] address the motion estimation between overlapping images in order to obtain the topology of the scene. The study proposes a generic framework for feature based image mosaicing, capable of obtaining the topology with a reduced number of matching attempts and to get the best possible trajectory estimation of the divers' track or robot motion. Another initiative is presented by Warren et al. [80] who move forward in the field of VO and present a technique for performing high accuracy sea floor mapping by integrating low-overlap stereo visual imagery and magnetometer data in a modified VO algorithm. The technique used a constrained motion and integrates magnetometer data in a bi-objective bundle adjustment stage to achieve low-drift pose estimates over large trajectories. To assess the trajectory estimation, the study performs a 3D reconstruction of the observed scene using the image data and pose estimates. The results show that the improvement of the VO method, avoids the accumulation of the pitch error by constraining the incremental motion to the 2D plan, having as a result a position error less than 2 m over the 400 m trajectories. Another 3D approach based on a stereo system has been proposed by McKinnon et al. [44]. Their algorithm used a bundle-adjustment to define the camera pose estimation and used the stereo data to perform the 3D reconstruction, creating a dense polygonal model of the scene. To evaluate the accuracy of the method, the study compared the 3D reconstruction with a laser scan of a piece of the staghorn coral, *Acropora cervicornis*. The comparison result shows that 77% of the pixels in the reconstruction are within 0.3 mm of the ground truth laser scan. Prados et al. [77], instead, concentrated their efforts on the image blending techniques, evaluating the state of the art and making comparisons regarding the available methods. The authors tackled the problems related with the scattering and light attenuation phenomena (impacts visibility range and colour reproduction), which limited the maximum area covered by a single photograph. They also studied the issues related with moving elements, such as fish and algae. The study assessed and presented all the steps needed to achieve a final image quality and visual consistency showing a standard approach that can be used and tested for large-scale underwater image blending.

5. Robotic technological advances

Nowadays deep coralligenous habitats can be reached by scientific divers using improved diving technologies such as mixed gas (e.g., TRIMIX) and closed circuit re-breathers, which reduce decompression time and decrease the respiratory gases narcosis and the risk of oxygen toxicity. Although the observation skills and the work abilities of scientific divers cannot be equalled, the employment of robots (ROV) provides a reliable and safe alternative to carry out surveys in deep coralligenous habitats. They can recover information at fine resolutions over relatively large and contiguous extents of the seafloor compared to diver-based assessments and can be deployed beyond diver depths. In recent years there has been increasing interest by the robotic community in the realisation of user-friendly technologies and tools for carrying out efficiently activities such as exploration and intervention in the marine environment. In particular, a lot of effort has been spent on the creation of tools to intervene with robots in delicate environments. This has fostered the research on unmanned underwater vehicles (UUV) and on their guidance and control systems, as well as the development of adequate sensory systems, so that many solutions are now available for performing scientific mission in underwater scenarios. The choice among different technologies depends on the objectives of the mission, the characteristics of the environment and the global amount of resources that can be exploited. In many instances, Remotely Operated Vehicles (ROVs) are preferred, since their use guarantees teleoperation on the mission scenario. On the other hand, they generally require skilled and highly trained pilots in order to assure efficiency and performances and this disallows scientists who are in charge of the scientific mission from directly guiding and controlling the vehicles. Up to some extent, when teleoperation is not crucial, AUVs can be used instead of ROVs. For example, Sattar et al. [92] explain how to enable autonomous capabilities in underwater robotics, and illustrate the approaches used during underwater sea trials in coral reefs. The idea of making the task of piloting an ROV simpler and easier, by developing suitable assisted guidance systems, appears to be potentially very fruitful. This is, for example, the solution proposed by Jordan et al. [93], consisting of a method for evaluating errors during a reference tracking mission which employs a teleoperated underwater robot. The system includes vision sensors in the control loop and combines pattern recognition and optical flow techniques. Improvement of the automatic control functionality and autopilot control systems has also been developed and tried on the ROV [94]. A complete pilot interface presents all important control data to the ROV's pilot, who is able to use a combination of touch display, joystick, gamepad and other input devices to generate commands, switch operating modes and enable/disable low-level controllers.

5.1 Data gathering in delicate biological marine environments with robots

A typical application area for UUV technologies concerns surveys and data gathering in delicate biological marine environments or in archaeological sites, where fragile artefacts or biological points of interest are found. In such situations, teleoperation becomes fundamental, as does using minimally invasive practices, which avoid any damage to the environment and its content. End user requests have driven the study and development of efficient systems for data gathering in underwater environments [95,96]. This necessity rises from the need to improve methods to obtain good quality information in the most efficient, economic and safe way. The same necessity has encouraged marine companies to develop multipurpose low cost micro underwater robots and tools. In those scenarios, complex robotic systems that integrate a large ROV equipped with one (or more) micro- ROV as a mobile appendix (or in which, reversing the point of view, the larger vehicle acts as a garage and supply vessel for the smaller one(s)) may provide an efficient solution, since they combine performance with versatility. The architecture of such a system was first proposed in [97]. A key issue in its realisation is linked with the complexity of the robotic structure, which gives rise to serious difficulties in guidance, in particular if it has to be entrusted, also partially, to scientists, who are experts of the application domain, such as biologists, instead of ROV pilots. The need for automatic navigation, guidance and control systems that can assist operators, especially in low level tasks, has therefore to be addressed in the development of such systems. An integrated robotic system for deep intervention, consisting of two coupled ROVs of different dimensions, has been developed by Scaradozzi et al. [98,99], and consists of a micro-ROV tethered to a large one, which is tethered to a surface supply vessel. This configuration allows the micro-ROV to work at considerable distance from the supply vessel without the burden of a long umbilical and with the large ROV acting as its mother ship. An ultra-short baseline (USBL) acoustic system, coupled with a digital global positioning system (DGPS) system, is an integral part of the structure and monitors the geopositions of both vehicles. A supervised control system should be developed to guide the large ROV, while a human operator on the vessel pilots the micro-ROV. Using position information from the acoustic system, the automatic guidance implemented by the supervisory control system maintains the large ROV in a stationary position or guides it along a predetermined path. This way, the bigger vehicle remains distant from the site, avoiding any disturbance or damage and, at the same time, allowing the micro-ROV to investigate the deeper areas due to its closer position. By using optical or acoustic measuring devices mounted on the large ROV, the operator can monitor the micro-ROV during operations. Low-level assistance consists of specific actions in the control loop, while high-level assistance consists of information provided by an external view, which is potentially useful for situational awareness, facilitating decisions for more effective actions. The presented architecture is organised on two levels. The higher level of the supervisory control system monitors and controls the mission status, detects faults, logs data and displays information. The lower level guides (either automatically or in response to a pilot's commands) the large ROV and generates information needed by the micro-ROV's Assisted Guidance System to govern the vehicle's behaviour.

For biological purpose a micro-ROV Assisted Guidance System was developed to support the robot operator, so its principal task is to avoid driving the vehicle too far from the large ROV. During operations, it is assumed that each vehicle moves on a horizontal plane at a constant depth, with the micro-ROV closer to the sea bottom. The large ROV is equipped with a downward looking video camera; the maximum admissible work space of the micro-ROV is defined by the intersection between the large ROV camera's pyramid of vision and the horizontal plane at the smaller vehicle depth. Essentially, the Assisted Guidance System modifies the micro-ROV response to the pilot's commands depending on the vehicle position within the work area, forcing the pilot to keep the robot inside the area. The Assisted Guidance System increases the joystick resistance as the distance from the boundary decreases, which encourages the operator to drive the micro- ROV toward the inner part of the work area. The presented robotic system can be employed according to static or dynamic operational mode. In the static mode, the large ROV works in station keeping and, therefore, the work area of the micro-ROV is static during the mission. This operational mode is suitable when the principal aim is to closely inspect and document a delimited area or a single spot. The operator can concentrate on moving and positioning the micro-ROV to optimise data gathering, and the Assisted Guidance System will help the operator keep the vehicle within the work area in spite of erroneous manoeuvres or environmental disturbances, such as currents. In the dynamic operational mode, the large ROV is supposed to move along a predetermined path and, therefore, the work area of the micro-ROV changes during the survey. In this way, the Assisted Guidance System will view the dynamic mode as a sequence of independent situations in which the static mode is active. This operational mode is suitable when the principal aim is to survey a large area, moving along transects. In that case, the Assisted Guidance System supports the pilot in order to make sure the micro-ROV follows a given path at a certain speed, in spite of pilot errors or disturbances. The motion of the large ROV indirectly defines both the path and the speed. Following the path at a given speed is essential, for instance, to assure coverage of large areas by photographic or video documentation, but, at the same time, the pilot can slightly deviate from the path or change speed and modify data acquisition frequency or amount of area explored. This flexibility, together with all the considerations and limits previously described, can help ensure achievement of the mission’s goals and is particularly valuable for marine scientists who have been increasingly employing UUV technologies. The novel approach proposed in [97,99] could present the ability for easily repeatable transects, making it is possible to revisit an area of interest for monitoring purposes.

6. Integrating acoustic and optical information datasets

The association, integration and fusion of data gathered by heterogeneous sensors has been previously discussed in other works [75,76,78,89,95–101]. As introduced in the previous section, an ultra-short baseline (USBL) acoustic system, coupled with a digital GPS (DGPS) system, is an integral part of the structure that monitors the geo positions and the track of the divers' or the robot motion. In addition to this, an Assisted Guidance System such as USBL has also been used to merge acoustic and optical information [92–101]. For instance, Conte et al. [100], used information collected from a side-scan sonar to locate the ROV with respect to the USBL system. In order to achieve a satisfactory level of accuracy between pictures and acoustic images of a geographical location, the authors enhanced all the navigation system with a module of real time managing the data flow coming from the USB/GPS positioning system, the on-board camera and videocamera, the on-board imaging sonar, the depth meter, the compass and the inertial measurement unit (IMU) (navigation data) for the synchronisation of the data recording. Pictures and correlated acoustic images of the sea bottom were taken from an average distance of 3 m, at a frequency that assures a complete coverage with overlapping of the explored area. The authors used the navigation data to orient the pictures and the acoustic images to scale them as well as to validate morphological features obtained with the side-scan sonar data. High definition images were also used to add information to selected locations and to allow zoom operations on the map. In addition, the result of the mosaicing produced by the optical information helps in fusing the bathymetric information obtained by the side-scan sonar together with that gathered by the ROV-USBL on-board instruments. The result of this process is a virtual model of the explored area, consisting of a surface in a 3D space on which the mosaic is pasted. Drap et al. [96] merged bathymetric data from a multibeam survey with the camera position given by the ROV-USBL system. The authors show that there is an absolute reference system consistent with the multibeam data. As a result a 3D model of the sea bed with the superimposed 3D model obtained with the photogrammetric approach is presented. In Scaradozzi et al. [87] new strategies for collecting data by means of advances in underwater technologies (acoustic localisation systems, diver propulsion vehicles and photo cameras) in mapping the growth *Posidonia* areas and their physiochemical and morphological characteristics are presented. Drap et al. [101] presented a method for modelling and visualising data coming from different sensors and measuring tools (as multibeam, photogrammetry at several scales).The authors claim that since the bathymetry obtained with underwater sonar is done at a certain distance from the measured object (generally the seabed), the obtained cloud point could be merged with the cloud point data resulting from the photogrammetry methods, making possible the fusion of 3D models of very different densities. As a result a high resolution 3D model of large complex scenes could be proposed to final users, with the production of different type of outputs. Furthermore, the resulting 3D models could be an interface to the end-user data and will be able to offer several types of visualisation, founded in the same 3D measured data, according to the needs of the experts. In addition, the information derived by merging acoustic and optical information data can be exploited to build up a geographic information system which could display physiochemical status or extension of the interested areas.

7. Future directions

We have clearly identified the problems that currently limit the assessment and monitoring of coralligenous habitats trying to suggest some possible solutions such the application of photo mosaic techniques and 3D reconstruction modelling. To our knowledge the use of these types of application has not been applied to coralligenous habitats and compared to acoustic mapping applications of benthic environments in the Mediterranean sea, limited research has been published on the field sample design and field calibration and validation data for mapping benthic habitats of the region from optical information and the 3D data set. Despite the promising capability of the mosaicing technologies care would have to be exercised in selecting the most adequate system and the application of the most suitable algorithms. Indeed, several tests should be carried out in order to assess the accuracy and to evaluate the potential of the 3D modelling reconstruction as a standard assessment for monitoring coralligenous habitats. Hence, future work using the methodology proposed here is needed, to determine if the approaches stated in this paper have wider applicability. If successfully validated, the photo mosaic techniques and 3D reconstructions would provide a cost-effective tool for assessing ecological status and monitoring changes due to natural or anthropogenic disturbance in these environments. Mosaic products could be useful for developing ecological indicators of the habitat health and for damage assessment; they will also be an excellent archive of information an therefore, suitable for tracking changes over time. In addition, the deliverable information can be incorporated later in a general mapping effort of the area, and be useful to forecast other potential locations. The methodology proposed in this paper fits in the regional spatial mapping of coralligenous habitats (The Marine Strategy Framework Directive, MSFD: 2008/56/EC), which will allow the production of high quality habitat maps as one of the first requirements for a sustainable management and therefore, provide measures to achieve or maintain Good Environmental Status (GES) by 2020. The suggested robotic system aims at simplifying the task of guiding the micro-ROV in achieving the mission goals, and in particular the data survey, coping with constraints, limitations and environmental conditions. In the future, this will allow pilots with few skills and limited experience to operate the micro-ROV directly, making it a user-friendly tool and, in general, facilitating its use. Scientists, such as marine biologists and archaeologists, can potentially benefit from the Assisted Guidance System in the framework of the described robotic structure or of others. Future works, regarding this part, will concern tests and validations of the whole structure in more field missions.

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Chapter 2

Innovative strategy and process for underwater data gathering and results elaboration

Astract

The development of new marine environment monitoring technologies is a field of research involving an heterogeneous public. The documentation and cataloguing of underwater sites as well as the supervision and sampling of biological parameters have always involved researchers like archaeologists and biologists. Moreover, sport activities regarding the sea have been showing a keen interest in more efficient devices that are specifically developed for storing data during the immersion. Within the introduced framework, it is important to let the user operate in an efficient and easy way, without creating damages to the environment. This paper describes the design and realization of a device, called DiRAMa, and the relative architecture for data gathering in underwater environments. The device is planned to make the image and data acquisition easy, and let the user upload all the information on an appropriate Web Server as soon as an Internet connection is available. Users can launch 3D reconstruction processes, which use photos and other materials just uploaded, while the Web Server sends notification on the mobile device informing about elaboration status. Innovation and potentiality brought by DiRAMa are introduced, and the general architecture of the system described. The validation of the structure out of water and its use in real field mission involving biologists and other scientist is discussed, together with possible future improvements.

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Introduction

THE underwater world has always fascinated researchers from different areas, as well as all lovers of the sea, because it hides treasures difficult to reach, and at the same time, many aspects of biological processes are still unknown. For these reasons, the study of submarine environments is affecting a growing audience in the fields of science, technology and entertainment. The main problem shared by several applications is the ability of obtaining detailed maps and documentations in an efficient, low cost and safe way; obviously, reaching such kind of objective is probably the most difficult in such a hostile environment [1], [2], [3].

Several application fields have proved the necessity of new easy instruments and strategies for:

- detecting potential sources of contamination related to industrial, agricultural, animal husbandry [4], [5]; monitoring and sampling data, physic, chemical and morphological features of the biological environment [6], [7];
- reconstructing archaeological sites with 2D or 3D maps, both for study purposes and presentation to the community [8], [9].

Even the recreational sphere requires an increasing assistance of technology for:

- taking pictures, storing data and distributing through 3G/4G networks explored areas directly from visited sites (with diving or snorkelling activities) [10];
- exchanging information through social networks, blogs or sharing applications.

Within the different application fields described above, a lot of work has been done in order to investigate methodologies and theories and to obtain measurement instruments and robotic systems optimized for final users. The technology available on the market requires development costs and huge work, foreseeing the employment of large vessels and qualified staffs, as well as efficient tools for data processing [11]. The conjunction of all these features, however, has becoming uncommon: experts search for economic solutions, the community prefers usability. Roman et al. in [12] and other publications explained their research on robotic systems capable of operating in complex dynamic environments. They work on 3D reconstructions, segmentation, data mining, and visualization for massive datasets gathered with robotic systems, developing even an iOS application to visualize 3d models of the seafloor. In [13], authors present a service, called ARC3D, that creates complete and realistic 3D models out of a set of photographs taken with a consumer camera. Results are made available for web browser viewing using WebGL. The system is very functional, but it lacks of a device which can guide users during images acquisition and through which they can directly upload photos and launch the processing.

Starting from this framework, the present work describes DiRAMa, a device designed for image acquisition and three-dimensional reconstruction of submarines heterogeneous environments. The project won the Working Capital 2012, Telecom Italy S.p.A. initiative aimed at rewarding the most promising ideas in the field of research. The project tries to answer the need for new tools to detect potential sources of contamination related to industrial, agricultural, animal husbandry and treatment of municipal wastewater, contributing to environment monitoring in an autonomous or semi-autonomous way. DiRAMa can also provide useful application in protection and preservation of marine cultural heritage, represented by marine species, connotative basic parameters or archaeological sites and wrecks. Regarding the protection of cultural heritage, it is interesting to underline that studies on the archaeological sites have always aimed at obtaining very accurate graphical representations of reality. In the field of recreational diving, divers can use the device to photograph and reconstruct the explored areas; the documentation produced in this way can subsequently be analysed by other divers before reaching the point of immersion.

The paper is organized as follow: Section II describes features and innovation aspects of DiRAMa; Section III explains the general architecture of the system, while Section IV illustrates solutions designed for each component implementation; validation and test results are presented and described in Section V, conclusions and future developments are illustrated in Section VI.

II. Features and Innovations

DiRAMa is an acronym meaning embedded device for the reconstruction of the physical, chemical and morphological status of marine environments; Fig.1 represents its logo.

Figure 1 DiRAMa logo

As introduced in the previous paragraph, it is conceived as an innovative device containing and managing instruments necessary for the 3D reconstruction of a given area; it includes different kind of sensors, though being low-cost and small. The project aims at providing the device with tools for image capturing, synchronized with inputs from sensors allowing specific knowledge of the position and inclination of the machine at the acquisition time; the microcomputer constituting its intelligence is able to process this different set of sensor information. No other device currently on the market is able to collect, process and synchronize data of a kind at low cost. The principal innovation brought by DiRAMa is the integration of multiple heterogeneous knowledge concerning the marine and underwater environment, using COTS component already tested and reliable. Images acquired during an immersion hide additional levels of information from the same area, concerning mainly location coordinates, pressure, and temperature, saved within the EXIF part at the time of shooting. This is achievable using sensors and low-cost intelligence, and developing a suitable software for managing collected data. A list of useful elements is the following, graphical represented in Fig. 2:

- a 2D or 3D camera;
- a microcontroller for data processing and synchronization;

- a series of sensors for geolocation and detection of other specific quantities, i.e. example temperature, pressure, brightness, PH, GPS sensors (usable on the surface), position sensors.

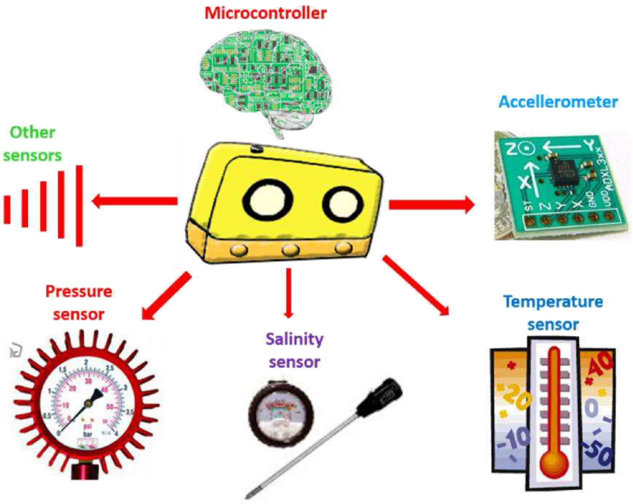


Figure 2 DiRAMa principal components

Data gathered by the device has to be stored in a database managed by a well-organized server technology, able to process them and return results to external users. This project is aimed at providing greater data processing, implementing 3D reconstruction algorithms on the external server; this expands the list of possible results with a three-dimensional model of the area explored, and answers to the necessity shown by several kind of researches [7], [8]. It is also important to let reconstruction being modifiable with software suites of common use or open source, even directly from the mobile device employed for taking mission data. Section III will describe the specific architecture and realization choices done to reach the project final aim.

III. Global Architecture

Developing DiRAMa has implied the implementation of a complete architecture. This section describes the general structure and its components, focusing on the choice done regarding the technologies used. Fig. 3 shows a schematic representation of DiRAMa system:

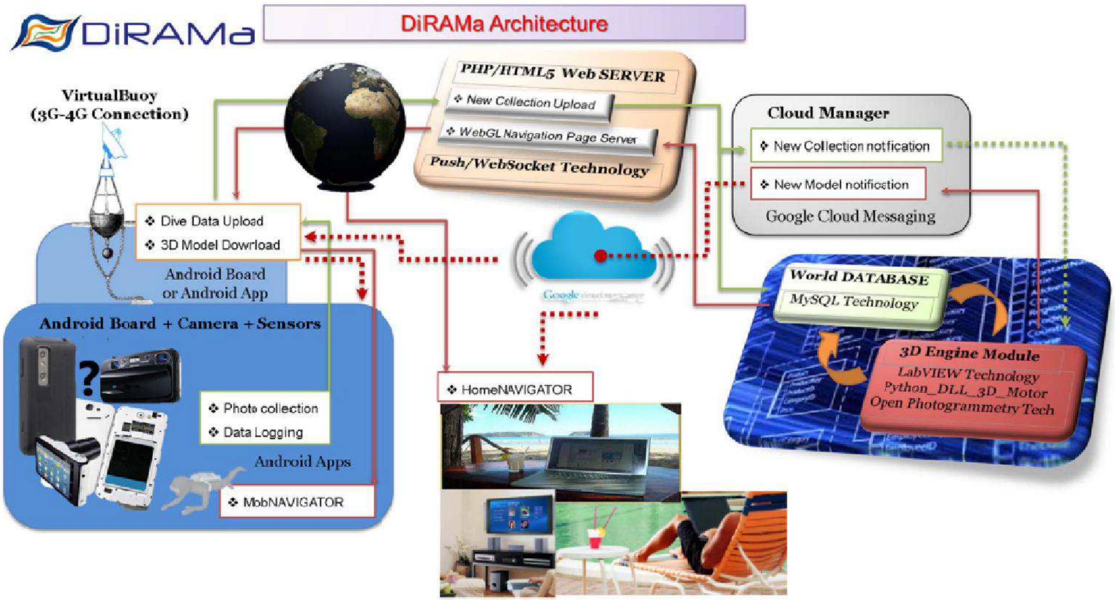


Figure 2 DiRAMa system: general architecture

The figure shows the single actors playing their role within the global framework. Lines represents the information exchange. In the following, each block is introduced.

A. Mobile acquisition device (Android Board)

This block characterizes each aspect related to DiRAMa, the device used by the final user to collect data. An image acquisition sensor, a microprocessor and other measuring device constitute it. When the device is brought out of the water and an Internet connection becomes accessible, it plays the role of a virtual buoy, sending the saved information to an opportune server. Scouting for a suitable technology, we identified smartphones, tablets and smart cameras equipped with open source Android OS, including the fundamental part needed for the project, which has been developed in a small slot of time (less than one year). Other external sensor data can be acquired using external hardware specifically designed (i.e., IOIO for Android). The realization of an interface has consisted in developing an appropriate application able to gather images together with other data, and send them to a server. The possibility of registering and login to services implemented in the Web application has been added to guarantee the user privacy. The same device allows displaying the post-processing results. In order to use DiRAMa underwater, commercial or custom underwater housings are available.

B. PHP/HTML5 Web server

The data acquisition and cataloging has been implemented on a web server. It takes care of managing customer data registration and photos sent with DiRAMa, storing them into the database, showing results to the user, and displaying the Web app developed in order to reach and edit the immersion information. Another fundamental role of this part consists in the connection with the 3D Engine Module, to which it requests to elaborate reconstructions and from which it receives back results. The Web application introduced above is based on PHP server-side scripting and HTML5 markup language.

C. 3D Engine Module and Database

The 3D Engine module implements complex reconstruction algorithms and shares information with the Web Server. The module make use of the database where info and elaboration results are stored. Users can request a 3D elaboration using both the Android application and Web interface; these commands are managed by the PHP Web server.

D. Cloud Manager

Users are able to monitor the elaboration progress thanks to the notification system, an additional functionality considered important by several beta tester. For this reason, the system implements notification using Google Cloud Messaging (GCM), a free service that helps developers to send data from servers to their Android applications. It could be a small acknowledgement or a message of up to 4 kb of data payload. In this framework, GCM is useful to send short text messages informing about elaboration success or eventual errors. The 3D Engine Module is also able to send email notification containing the same kind of information, useful for Web application users.

E. *Home navigator*

Results can be handled using free software available online, such as MeshLab [19], an open source software is able to display and modify models of three-dimensional geometries and the relative texture. Results are presented in PDF format too, so they can be visualized with Adobe Acrobat Reader

IV. Implementation

This section describes the global architecture just introduced, detailing implementation procedures and choices. The system is basically a client-server application. In the following, client applications and the server side development are detailed.

A. *Android Application*

First of all the attention has been focused on the client, and then on the end user: the principal aim is to provide a user friendly interface, through which managing data and information. For these reasons, the use of devices such as Android smartphones and tablets required the development of an appropriate application able to guide the customer to an efficient data-gathering mission. The Android application integrates the management of registration and user login, shooting, ability of displaying data from missions already loaded on the server, and reconstruction lunch. It was written using Eclipse as an IDE, integrating the appropriate Android SDK released by Google. The application has been divided into 4 modules:

- **camera management**: contains everything related to camera management: shooting, integration of location data from GPS and accelerometer, the choice of camera settings, image upload on the server, and reconstructions launch;
- **libraries:** this module implements libraries needed to communicate with the web server via JSON , the management of Android device internal database, the wake locker management useful for notifications delivery;

- **user data:** contains the code for user registration and log in, creation of a new mission, missions list and mission details display;
- **notification:** contains the classes essential to use the GCM.

Fig.4 shows the Application Activities and their relation:

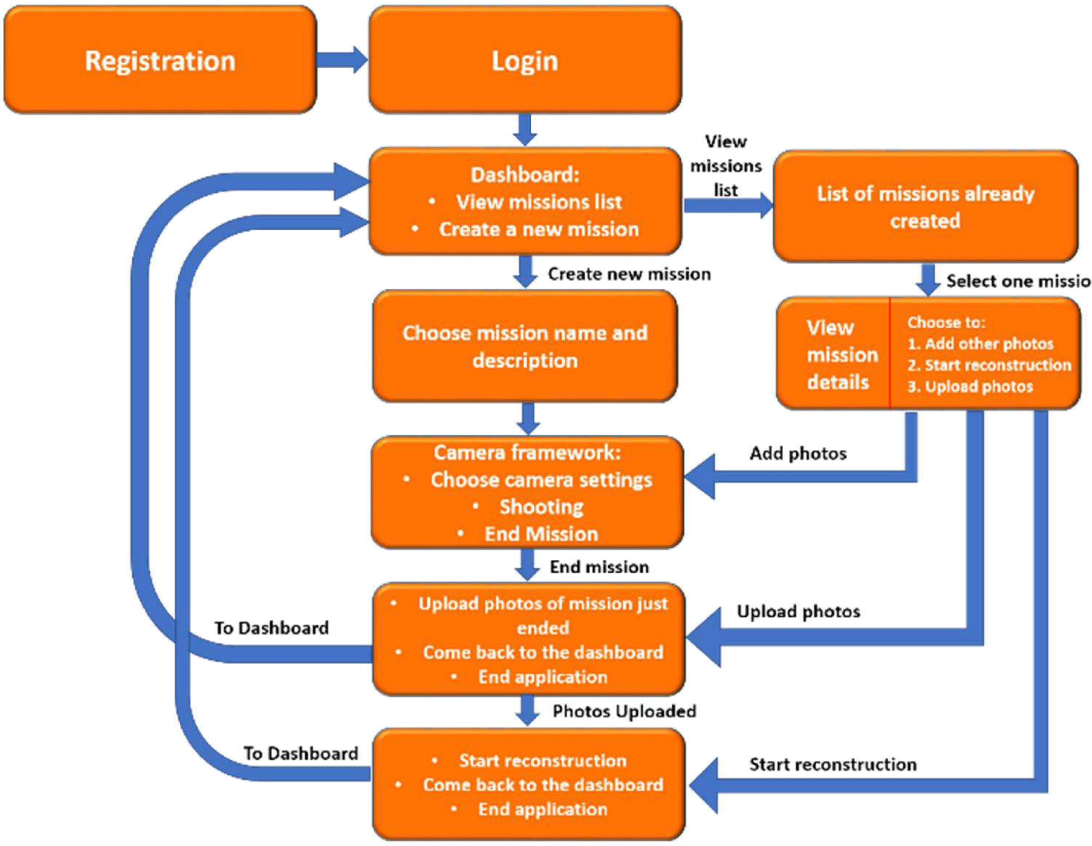


Figure 4 Android Application: Activities and their relations

First, the user as to register or, if he has an account, can directly choose to login: if the operation is successful, the device is automatically register to the GCM notification system. Once logged in, it is possible to create a new task, or to visualize other missions already generated. Mission details contain the principal information useful to recognize it; other details are accessible from the Web interface. At the end, it is possible to upload immediately images just gathered; vice versa, the user can decide to make this operation successively, through the mission details menu. Communication with the Web Server has been implemented using get or post methods, encoding data with the open format JavaScript Object Notation (JSON). A post method has been used also to inform the server that the user wants to start a reconstruction. From the application, indeed, it is possible to choose between 9 combination of quality-type of result as described in the following figure:

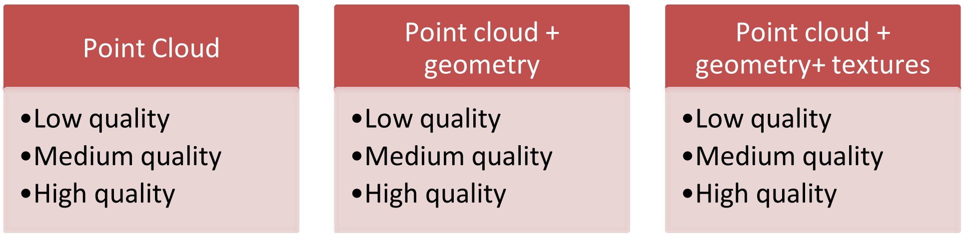


Figure 5 Android Application: possible quality – type of reconstruction

This corresponds to predefined process parameters, which will be distributed to the 3D Engine Module by the Web Sever. The Web server sends periodical notifications to the device informing about the reconstruction status, using the GCM; notifications appear as status bar on the mobile display.

B. Web Application

The development of a Web Application was considered important in order to allow the user to access data using the personal computer, and to manage them easily when at home. Moreover, the Web Interface can be used independently from the mobile application, giving to the customer the same functionalities (except the camera capturing) and the possibility of uploading images taken with device. This step make the system completely cross-platform. Pages related to the graphical interface are hosted on the PHP/HTML5 Web server.

The development of the Web interface has been carried out using modern capabilities of HTML, generating pages dynamically thanks to insertion of the markup code in PHP scripts executed by the Web server. The access is always allowed with the same credentials used in the Android application, and vice versa. Functionalities implemented on the Web App are represented in Fig. 5:

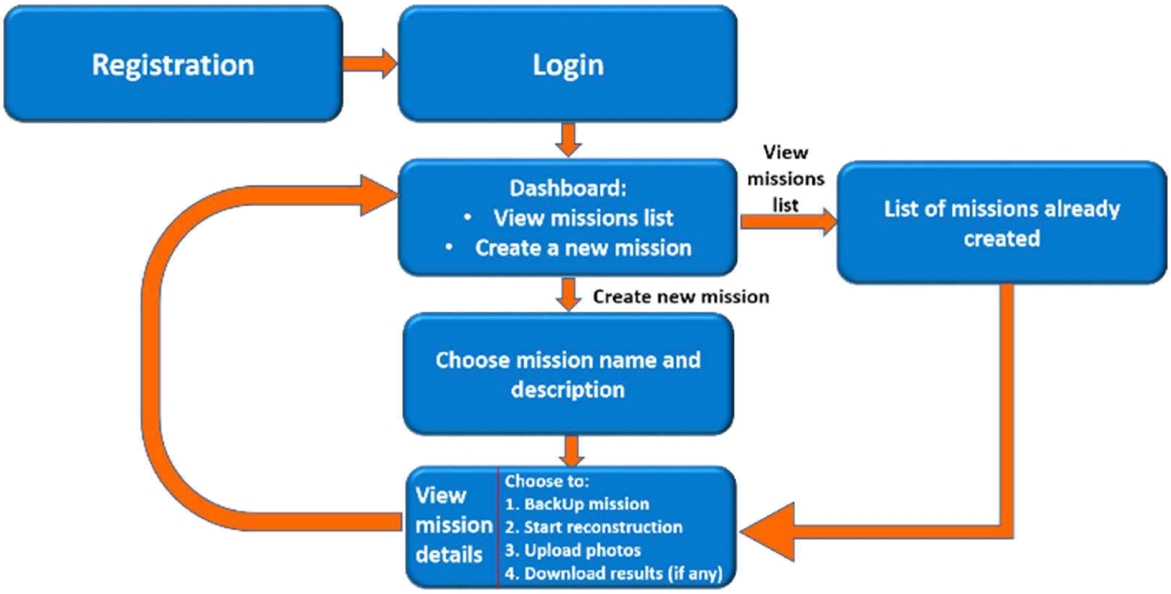


Figure 6 Web Applications: pages and their relation

From the figure it results clear that a lot of tasks are the mirror of Android Activities. The main differences are the following:

•the camera capturing has been substituted by the possibility of upload images taken with other cameras;

•the notification service implemented on de mobile device thanks to GCM is substituted by an email report service;

•from the Web it is possible to download 3D elaborations results

C. *Web Server*

The global architecture depicted in Fig. 3 requires a server able to manage users, store their data, keep track of all information regarding gathered data and show a simple and intuitive interface as the one describe in point B, through which users access and manipulate materials. The work presented in this paper involved the development of a Web Server with the feature just introduced, and the ability of talking to the 3D Engine Module, launching reconstructions and recovering results to make available.

The following figure presents the script structure and the main functions of the Web Server:

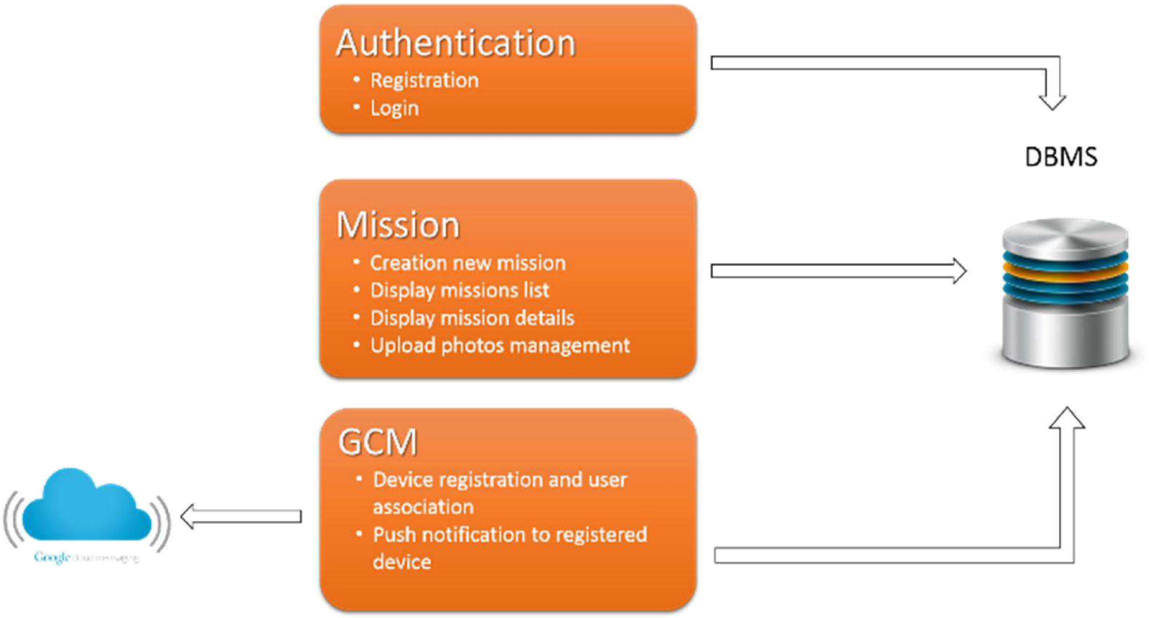


Figure 7 Web Server software structure

- **authentication**: is responsible of let the user register and login to the system services, storing opportunely his data on the database. As introduced previously, this is possible both from the mobile device and the Web App, using the same credential;

- **mission:** concerns all the script managing the missions; in this part all commands and data recovery to the 3D Engine are implemented;

- **gcm**: contains the code which allows the dialog with Google servers and the mobile device through which the user have logged in.

D. 3D Engine server

The 3D Engine Module depicted in Fig. 3 is responsible of processing images gathered by the user to obtain three- dimensional reconstructions of the explored environment. The algorithms able to carry out this task are implemented in a server physically separate from the one described in point C and make use of the LabVIEW Web Server technology. LabVIEW is a system-design platform and development environment for a visual programming language from National Instruments. Here the LabView Web Server is responsible for starting scripts implementing the 3D reconstruction algorithms, after having received POST requests from the PHP/HTML5 Web Server. At the end, the same Web Server sends back results, stored in the most common modelling formats as PLY (Polygon File Format), OBJ + MTL, DAE (Collada), and PDF. PLY, OBJ and DAE. It should be emphasized that these are easily usable through common GIS (Geographic Information System) and processing software including MeshLab, open source and available for multiple platforms. In the future, the Web Server controlling the 3D Engine will be implemented using python on a Linux machine.

V. Results

This section shows the system validation, presenting firstly the reconstruction of an out-of-water object; then, results obtained from coralligenous environments using the system on the site of Gallinara Island (Ligurian Sea, Italy) will be described and discussed. The Android application was employed to take few images of an external bench. Fig. 8 shows the visualization of the obtained 3D geometry model directly on the mobile device, using MeshLab [14] for Android, freely available on Google Playstore.

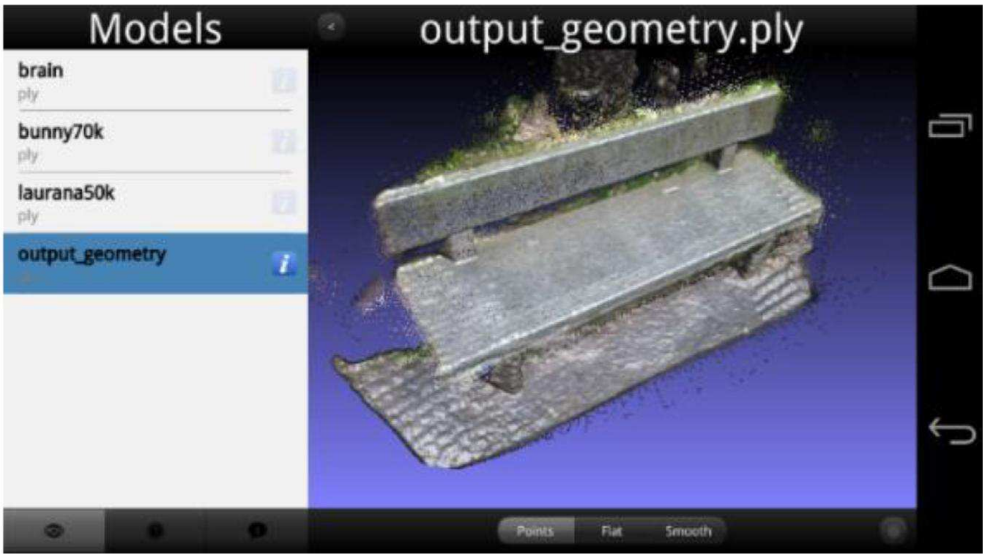
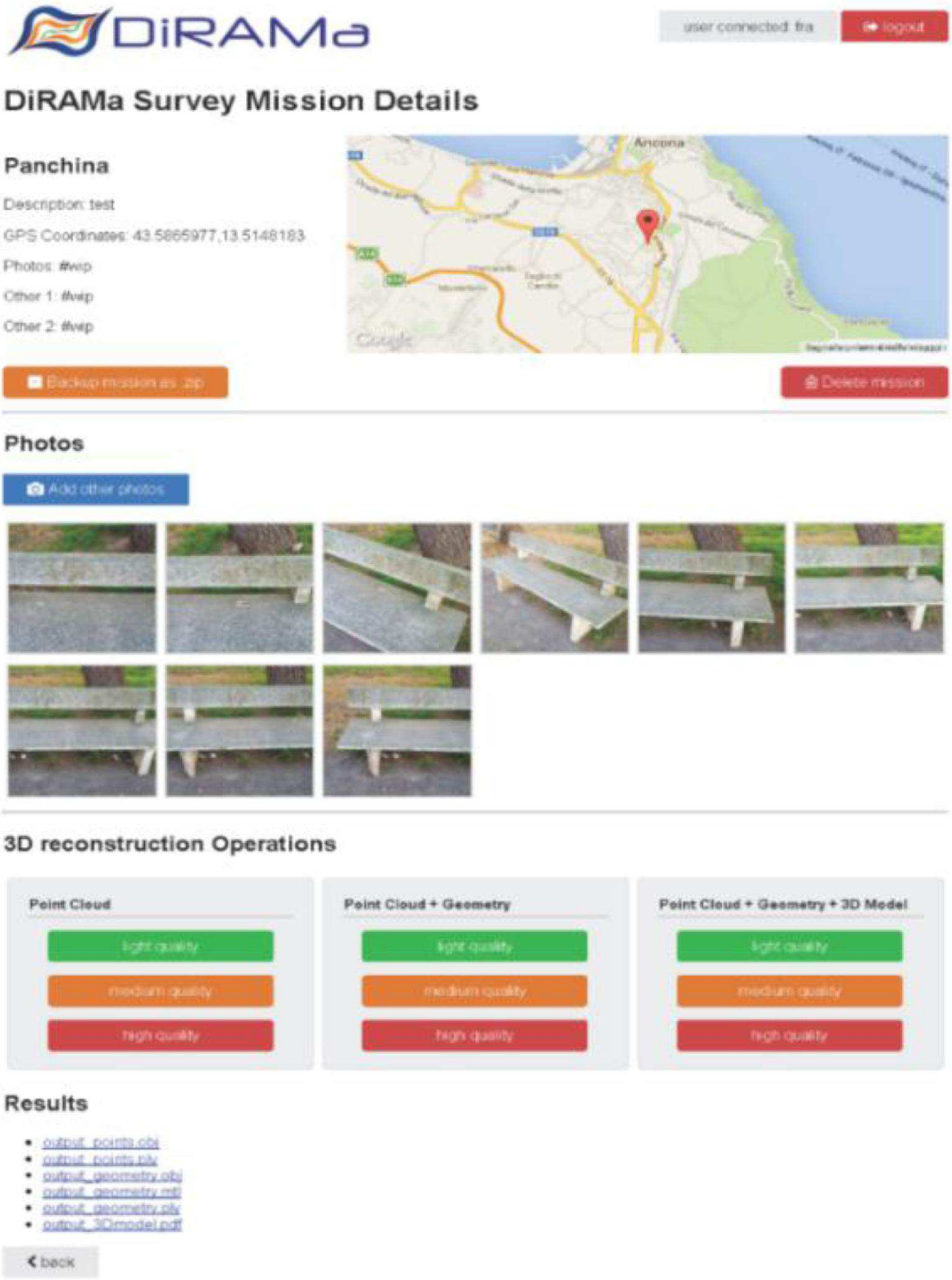


Figure 8 Bench model on MeshLab for Android

The same figure demonstrate the possibility of access elaboration results directly from the smartphone or smart camera. Fig. 9 depicts the detail page of the Web Application relative to the same test. User has an immediate feedback on mission position, images uploaded, and results available. Among the possible formats for the 3D elaboration, fig. 10 shows the PDF one using Acrobat® Reader®.

Once fixed the system in a terrestrial context, the proposed method has been validated on real marine data; the first underwater test has regarded the acquisition of images depicting coralligenous habitats located at Gallinara Island (Ligurian sea; Italy) [15], using external cameras and the Web Application. The final biologists ‘aim was to provide baseline maps for future monitoring of coralligenous environments changes and evolution in the Mediterranean basin. Another key aspect is represented by the opportunity of involving trained volunteers not necessarily confident with technologies, sponsoring the collaboration of heterogeneous teams and exploiting with higher frequency innovative web technology [16].



DiRAMa Survey Mission Details

Panchina

Description: test

GPS Coordinates: 43.5865977,13.5148183

Photos: #wip

Other 1: #wip

Other 2: #wip

Photos

3D reconstruction Operations

Results

- output_points.obj
- output_points.ply
- output_geometry.obj
- output_geometry.mtl
- output_geometry.ply
- output_3Dmodel.pdf

Figure 9 Mission detail page of DiRAMa Web Application

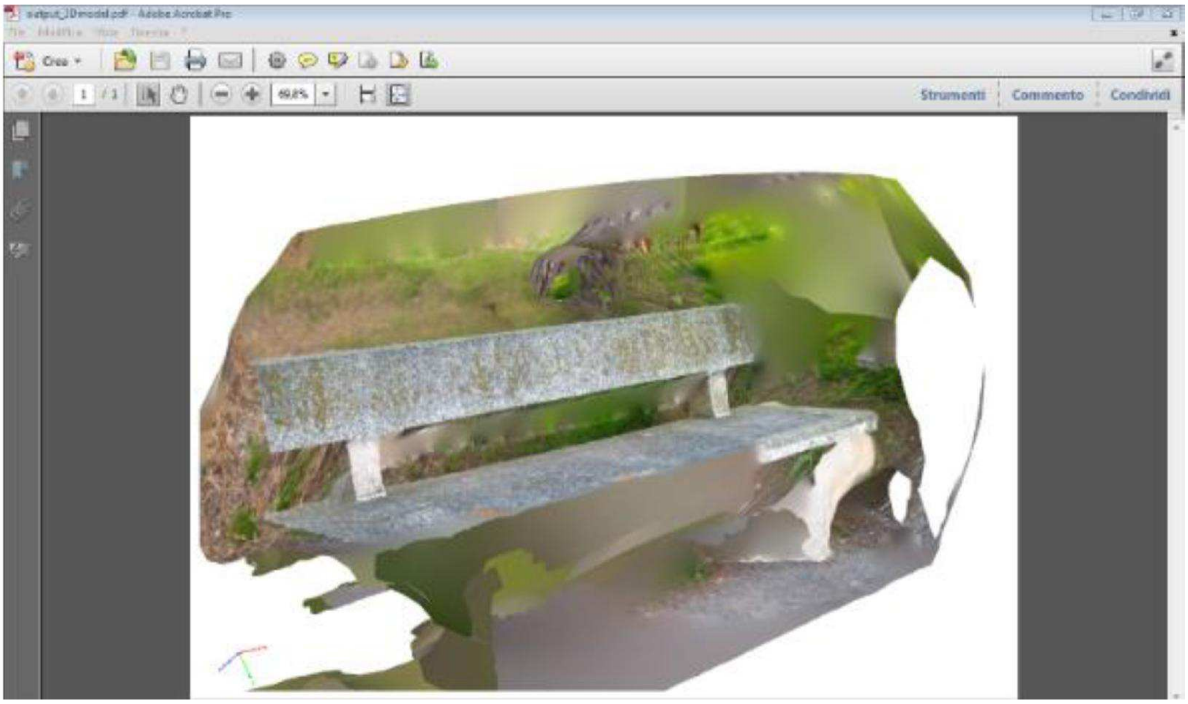


Figure 10 Bench 3D Model: PDF format

Two calibrated Go-pro Hero (3D system) were used to collect video, while one Go-pro Hero 2 had the role of acquiring only images. The SCUBA diver moved the cameras trying to maintain always the same distance over the substratum (around 40 cm) and progressed around the locations (Fig. 11).

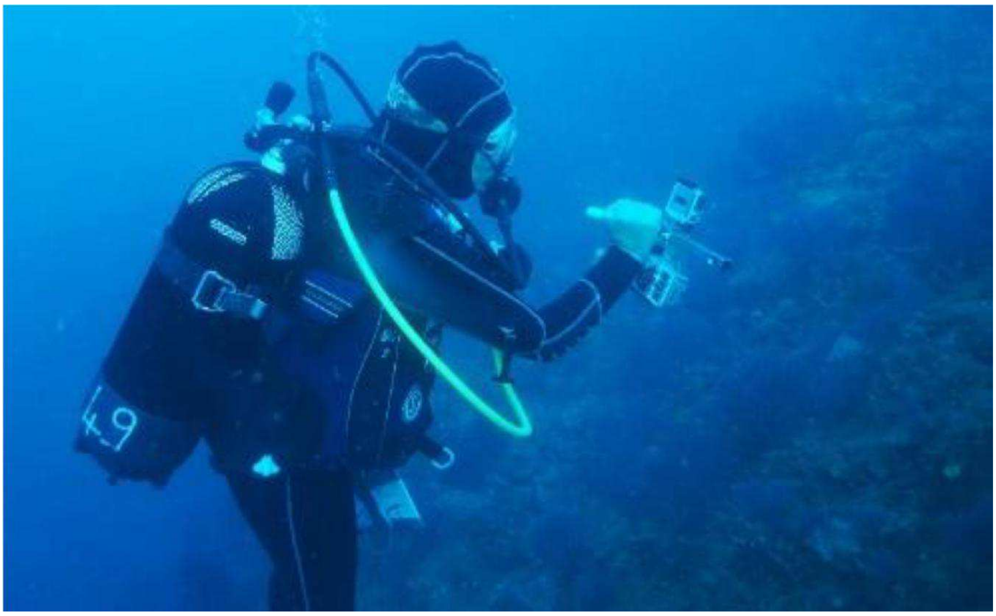


Figure 11 Field trip data collection: diver holding 3D system camera

Cameras were moved over transects measuring about 10 meter in flat position or inclined 45°: five or six transects were collected at each location. Moreover, specific targets where deeply investigated, such as sponges, and used as reference points. The accessory data to be used during the reconstruction and documented by divers are depth and direction information. In this case, the same information have been constituted a starting point for auto localization algorithms swallowed in the 3D Engine module. Results have shown and interesting overview on coralligenous structure and the spatial heterogeneity of marine organisms composing the habitat. Biologists have underlined the high-resolution of the results: the selected areas can be exactly re-examined in post processing and used for future immersions (Fig. 12); this is strengthened by the fine scale features of the terrain visible within the 3D documentations: the reader can analyze the surface roughness and slope that provide notion of the habitat structure.

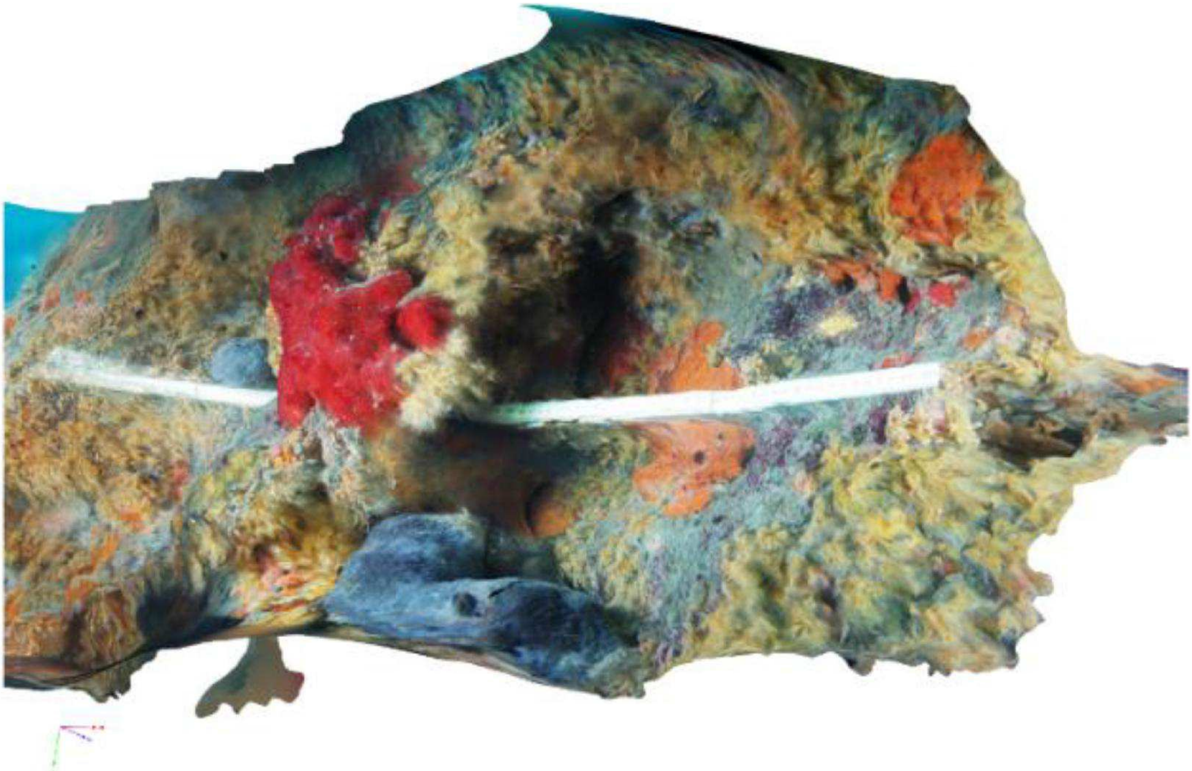


Figure 12 Gallinara Island survey: 3D reconstruction using DiRAMa

In addition, spatial relationships within the data are preserved, and users can move from a high-level view of the environment down to very detailed investigation of interesting features within it (see for instance the high resolution of *Parazoanthus axinellae* in the scene, represented in Figure. 13). The collected data allowed the valuation of the substrate types and the characterization of the epibenthic assemblages associated with coralligenous environments. The relative 3D representation make biologists able to monitor any kind of transformation in these environments. Next target is represented by identification of patterns that can be used for automatic classification of images.

VI. Conclusion

This paper discussed the design and realization of DiRAMa, a device aimed at acquiring photos and other information from the underwater environment, and the infrastructure through which users can upload images on a Web Server, store their data and launch 3D reconstruction with gathered images. System validation and results obtained underwater have proved the robustness of DiRAMa architecture, able to present professional documentation in an easy framework to common users. Results can be used to analyse the environment with scientific methodologies, or can be shared in the recreational scuba community.

Future works will concern the extension of both mobile and Web applications with new functionalities, the implementation of the 3D Engine and the PHP/HTML5 Web Serve in a common framework, tests and validations of the whole structure in other field missions.

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Chapter 3

"A multi approach to map and model the distribution of coralligenous and cave environments. A case study at Portofino Marine Protected Area (Ligurian Sea, Italy)."

Abstract

Increasing threats to coralligenous and cave environments from local to global stressors are reinforcing the need for baseline data on the distribution and the condition of these habitats, as required by the Marine Strategy Framework Directive (MSFD) to achieve and maintain a Good Environmental Status (GES) by 2020. Here we tested the potential of well-known remote sensing and distribution modelling techniques to map the distribution of coralligenous and cave environments that could provide standard methods for the assessment of the status and monitoring activities. We show how primary multi-beam bathymetry echosound systems (MBES) were used in combination with optical data, collected during the ground truthing sampling, to map these bioconcretions with acceptable accuracy and discriminate the main habitat types and facies. Results shows that the methodology would be a valuable simple tool to asses several MSDF descriptors and indicators and could strengthen management efficiency to make informed ecologically relevant decisions.

Keywords: Portofino Marine Protected Area, Models, Indicators, Ecosystem management, Monitoring.

SUBMITTED

Zapata-Ramirez, P.A; Huete-Stauffer, C; Scaradozzi, D; Marconi, M and Cerrano, C. A multi approach to map and model the distribution of coralligenous and cave environments. A case study at Portofino Marine Protected Area (Ligurian Sea, Italy)." Submitted to Marine Environmental Research.

1. Introduction

Sustainable management and exploitation of coralligenous bio-constructions and cave-overhang biocoenoses are one of the most important concerns of the last decades throughout the Mediterranean basin. The importance of these environments has been recognized under different international, European and Italian national conservation frameworks (e.g. Habitats Directive; European Water Framework Directive). In this European context, coralligenous habitats are considered as habitats of "community interest" (Habitats Directive 92/43/CEE, code: 1170-14) and they have been also recognized as protected habitats in the EC Regulation No. 1967/2006 concerning management measures for the sustainable exploitation of fishery resources in the region (European Commission, 2006). It has been also shown that, in particular, bottom trawling, artisanal and recreational fisheries, damage or destroy corals and sponges, modifying the three-dimensional complexity of seabed, and consequently decreasing species diversity and biomass (Bavestrello et al., 1997; Zapata-Ramirez et al., 2013a; Markantonatou et al., 2014). Caves are also remarkable habitats listed as well by the EU Habitats Directive 92/43/EEC, Habitat type 8330, particularly fragile owing to the low connectivity among them and the hosting of rare species. There are species typical of those habitats that face a strong harvesting pressure (Linares et al., 2012; Bramanti et al., 2014), and lately undergo mass mortality events linked to positive thermal anomalies putatively due to ongoing climate change (Cerrano et al., 2000; Linares et al., 2005; Cupido et al., 2008; Garrabou et al., 2009). CO2 sequestration (Martin et al., 2013; Noisette, 2013) and seafloor stability (Pedel et al., 2013) have also been appointed as services provided by these habitats. One of the main goals of the Marine Strategy Framework Directive (MSFD) is the establishment of innovative cost-effective monitoring programs and protocols for status assessment, effective management and protection measures of these habitats. The MSFD delineates descriptors, tasks and indicators to achieve "Good Environmental Status" (GES) in the Mediterranean Sea by 2020. Eleven descriptors are the final "traffic light" system for the monitoring activities defined by the European Commission (2010, 2011); Rice et al. (2012); Borja et al. (2013); (2014) and Galparsoro et al., (2013). Relevant tasks in this study concern descriptor 1 (“Biodiversity”) and 6 (“Seafloor integrity”). Geomorphological cartography, habitat mapping, distribution modelling and remote sensing techniques are some of the tools used to achieve these tasks (Dutertre et al., 2013; Galparsoro et al., 2013; Buhl-Mortensen et al., 2015). These tools offer a broad-scale synoptic view of benthic environments and provide data that could be used to evaluate temporal and structural changes in the communities (Elith et al., 2011; Reiss et al., 2015; Zapata-Ramirez et al., 2013b; 2014).

Current improvements in remote sensing tools (e.g. Multibeam echosounder systems (MBES) and georeferenced photo or underwater videos) result in an increasing availability of environmental data in the Mediterranean sea (Rovere et al., 2010; Bo et al., 2011; Micallef et al., 2012; De Juan et al., 2013; Fabri et al., 2014; Lo Iacono et al., 2014). Contributions from these approaches combined with habitat/species distribution models are substantially advancing the knowledge about the relation of environmental data and habitat/species at different geographic scales (e.g Brown et al., 2011; 2012, Levin et al., 2014). These models estimate the response of species to environmental factors, projecting them into the geographical space to derive the probability of the presence in the areas under consideration. As well, they can define the suitability of specific environmental conditions for the target species (Mellin et al., 2010; Fourcade et al., 2014). More specifically modelling techniques can be applied (i) to forecast changes in benthic species distribution patterns and their possible relation with climate change (Elith et al., 2011; Gomley et al., 2013; Reiss et al., 2015), (ii) to aid in the assessment of habitat distributions in areas that, due to their complexity and/or depth, are difficult to evaluate and show limited data access (Davis and Guinotte, 2011), (iii) in areas where no systematic surveys are available, to predict habitat and species presence (Martin et al., 2014), (iv) to identify the importance of Environmental Variables (EVs) in structuring marine benthic habitats (e.g Dolan et al., 2008; Tong et al., 2013; García-Alegre et al., 2014) and, (v) to assist marine spatial planning (MSP) by proposing new zoning procedures (Greathead et al., 2014).

Coralligenous habitats, and organisms inhabiting caves and overhangs, are ideal for habitat mapping and predictive modelling approaches due to their sessile nature, their longevity and because they are native carbonate build-ups that increase complexity producing structures with three dimensional shape (Zapata-Ramirez et al., 2013a). However, only a limited number of studies that include interpretations of coralligenous and cave distribution together with their associated biocoenoses have been conducted (Bo et al., 2011; Barbera et al., 2012; Gordini et al., 2012; Bonacorsi et al., 2012). Regarding distribution modelling techniques, MaxEnt has been used recently to predict coralligenous distribution throughout the Mediterranean basin (Martin et al., 2014). Even if these first results are very important, and are stimulating new research in this field, the resulted resolution in the spatial analysis remains low and coarse to be applied as a management tool in Marine Protected Areas (MPAs). In fact, the International Union for Conservation of Nature (IUCN) in their 2012 report stated that “80% of the Mediterranean MPAs were smaller than 200km2 and, thus only fine-spatial-scale-resolution data could result adequate for management and urgent maps are required at this scale” (IUCN, 2012). Consequently, the main objectives of this study were two-fold: i) test the potential of well-known remote sensing and distribution modelling techniques to detect the importance of the EVs that contribute to the distribution of coralligenous and cave environments in Portofino MPA and ii) assess the resulting maps as a potential tool in management strategies contributing to the MSDF requirements.

2. Study area

2.1. Regional setting

The study area is situated in the Ligurian Sea, which is located at the northernmost sector of the western Mediterranean (Fig. 1). The region presents a very complex tectonic setting characterized by patterns of differential uplift and subsidence that has previously been described in detail together with the geological characteristics (Fanucci, 1987; Federici and Pappalardo, 2006; Faccini et al., 2009; Corradi et al., 1984; Rovere et al., 2010, 2011). The Portofino Promontory is located about 25km E of Genoa, extending into the Ligurian Sea for more than 3km with a coastline of about 15 km (Figure 1). The Promontory breaks the continuity of the coastline covering a surface area about 18 km2

(Brandolini et al., 2006; Faccini et al., 2008). The vertical cliff of the Promontory is characterized by an Oligocene conglomerate that is cut by many tectonic lineations that shape the present geomorphology of the area (Faccini et al. 2008). On the western side, the promontory extends in a N-S direction and is almost rectilinear for about 3 Km (between Camogli and Punta Chiappa); the eastern side which runs parallel to the western side, evidences the geomorphological variability in the study area (between Santa Margherita and Punta del Faro). In the southern side are located the inlets of Cala dell'Oro and San Fruttuoso, which present a general E-W orientation and extends for a length of about 6.5 km (Figure 1). The shelf-break runs along the coast, at an average distance of 10 km from the waterline and at a depth of 115-150 m (Corradi et al., 1984). From an oceanographic perspective Portofino MPA lies within the Ligurian current, which moves from east to west (Zeichen et al., 2008). The narrow continental shelf, produces a tunnel effect of the coastal current that considerably increases the dynamic of the area (Zeichen et al., 2008). The high active cliffs along large stretches of the coastal sector are characterized by karts landforms that are due to the continuous wave action (Brandolini et al., 2006). In addition, occurrences of rock fall and topple are common along the active cliff bordering the entire Promontory and are due to wave and gravity actions (Faccini et al. 2008).

2.1.1.The Portofino MPA

Portofino was declared Marine Protected Area (MPA) by the Environment Ministry Decree in 1999 (Law_979/1982), though, was not effective until 2001. The entire MPA (Eastern Ligurian Sea 44°18.18'N; 09°12.83'E) covers about 346 ha and contains one small "no entry-no take" area (A zone or integral reserve), two "entry regulated" and –"take regulated" zones (B zones) and two buffer zones (C zones). For monitoring convenience, the staff of the MPA has divided the coastline in 18 smaller management units (Fig.1). The choice of the limits of the A, B, C zones was based not only on their environmental value, but also on the different local economic interests such as, artisanal and recreational fishing, tourism, diving and mariculture activities.

3. Method

3.1 Classification approach

The implementation of the MSFD requires properly classified habitats in an understandable and integrated way. For this, the European Nature Information System (EUNIS) provides a common European reference set of habitat types to permit the reporting of habitat data in an analogous way for nature conservation such as inventories, monitoring and assessments (Galparsoso et al., 2014). In order to provide insights about MSFD descriptor 1 ("Biodiversity"), habitat mapping classifications were defined based on EUNIS (A4) "Circalittoral rock and other hard substrata": 1) ''Mediterranean coralligenous communities moderately exposed to hydrodynamic action'' (code A4.26) and *facies* associated with *Eunicella cavolini* (code A4.269), *Eunicella singularis* (code A4.26A), *Paramuricea clavata* (code A4.26B), 2) communities of circalittoral caves and overhangs (code A4.71) and *facies* associated with *Parazoanthus axinellae* (code A4.712); *Corallium rubrum* (code A4.713) and *Leptopsammia pruvoti* (code A4.714). Other types of substrates were also included in the classification and related to EUNIS (A5); Sublittoral sediment: 3) "Mediterranean communities of well sorted fine sands" (code A5.236) and 4) Mediterranean animal communities of coastal detritic bottoms (code A5.46)

Although, there is not a standard classification system for descriptor 6 (seafloor integrity), it is well known that the geomorphology defines the boundaries of ecosystems (Post et al., 2007). Therefore, we accounted during the ground truthing activities for the bedrock geomorphic features such as cliffs, rock falls, stacks, caves and overhangs as indicators of the seafloor integrity which are commonly associated with particular habitats and biological communities (Marine habitats in Annex I). Thus, the final classification habitat map was based on layers with information of: i) the type of substrate associated (indicating the level for hard and sedimentary habitats) with their geomorphic features respectively and ii) biological zoning (associated facies) to produce a EUNIS distribution map of coralligenous and communities of circalittoral caves and overhangs (Table 2).

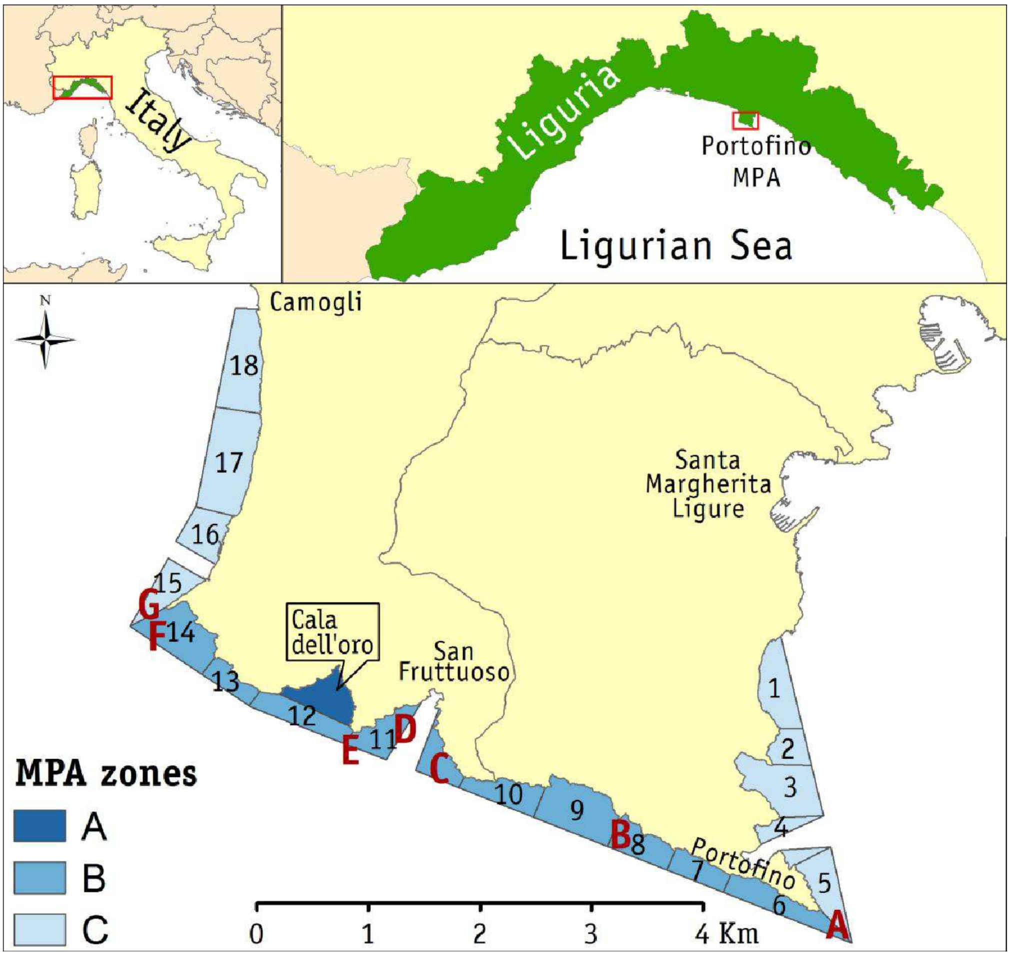


Fig. 1. Location of Portofino MPA in the Mediterranean Sea. The map illustrates the management zones (ZA,ZB,ZC) and subzones (1-18) as well as the sampling sites: A- "Punta del Faro", B- "Altare", C- "Colombara", D- "Punta dell' Indiano", E- " Punta Torretta", F- "Secca dell' Isuela" and G- "Punta Chiappa".

3.2 Remote sensing and in situ measurements

We used processed Multibeam bathymetry data collected with a Multibeam system SONIC 2024 (Selectable Frequencies 200-400kHz) during 2010 and provided by the Ligurian Region (Dipartimento Ambiente, Regione Liguria, ARPAL). Bathymetric data were exported as 32-bit raster files with a cell size of 1m. Such output was projected from Monte Mario (fuso 2) to ETRS-89 LAEA spatial reference system. A suite of techniques that segment the acquired MBES data in terms of seabed morphology and composition were combined.

Table 2 European Nature Information System (EUNIS) classification system employed to characterize the benthic habitats presented in Portofino MPA

CLASSIFICATION	CODE	TITLE
EUNIS	A4.26	Mediterranean coralligenous communities moderately exposed to hydrodynamic action **(here refered as Octocorals facies)**
	A4.269	Facies *Eunicella cavolinii* **(scatter Octocorals)**
	A4.26A	Facies *Eunicella singularis* **(scatter Octocorals)**
	A4.26B	Facies *Paramuricea clavata*
EUNIS	A4.71	Communities of circalittoral caves and overhangs **(here refered as semi dark communities**)
	A4.711	Sponges, cup corals and anthozoans on shaded or overhanging circalittoral rock
	A4.712	Caves and overhangs with *Parazoanthus axinellae*
	A4.713	Caves and overhangs with *Corallium rubrum*
	A4.714	Caves and overhangs with *Leptopsammia pruvoti*
EUNIS	A5	Sublittoral sediment
	A5.236	Mediterranean communities of well sorted fine sands **(here refered as sandy silts and silty sand)**
	A5.46	Mediterranean animal communities of coastal detritic bottoms **(here refered as a rocky fall deposits and/or coarse sand)**

i) We used the Benthic Terrain Model (BTM) extension on ArcGis 10.2 platform (ESRI, Redlands, CA, USA) to define sea-bed morphology. The BTM generates a basic acoustic-sampling model for habitat mapping, which has been developed and implemented within a GIS context (Wilson et al., 2007). This model is based on bathymetric data derivate by the MBES. We calculated depth, slope, rugosity, and the Bathymetric Position Index (BPI), which is a measurement related to a referenced location that is relative to the location surrounding it. Positive values for instance, generally characterized ridges and other associated features within the benthic terrain (see Wilson et al., 2007 for an extended description of BPI). Besides the classical BTM model, we measured the curvature, due to its relevance outlining currents at local and regional scale, and thus providing information of the exposure to water movements and, in consequence, to the shaping of the habitats (Wilson et al., 2007).

ii) We applied a combination of the MBES derivate layers (slope, rugosity, depth and BPI), carrying out an unsupervised ISODATA classification using ENVI 5.1 software (EXELIS VIS, Boulder, CO, USA) (see Zapata-Ramírez et al., 2013b) in order to map the seabed composition of the study area. The ISODATA map (Fig. 2) shows a rough estimation of the different seabed zones within the study area and with respect to the topography and kind of sediment distribution, providing an indication of where we can expect to find different habitat types (Brown et al. 2012; Buhl-Mortensen et al., 2015). We obtained 7 seabed zones as a result of the classification and later on, after the ground truthing, we related them with the EUNIS classification (Table 1). As coralligenous occurs at the circalittoral zone (Peres and Picard, 1964; Laborel, 1987) we cut the shallow area (-0 to -19m) of the ISODATA classification. Finally, total surface area considered for the models were 5.45 Km2, of which 2.57 Km2 fall inside of the MPA.

We evaluated marine benthic habitats between 2013 and 2014 through ground-truthing, over 285 sites using a survey technique based on checkpoints and video (Zapata-Ramirez et al., 2013b). Ground truthing activities were designed using a random-stratified approach identifying the checkpoints inside of each seabed zone according to the distribution of the ISODATA classification. The sampling design also considered several parameters such as: MPA Zonation, Complexity (rugosity/slope), and the accessibility from land that could help guarantee future monitoring activities as well as potentially more impacted areas.

In order to evaluate the variation in the structural groups relative to the geomorphology, we visited multiple sites within the MPA putting particular attention to the vertical walls and terraced slopes as coralligenous most probable occurrence. The ground truthing was carried out by divers or a VideoRay Pro 4 micro ROV system for areas deeper than 40m. High-definition digital video and images were acquired using two calibrated Gopro Hero (3D system) to collect images, and One Gopro Hero 2 to gather video, lasers and strobes for the divers or the ROV

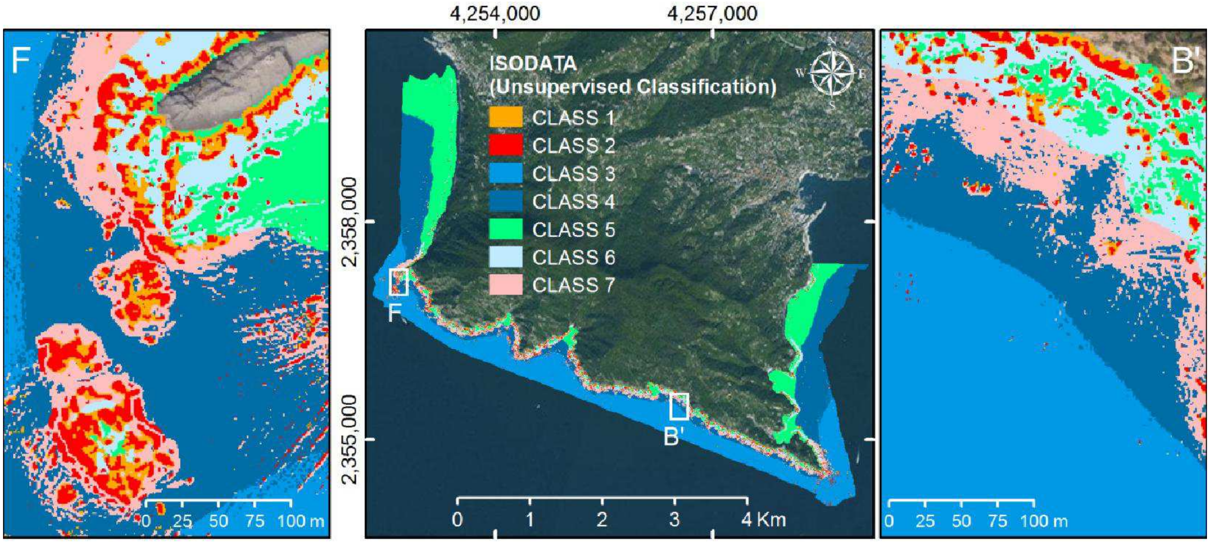


Fig. 2. Unsupervised classification (ISODATA) showing the main seven seabed zones in the study area. On the centre, a general map displaying the results of the entire MPA. On the left, the figure shows a close-up of the study area recognised as “Isuela” - F, a stack formation along the cliff. On the right the figure shows another close-up of the area.

We follow the methodology proposed by Zapata-Ramirez et al., (2013b) where the diver or the ROV swim over the bottom recording benthic composition with video and still photographs for 15 minutes carrying out random horizontal 50m transects (visual census). The video was pointed directly at the seabed and held between 1.0 and 1.5 m from the substratum. Positional information was obtained from an Ultra-Short Base line transponder to record the position of the diver and the ROV in relation to the boat position (Sonardyne Scout System). Ground-truth variables were recorded as seafloor indicators and based on a combination of the main sediment types, the presence absence of the geomorphological features and the presence of the benthic habitat as defined in EUNIS (see table1). Information on physical characteristics and associated *facies* were extracted and linked to the geographic location of the images-video records. In order to assist the habitat distribution modelling, all the information were managed using ArcGIS software.

3.3 Supervised classification and accuracy assessment

We applied a supervised maximum likelihood classification (SMLC) with ENVI 4.5 using the 285 checkpoints records to train and test the SMLC. The classification algorithm is based on image statistics derived from training pixels, representative of each benthic community type that have been determined from the field data and from the BTM. Formal accuracy assessment results were summarized in a standard error matrix and Kappa statistic (Congalton, 1991) was calculated. This matrix was computed over the 285 pixels used for training the classification and compared the 'real' pixel values with the corresponding values attributed to pixels by the classification process (Table 2). The highlighted elements along the diagonal of the matrix contain the cases where the mapped class depicted in the image classification and the ground true data set agree, whereas the off-diagonal elements contain those cases where there is a disagreement in the labels (errors) and are tabulated as totals in the margins (Congalton,1991). These marginal errors represent the proportional error by category. The error of commission was used to determine how to fix the map to increase the accuracy, measuring the probability that a pixel on the map represents that category on the ground (Eastman, 2003). Overall accuracy was computed by dividing the total number of correctly classified pixels by the total number of pixels in the matrix (Congalton, 1991). The Kappa value describes the proportion of correctly classified validation samples after random agreement is removed (Zhang, 2014). Tau coefficient was applied to calculate the global accuracy of the classified map. Tau coefficient statistically represents the chance of agreement between the random classification, the misclassifications, and the true environment (Ma and Redmond, 1995).

3.4 Habitat suitability model and accuracy assessment

In order to predict the habitat suitability (HS) of the bioconcretions within the MPA, we used the machine learning method, MaxEnt. This machine learning approach has performed well in comparable studies and its use is recently increasing in marine ecology (e.g.; Mellin et al., 2010; Gormley et al., 2013; Fourcade et al., 2014; García-Alegre et al., 2014; Reiss et al., 2015), particularly in areas where the focal species is sessile and has a strong relationship with the seafloor characteristics (Brown et al., 2012).

As MaxEnt is a “presence-only” modelling approach, we built the HS models using: i) presence data of coralligenous and cave and overhangs with the checkpoints (88 points) collected during the ground truthing activities and, ii) environmental variables (EVs) that consisted of five layers (depth, slope, aspect, rugosity and BPI derived from the MBES data set. Being aware of our occurrence value (88/285=0.3), we tested the 0.3 prevalence in the advanced settings. However our results do not show any difference using the default prevalence parameters (0.5). Therefore, we used the default parameters as they performed well in other benthic studies (Phillips and Dudık, 2008; Fourcade et al., 2014). The presence data was randomly divided into a training subsample (75% of the total points) and 25% for model testing. We used a 10-fold cross validation to assess model performance. In order to compare the contribution of each variable (when absent from the model) in the model, we used the jack-knifing procedure with a second model that included the variable within the software. Model accuracy between the test data and the predicted suitability models was assessed using a threshold-independent procedure that used a ROC (receiver operating characteristic curve) with area under curve (AUC). The AUC varies between 0 and 1. Values below 0.7 indicate poor prediction, between 0.7 and 0.9, good prediction, and those above 0.9 indicate very good prediction (Greathead et al., 2014). These procedures were used to validate the success distribution of the model and a threshold-dependent procedure that assessed misclassification (Phillips and Dudık, 2008). The final habitat suitability maps were produced by applying the calculated models to all cells of the total surface area (5.45 km2) in the study region, using a logistic link function to yield a habitat suitability index (HSI) between zero and one (Phillips and Dudik, 2008). The logistic probabilistic output map was imported as grid file in ArcGIS. The total area was calculated and used for the zonal statistical analysis.

4. Management applications

We discussed the results of the SMLC and HS resulting maps, and then related them to the management sub-zones areas (see Portofino's MPA description, section 2.1.1) to identify the effectiveness of the management plan and to highlight areas potentially remarkable for protection policies.

5. Results

5.1 Description of the area

A total area of 5.45 Km^2 of which 2.57 Km^2 fall inside of the MPA was classified according to the European Nature Information System (EUNIS) hierarchical classification. Combining bathymetric, BTM derivatives with ground-truthing from visual check-points has proven to be particularly useful in showing the features of the complex topography of the MPA and EUNIS *facies* to be identified. The area studied spans depths ranging from 20 to 90 m covering a variety of geomorphological features including cliffs, caves and overhangs, stack formations, rock-fall deposits, toppling deposits, bedrock, loose sediments and coarse sediments (pebbles and cobbles). MBES data reveal large and high bedrocks outcrops and several marine terraces at 7-10 m; 15-20 m; 25-35 m; 50 m, 70 m developed in a series of steps, each corresponding to the sea level at a given time. Rocks along these typologies are cut by tectonic lineation that allow the formation of caves and overhangs of karst origin successively shaped by marine erosion and characterized in different ways according to the location of the outcrop and their erosive processes. Conversely, platforms with low-relief and smaller scale terraces along slopes and below 40 m depth often contain patchy deposits of rhodoliths which gradually merge into sand sheets. Sediment grain size decreases towards the shelf break and at this point the sediments can be classified as sandy silts with the presence of sediment bed forms and where sparse epibenthos was observed during the ROV inspections at depths between 60 m to 90 m. Some sloping areas contains scattered large blocks and boulders, and lenses of coarse-grained sediments derived from the wall and platform top. In these areas *facies* of

Parazoanthus axinellae (code A4.26C) and *Leptopsammia pruvoti* (code A4.714) are frequent, especially on the eastern side of the promontory, where boulders and pebbles with a patchy distribution occurred. In general terms, fine sediments were generally found in areas with lower slope values (slope ranging from 4° to 12°) and related with Mediterranean communities of well sorted fine sands (code A5.236).

Video-image examination indicated that the majority of the bioconstructions are found on vertical walls and in caves-notch and overhangs where in particular, the slope plays an important role. Cliffs, rocky outcrop and toppling deposits are highly represented MPA management zones “B” and “A” and on the contrary are less frequent in zone “C”. According to our observations, bioconcretions related with EUNIS code A4.26B are linked to the presence of medium to steep rough walls with sparse sedimentary coverage where the slope (ranging from 40° to more than 60°) is steep enough to avoid the deposition off fine particles. A general characterization of the area from East to West show for instance that EUNIS code A426B is well presented in “Punta del Faro”, where scuba and ROV surveys identified several rocky outcrops reaching from 25 m to 70 m depth. In addition, several toppling deposits occur along the cliff and debris and rock falls are often located lying on a bedding plane originated from the face collapse of the cliff.

In “Altare” features of submerged caves notch and overhangs are characterized by typical facies of *Corallium rubrum* (code A4.71). In general terms the place is characterized by a vertical cliff with coralligenous rims where several overhangs between 18-40 m depth occur. Along the cliff there are isolated rocks with no particular orientation and some of them are onlapped by sediments creating a more gentle dipping side. The cliffs are characterized by semi dark communities (A4.712, A4.713, A4.714).

The shallower part of "Colombara" is characterized by rock erosion and surface areas containing fluvial terraces above the mid slopping areas. In this area a wider circular cave around 36 m depth with a very conspicuous presence of *Corallium rubrum* (code A4.71) is well defined. Semi dark communities (codes: A4.712 , A4.713, A4.714) are also denoted on the scattered blocks located in the muddy bottoms of debris below (Rocky fall deposits). Some of the blocks are partly buried, others have scours of up to 15 m adjacent to the blocks along their north-eastern side.

Terraced surfaces such the ones close to “Punta dell’Indiano” are well represented by *facies* of *Eunicella singularis* (A4.26A); “Punta Torretta” shows scattered *facies* of the octocoral *Eunicella cavolini* (A4.269) are present. In these areas seabed morphology shows a well-defined grain size distribution up to the 60m depth. The slope is less steep (ranging for 20◦ ° to no more than 40◦°) ending at 40 m depth in a sandy strip grading from a coarse sediment to silty sand. Generally these *facies* contain a high percentage of biogenic detritus and mainly appear on the foot of the walls and around the rock fall deposits.

In the West part, in front of “Punta Chiappa”, 200 m from the coast is located the “Secca dell’Isuela” (Fig. 1 and 2) an isolated outcrops (stack formation). The formation is characterized by a flat surface that begins at 13 m and then is interrupted at 20 m depth by a large vertical drop descending in a steep cliff ending in a sandy deposit at 60 m depth. Bioconcretions developed along the stack and healthy communities of *P. clavata* (EUNIS A426B) are observed. The presence of caves and overhangs with *Corallium rubrum* (code A4.713) are also well represented. Around “Punta Chiappa” area, the western “C” zone, characteristic of marine planation where meadows of *Posidonia oceanica* reach 35 m deep. Conglomerate deposits of a height of several meters are also present.

5.2 Results from different classifiers

Unsupervised classification, executed considering the 5 data layers extracted from the MBES data set (bathymetry, slope, BPI, curvature and rugosity), resulted in a classified image with 11 classes where 5 of them occupy large areas. The remaining classes were scattered around the study area forming small clusters which in total do not exceed 1.5% of the total area. These clusters were filtered out and the pixels were assigned to the class represented by the majority of neighbouring pixels. Analysing the dendrogram and based on the percentage of cells (pixels) we decided to reduce the original 11 classes into 7 broader classes (Fig. 2).

Regarding the supervised classification method, assessment of the classification accuracy reveals that MBES data allows us to classify the seabed zones and the EUNIS classification of the area, with an overall accuracy of 76% (Table 2). Meanwhile, the overall accuracy of the classification using the Tau coefficient, resulted in τ = 77.1%, which is the percentage of correctly classified pixels. Classification of mapped habitats to EUNIS level was only undertaken where it was felt that the biotope showed an adequately-distinct 'signature' in terms of bathymetric features, slope, rugosity and BPI data values. In general, classes related with Class 3, Class 4 and Class 5 were mapped with high accuracy (100%, 95.7% and 100% user accuracy, respectively), Class 6 as well classified with very high accuracy (92.3%) and octocorals *facies* (Class 2) with good accuracy (86.7%), but is was harder to reliably distinguish between Semi dark communities (Class 1) and Scatter octocorals *facies* (Class 7) (48.5% and 50% accuracy, respectively). The greatest amount of misclassifications occurred between Class 2 and class Class 7. From the 33 points for Class 1, 8 points were classified as Class 2 (octocorals *facies*). Some confusion also occurs between class Classes 4 and 7. From 56 points visited of class 7 (scatter octocorals *facies*), 16 points fall down in class 4 (commission error 30.8/3.4). The standard error matrix is shown in Table 2 and the obtained map from the supervised classification is presented in Fig. 3.

We analysed the performance of the Maximum Entropy approach (MaxEnt) to detect the most suitable habitats for the species present in the bioconcretions and to identify which environmental variables influence their distribution. As MaxEnt is a presence-only modelling approach we merged Class 1, 2 and 7 as presence and we used the layers extracted from MBES measures of geophysical substrate properties as the environmental variables (EVs). The MaxEnt model achieved an AUC score of 0.976 for the training data set and 0.975 for the test data (see supplementary material Figure S1) and were significantly different from that of a random prediction of AUC= 0.5 (Wilcoxon rank-sum test, p=0.01) proving that the model can be considered useful (Phillips and Dudik, 2008). The result shows that the EVs chosen are important parameters to explain the distribution of the bioconcretions in the MPA. Slope (53.2%), and rugosity (19.4%) were the two main contributors to the model, followed by Bathymetric Position Index (17%); reflecting the bioconcretions association with elevated topography, while Depth (8.5%) contributes less to the final model. Curvature (1.9%) was the least significant variable for the bioconcretions as no clear curvature preference occurred (see supplementary material Table S1).

Table 2. The error matrix containing a tabulation of number of sample check-points found in each possible combination of true and mapped categories.

ERROR MATRIX									
Class	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**Total**	**Commission error (%)**
1. Semi dark communities	**16**	7	0	0	0	0	1	24	33.3
2. Octocorals facies	8	**52**	0	0	0	0	1	61	14.8
3. Sandy silts	0	0	**36**	2	0	0	0	38	5.3
4. Silty sand	3	0	0	**45**	0	1	16	65	30.8
5. Coarse sand	0	0	0	0	**27**	1	1	29	6.9
6. Rocky fall deposits	5	1	0	0	0	**24**	9	39	38.5
7. Scatter octocoral facies	1	0	0	0	0	0	**28**	29	3.4
Total	33	60	36	47	27	26	56	285	
User accuracy (%)	48.485	86.7	100	95.7	100	92.3	50		0.2
Overall accuracy (%)	**76.40%**								
Tau (%)	**77.10%**								

Notes: The total in each column represents the total of ground sampling points for the class; the total in each line represents the number of pixels attributed to this class. The highlighted elements along the diagonal of the matrix contain the cases where the image classification map classes agree with the ground truth data. Off-diagonal values represent the number of wrongly classified ground points: in each line these values represent the number of ground point wrongly attributed to the class; in each column these values represent the number of ground points not attributed to that class. Overall accuracy and Tau percentage are also presented.

The interpretation of the Jacknife tests of variable importance revealed that in general terms, the model generated relied heavily on the slope showing that it was the most influential EV in determining HS as well as the one having the most information that was not contained in other EVs (see supplementary material Figure S2). Analysis of response curves, produced using only the corresponding variable, reflect the dependence of the predicted HS on the slope, especially in areas with high-relief bedrock and where the BPI shows positive values. Fig. 4F reveals the predicted occurrence of the bioconcretions in a representative area of steep slopes located at “Secca dell’

Isuela", and where facies of Class 1 (semi dark communities) and Class 2 (octocorals facies) are well distributed and distinguished.

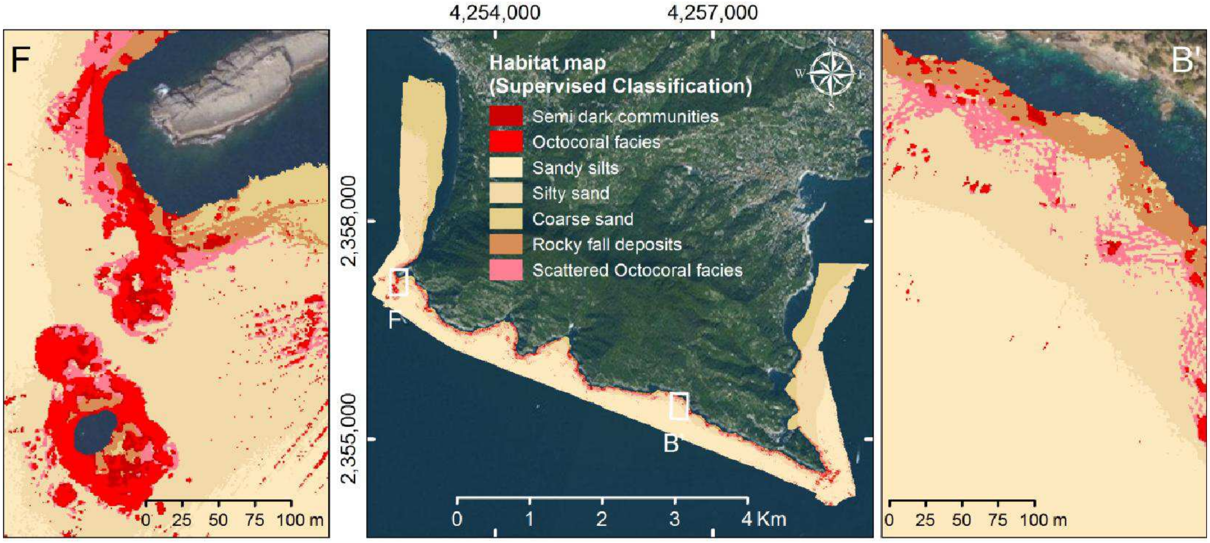


Fig. 3. Map of the supervised classification (maximum likelihood classification (SMLC)) of the marine benthic habitats located at Portofino MPA. On the centre, a general map displaying the results of the entire study area. On the left, a zoom in one of the sampling sites ("F-Secca dell' Isuela") and on the right a close-up showing a different distribution pattern of the communities located at the North-West of "Altare" – B'.

5.3 Zonal statistical analysis.

Cumulative analysis shows that the management units with higher surfaces areas where our habitats in consideration occurred (54% for SMLC and 58% for MaxEnt) are located in subzones 11, 14, 6, 5 in both models. As shown in the Table 2, both models order the management subzones, based on the rank percentage, in a similar way.

6.Discussion

This study employed remote sensing, habitat mapping techniques and HS models commonly and extensively applied in marine benthic habitats (Brown et al., 2011, 2012; Micallef et al., 2012; Dutertre et al., 2013; Tong et al., 2013; Zapata-Ramirez et al., 2013b; Martin et al., 2014; Fourcade et al., 2014; García-Alegre et al., 2014; Buhl-Mortensen et al., 2015) to examine habitats/facies relationships on coralligenous and cave environments based on MBES acquired data of Portofino MPA. We adopted a three-step approach to empirically map the distribution of coralligenous and cave environments at this MPA. First using a combination of textural and morphometric analyses of the bathymetric data with which we applied an unsupervised classification model to detect seabed zones in the study area and to support the definition of training and test data for the SMLC. Then we used a supervised classification model to estimate and to identify the areas dominated by bioconcretions. Finally we adopted a machine learning approach (MaxEnt) to recognize how EVs based on high resolution bathymetry influence the distribution of these bioconcretions at the MPA.

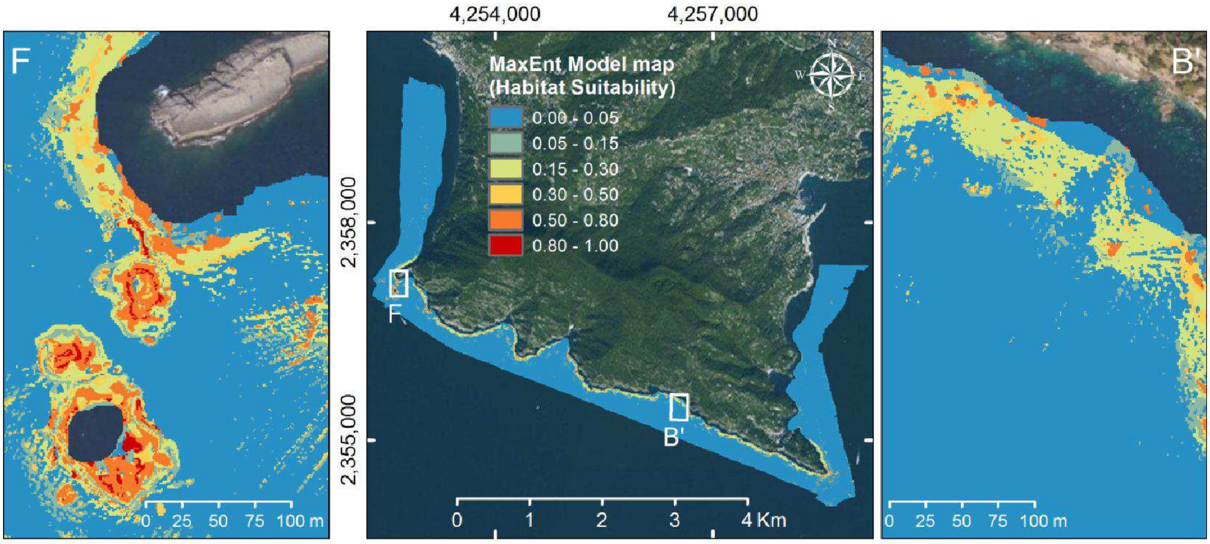
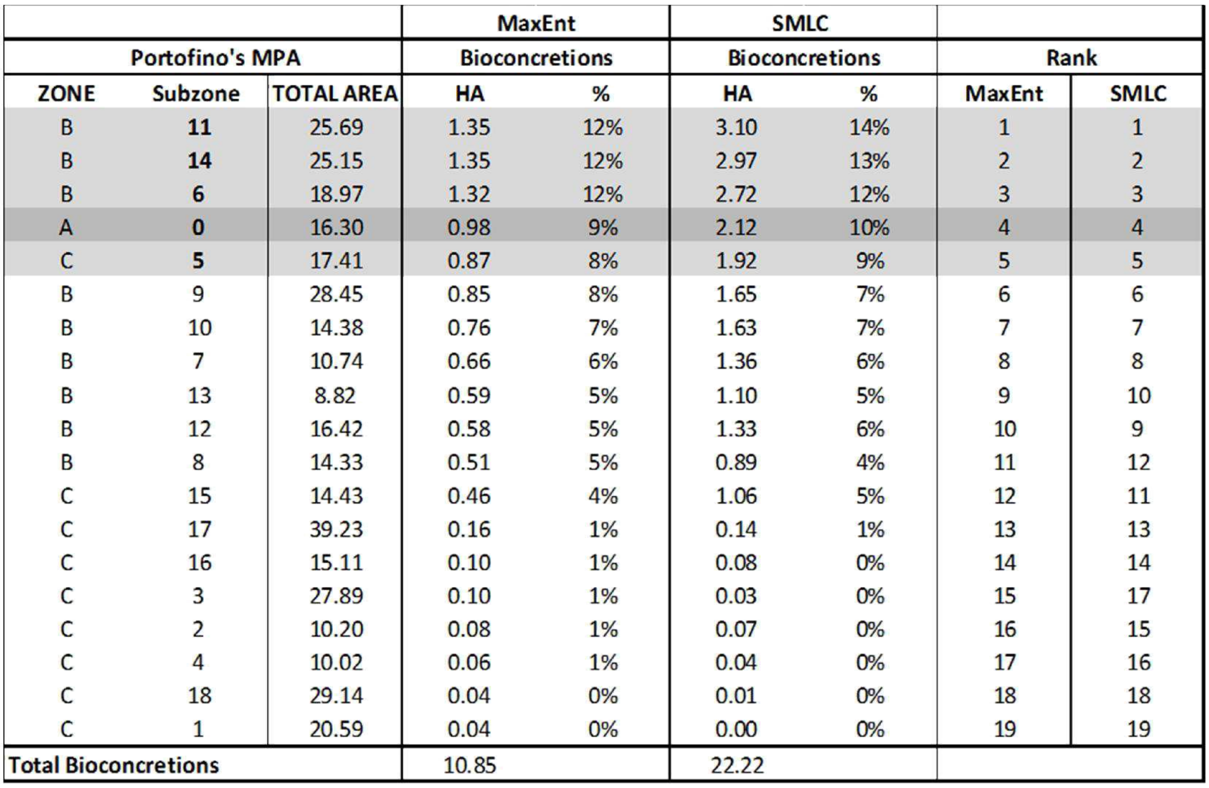


Fig. 4. Habitat suitability model (MaxEnt) revealing the predicted occurrence of the bioconcretions located at Portofino MPA. On the centre, a general map displaying the results of the entire study area. On the left, a zoom in one of the sampling sites ("F-Secca dell' Isuela") and on the right a close-up showing a less suitable area for coralligenous located at the North-West of "Altare" B' Blue background indicates that bioconcretions are not present (probability < 0.05). Light blue – green and yellow shades indicate low probability (< 0.50). Orange and dark red indicate high probability of presence (> 0.50).

A clear association between *facies* distributions and the physical structures was observed, yielding 6 distinct associated *facies*: *Eunicella cavolini* (code A4.269), *Eunicella singularis* (code A4.26A) and *Paramuricea clavata* (code A4.26B) associated with class 2 and 7. We kept these two classes, octocorals *facies* (class 2) and scatter octocorals (class 7) in order to have specific information on the reef structure, which is mainly related to dense coral. Finally *facies* of *Parazoanthus axinellae* (code A4.712), *Corallium rubrum* (code A4.713) and *Leptopsammia pruvoti* (code A4.714) associated with class 1 (semi dark communities).

Table 3. Zonal statistical analysis between management subzones in Portofino MPA. Percentages show the hectares (HA) covered by bioconcretions out of total area. The subzones are sorted according to the bioconcretions presence from the most (1) to the least (19) covered (columns Rank). The order is very similar for both methods.



			MaxEnt		SMLC			
Portofino's MPA			Bioconcretions		Bioconcretions		Rank	
ZONE	Subzone	TOTAL AREA	HA	%	HA	%	MaxEnt	SMLC
B	**11**	25.69	1.35	12%	3.10	14%	1	1
B	**14**	25.15	1.35	12%	2.97	13%	2	2
B	**6**	18.97	1.32	12%	2.72	12%	3	3
A	**0**	16.30	0.98	9%	2.12	10%	4	4
C	**5**	17.41	0.87	8%	1.92	9%	5	5
B	9	28.45	0.85	8%	1.65	7%	6	6
B	10	14.38	0.76	7%	1.63	7%	7	7
B	7	10.74	0.66	6%	1.36	6%	8	8
B	13	8.82	0.59	5%	1.10	5%	9	10
B	12	16.42	0.58	5%	1.33	6%	10	9
B	8	14.33	0.51	5%	0.89	4%	11	12
C	15	14.43	0.46	4%	1.06	5%	12	11
C	17	39.23	0.16	1%	0.14	1%	13	13
C	16	15.11	0.10	1%	0.08	0%	14	14
C	3	27.89	0.10	1%	0.03	0%	15	17
C	2	10.20	0.08	1%	0.07	0%	16	15
C	4	10.02	0.06	1%	0.04	0%	17	16
C	18	29.14	0.04	0%	0.01	0%	18	18
C	1	20.59	0.04	0%	0.00	0%	19	19
Total Bioconcretions			10.85		22.22			

Analysing the classification output of both models (SMLC and MaxEnt) on a more general basis, the results indicate that the bioconcretions were more likely to occur in areas characterized by a rocky seafloor with complex topography, steeply sloping seabed and higher rugosity, as opposed to flatter areas, located in water depths between 20 and 70 m. Narrow continental shelf produces a tunnel effect of the north westward coastal current, which flows approximately along the isobaths increasing significantly the hydrodynamic of the area (Zeichen et al., 2008). Therefore, it provides favourable conditions for suspension feeders, and corals in particular, to grow. In addition, the high current velocities are believed to cause high re-suspension, providing increased of food supply (Gori et al., 2011; Bo et al., 2011) since these structures are well-known to accelerate the local current flow (Brandolini et al., 2006). The vertical cliffs and overhangs identified prevent the coral framework being buried by sediments (Balata et al., 2005; Piazzi et al., 2010; Huvenne et al., 2011). Siliciclastic sediment observed around the coral framework is mostly coarse sand, which suggests that strong currents prevented fine-grained sediments from settling or washed it out in coral rich zones. These observations indicate that baffling of sediments by the coral structures support the framework and strengthens the construction. The influence of food supply and their relation with the topography and the current patterns has been previously recognized (Gori et al., 2011 and reference therein), it is thought that they determine the distribution of gorgonians and cold-water corals on both large and small scales. The *facies* observed in this study showed similarities in their basic geomorphology to others described in areas characterized by vertical cliff and overhangs of the seabed (Gori et al., 2011; Kipson et al., 2014; Gatti et al., 2015; Casas- Güell et al., 2015) which indicated that our predictive maps are consistent with spatial patterns previously documented for the same bioconcretions in the Mediterranean region with a variety of methods.

Likewise and more in detail, both models (SMLC and MaxEnt) mapped and predicted similar spatial distributions of the bioconcretions at the study area. However and as discussed below, MaxEnt was more conservative in its estimation whereas the SMLC displayed broader predicted presence. From the analysis of statistical results of the SMLC, sand was in general well classified and only relatively minor misclassifications occurred (Table 2). Although sediment samples were not collected and just check point observations were performed, we feel confident about the visual identification of the grain sizes and the high accuracy achieved. This high accuracy can be explained by their distinctive backscatter response, where finer sediment classes and smoother bottoms absorb more sound (Harris and Baker, 2012) making them more easy to detect . Conversely, major misclassifications occurred between class 1, 2 and 7 (that contain the main 5 associated facies) and were difficult to separate. Octocoral *facies* (class 2) were easily distinguished from scattered octocorals *facies* (class 7) but were acoustically confused with semi dark communities (class 1) resulting in low map accuracies for semi dark communities (class 1). Large changes in the geomorphology over short distances, especially near the notches, caves and overhangs, probably caused some misclassification and increased prediction error in Class 1. These findings are also in general agreement with the earlier study by Laborel (1987) which reports that lips and rims are found in the outer part of marine caves and on vertical cliffs and show a striking parallelism one to another. The peculiar geological features of the Promontory and its related karstic processes along the cliffs, have allowed the formation of marine caves (Rovere et al., 2010) along a definite bathymetric range. Therefore, they present small spatial scales (10’s of m) providing physical habitat to specific marine communities as for instance caves and overhangs with *Corallium rubrum* (code A4.713). Regarding this misclassification, Huvenne et al., (2011) stated that steep cliffs are generally not represented accurately, due to the limited spatial resolution of acoustic systems in deep water and the associated smoothing effect of the gridding process. This issue is documented in the scientific literature, and has been recognized as an area of research requiring further consideration in order to enable significant advances in mapping activities for coralligenous and cave environments (Garrabou et al., 2014). Nevertheless, larger accuracy improvements could be obtained in the near future with the growing availability of remotely operated vehicles (ROVs) and autonomous underwater vehicles (AUVs) and the ability to install the MBES forward-looking to the wall rather than the normal downward-looking, configuration (Huvenne et al., 2011). Therefore, in the future, more accurate estimates of total extent of these bioconcretions will be best achieved and will be of significant value for regional-scale marine habitat modelling. Some confusion also occurred between scattered octocoral *facies* (56 visited points of Class 7) were classified as silty sands (16 points fell in Class 4). One possible explication, is that for instance in the case of facies of *Eunicella singularis* (code A4.26A) and *Paramuricea clavata* (code A4.26B) they can occur on bottoms with different inclinations; as well in areas often partially covered with sediment and not in hard bottoms, they could also be present on detritic bottoms where coarse fragments can allow larval recruitment (Weinberg 1975; Ballesteros 2006; Fava et al., 2010; Gori et al., 2011). Therefore, this could be not a real "misclassification" in this case since these *facies* could be also found in Class 4 in less proportion. Highest abundances of a certain species are commonly found in areas where environmental conditions are most favourable, though gorgonian colonies have been reported to occupy less than ideal regions of the seabed (Tong et al., 2013). Moreover, recent massive mortalities events can have altered the pristine densities of these species (Cerrano et al., 2005). In general, different misclassification difficulties have been reported by previous studies in similar marine benthic habitats, where overall mapping accuracy decreases with an increase in spatial complexity or richness of benthic communities (Zapata-Ramirez et al., 2013b and references therein). Nevertheless, the relatively high spatial density of check points allowed to characterized the differences of the *facies* distribution across the MPA caused by changes in the morphology of the seabed. This allows us to predict with a good accuracy the distribution of the main *facies* and build fine-scale maps for the MPA. In addition, the estimation of the accuracy provided by this method is a useful tool for future improvements in planning models based on a quantified degree of confidence (Rattay et al., 2009). The result of the HS model shows that slope (53.2% of contribution) was the most influential EV in determining the distribution for coralligenous and cave environments. This result is in line with a recent investigation at the study area conducted by Giusti at al.,(2014a). The authors found the slope as one of the main contributors to predict the distribution of *Corallium rubrum facies* at "Isuela". The study used Ecological Niche Factor Analysis (ENFA) predictive model to simulate the distribution and identified rocky sites with high inclinations as preferred habitat for corals. Our findings are also in general agreement with a recently study at Mediterranean scale by Martin et al., (2014). They also found the slope (31.9 % of contribution) as one of the main contributors for coralligenous distribution in the region using MaxEnt and producing a broad-scale distribution map. Slope has been considered a key factor determining the distribution of coralligenous and cave environments at different levels: regulating the presence of and abundance of gorgonians (Gori et al., 2011), maintaining the community beta diversity (Piazzi et al., 2009), supporting the quality of coralligenous reefs (Gatti et al., 2015) and enhancing the coexistence of communities with different bathymetric requirements (Bo et al., 2011). In addition, our Jackknife tests (MaxEnt) highlighted the slope as well as the most influential EV in determining HS. Results also show rugosity (19.4% of contribution) as an important EV factor demonstrating that the physical structure and complexity can be extremely variable in coralligenous and in cave environments where little-scale rugosity of the limestone is frequently present. However as previously stated, this variable was no easy to map due to the vertical organization of the *facies*. Nevertheless, and acknowledging this issue similar results were found by Giusti et al*.,* (2014b) who identified rugosity as an important EV for the distribution of *Savalia savaglia,* another associated coralligenous species. Rugosity promotes lithification of depositing particles and retains sediment (Ballesteros, 2006), provides three-dimensional space for different species influencing the structure and diversity of the associated fauna and has been identified as an important factor to determine seafloor integrity (Rice et al., 2012). BPI was also a good predictor (17% of contribution) and a good indicator for the establishing differences between terrain features. Results indicate lower *facies* distribution in flat areas, a trend also supported by the relationship observed between general slope and rugosity values. Among these, depth appears to play a smaller role (8.5% of contribution) than slope and rugosity. While the use of depth-related features is a known parameter in explaining coral distribution (Daveis and Guinotte, 2011), we found that this EV is important but not as critical as the slope in terms of structuring the bioconcretions in the study area. These findings coincide with other biological studies on coralligenous environments independently of their geographical occurrence were the structure of the assemblages is related to the geomorphological zonation rather than depth (Ferdeghini et al., 2000; Piazzi and Balata, 2011; Bo et al., 2011). In general, the results of the HS models show how each one of the EVs derivate from MBES contribute with their development and respond to the local geomorphology, showing that the highly suitable habitats were located in steeply sloping areas where the terrain is structurally very complex.

As stated before, the resulting models obtained by this study reached good accuracies, scoring between 76.4% and 98.4% suggesting usefulness of the models (Phillips and Dudik, 2008). Although predictions between SMLC and MaxEnt differed slightly (see Table 2), the general features follow similar trends, in particular in the areas where most of our considered habitats occur (subzones: 5, 6

,14 ,11). Hence, both models were able to produce high-resolution maps providing valuable spatial representations of the seafloor characteristics and the distribution of the bioconcretions of the survey region. Overall, our results show that it is possible to implement the principles methods and specific techniques used in habitat mapping applications (Dolan et al., 2008; Brown et al., 2012; Micallef et al., 2012; Dutertre et al., 2013; Zapata-Ramirez et al., 2014; García-Alegre et al., 2014; Buhl- Galparsoro et al., 2013; Mortensen et al., 2015;) to assess and classify the main characteristics that delineate the distribution of coralligenous and cave habitats. Although in this study the supervised classification used resulted in low accuracies for Class 1 and 7 and high ambiguity between Class 1 and 2, the substrate types had distinct acoustic signatures and better accuracies, implying that the MBES data alone through the unsupervised classification method (ISODATA) could be used to map different seabed zones. Then, this classification method could be used as a surrogate variable to determine the highest probabilities of *facies* distributions, using the results as an EV to run further distribution modelling approaches. In addition, the ability of MaxEnt algorithm to evaluate the importance of the various predictors was used to build a simpler model and to detect how EVs based on MBES influence the distribution of the habitats in consideration. Therefore, the results bring insights on how MBES acts as a potential tool to define the distribution on the studied habitats and the expected biocoenosis at the different habitats, allowing the evaluation of the possible reasons of discrepancy in the model results. If the estimated habitats or biocoenoses are not present it could be possible to investigate if pressures alter the expected GES. Given the inherent errors associated with the natural heterogeneity and the complexity of coralligenous and cave/overhangs environments, we consider this approach to have been successful representing the first application of these techniques at such fine scale in these habitats. Given our results, we can reasonably argue that the identified morphologies could represent distinct phases of morphological development from cliffs to caves-overhangs. Therefore and depending on the monitoring protocols implemented, we suggest that in the case of Portofino MPA monitoring activities should be combined since these *facies* develop at the same sites. Hence, the integration between the two habitats and their connections in management strategies, protection and conservation would be more effective.

6.1 Implications for management

Our results show the applicability of the produced maps for management proposals, identifying areas of greater coverage of bioconcretions in management sub-zones (*i.e* 5, 6 and 14) where the level of protection is low. In addition, MPA management report (Cappanera et al., 2013) shows the same sub-zones are the most impacted areas regarding recreational fishing. Furthermore, the report states that zone B is more frequented by fishermen than zone C (56% vs 44% respectively). Another detailed work recently published by Markantonatou et al., (2014), shows that in addition of the subzones identified by the MPA managers, subzone 11 is as well strongly impacted by fishing activities such as longlines, trolling and “natelli”. Lost fishing-lines were observed during field trip activities, most frequently at “Punta del Faro” (subzones 5 and 6) and “Punta Chiappa” (subzone 14 and 15) mainly entangling *Paramuricea clavata* colonies (code A4.26B). The fishing impact at “Punta del Faro” had already been acknowledgment event before the establishment of the MPA (Bavestrello et al., 1997) as well as recently (Vezzulli et al., 2013). These researches emphasize fishing activities as a possible factor enhancing the vulnerability of *P. clavata* colonies towards climate change, highlighting the necessity of considering a revision of the sub-zone level of protection in order to improve and reach a GES at the study area. In light of the MSFD requirements, the methodological assessment would be an asset for managers providing information regarding descriptors 1 and 6. In particular, the results present a valuable tool for criterion 1.4 (Habitat distribution); Criterion 1.5 (Habitat extent); Criterion 6.1 (Physical damage, having regard to substrate characteristics); Criterion 6.2 (Condition of benthic community) and Indicator 6.2.4 (Parameters describing the characteristics (shape, slope and intercept) of the size spectrum of the benthic community) providing robust indicators and possibly control sites in the MPA. Moreover, the results obtained suggest potential applications for ecosystem based management, strengthening the importance of fine-scale habitat maps as a baseline data for monitoring activities. The methodological framework presented here, can represent a step forward in constructing cost-effective, time saving and highly repeatable monitoring actions for MPA management decisions that could be in addition, applicable at different marine ecosystems.

6.2 HS Potential improvements

For HS distribution models, inclusion of water quality parameters and hydrodynamic models in the methodological framework may further improve the classification accuracy. Adding supplementary information on current velocities, temperature and salinity has been reported useful to help to elucidate the spatial patterns of benthic organisms (Dutertre et al., 2013; Greathead et al., 2014; Reiss et al., 2015). However, and as stated by Brown et al.,(2011), oceanographic data resolution is considerably coarser in relation to topographic variables derived from acoustic methods, and the high variability of these oceanographic variables makes comparison difficult, thus adequate detail and variability levels have to be well assessed before integrating all these variables.

6. Conclusions

We mapped and model the area with acceptable accuracy (Tau coefficient = 77%/ AUC score of 0.976) providing a critical baseline information of the current state and extent of benthic habitats at Portofino MPA. Moreover, a general structural scheme and classification has been implemented and the procedure is an attempt for the application of well-known methods for the first time employed in these habitats. The information provided could help to build definitions of new synoptic indicators of GES for coralligenous and cave environments. Results show that our methodology provides high-resolution and full coverage surveys of selected areas beneficial to accurately revisit zones during monitoring activities. In addition, the maps produced could facilitate decision makers to address specific management needs within the MSFD. The methods here presented are simple and cost-effective and thus represent a useful solution for extended monitoring of benthic habitats and assemblages. Hence, the results presented here fit the aims of MSFD by generating spatial mapping of coralligenous and cave/overhangs environments, building a key baseline for their monitoring and to define GES.

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“A multi approach to map and model the distribution of coralligenous and cave environments. A case study at Portofino Marine Protected Area (Ligurian Sea, Italy).”

Paula A. Zapata-Ramirez, Carla Huete-Stauffer, David Scaradozzi, Michele Marconi and Carlo Cerrano

Supplementary data

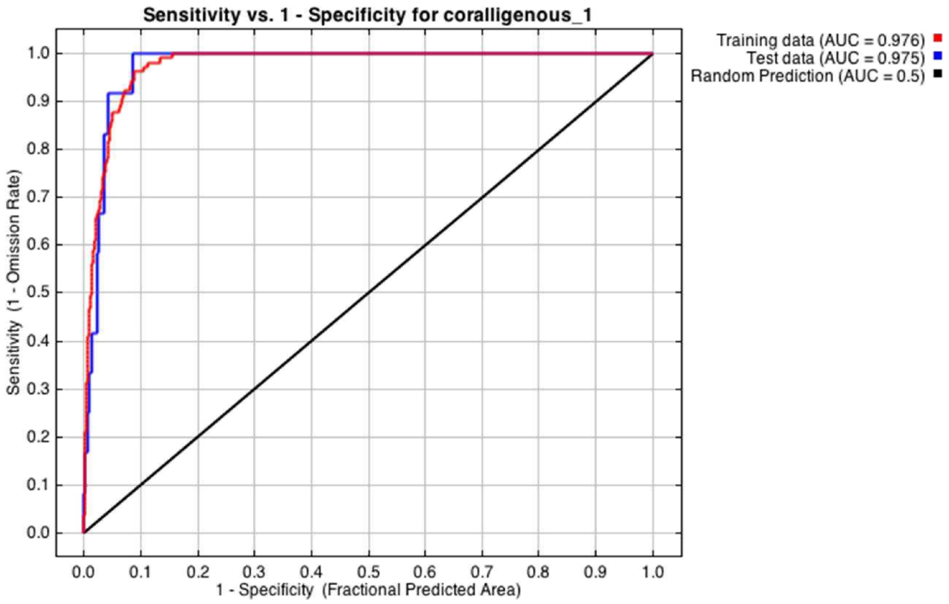

Figure S1. ROC curves for the training (red) and test (blue) sets of bioconcretions occurrence.

Table S1. Analysis of variable contributions. The table gives estimates of relative contributions of the environmental variables to the MaxEnt model.

Variable	Percent contribution	Permutation importance
Slope	**53.2**	**58.3**
Rugosity	19.4	9.9
BPI	17	7.4
Depth	8.5	21.7
Curvature	1.9	2.7

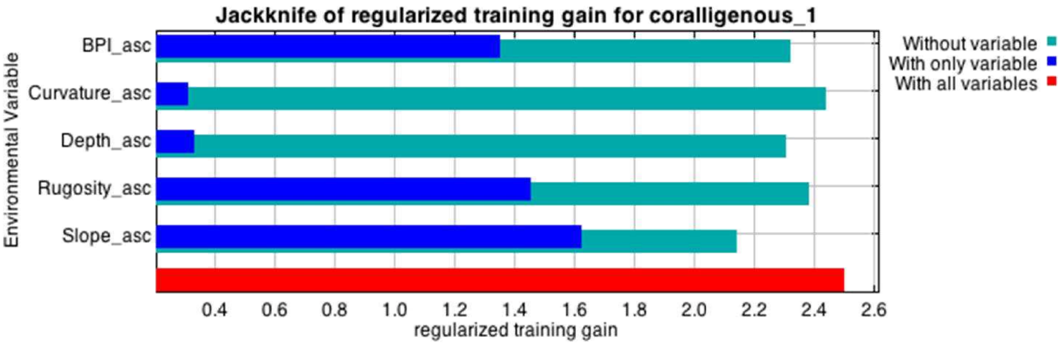

Figure S2. Results of the jackknife test of variable importance of the training data.

Chapter 4

Using Maxent to understand and predict the distribution of coralligenous environments

Abstract

The Marine Strategy Framework Directive (MSFD) defines monitoring goals for coralligenous environments as well as their good environmental status assessment within the Mediterranean by 2016. Developing methods to monitor and evaluate challenging ecosystems at multiple scales is a necessity and advance to achieve these goals. Habitat distribution modelling and remote sensing techniques are important tools for ecosystem based management, conservation planning and impact assessments. Therefore, we aimed to analyse the performance of the Maximum Entropy approach (MaxEnt freeware) for modelling the distribution of coralligenous habitats. We built the habitat suitability models using i) presence data collected in the Portofino Marine Protected Area (Ligurian sea) and, ii) geophysical substrate properties extracted from multibeam sonar measures (depth, slope, aspect, rugosity, and geomorphic zones) to allocate known coralligenous communities in the MPA and to forecast new undescribed areas. We conclude that predictions based on combined model results provide more realistic estimates of the core area suitable for coralligenous environments and should be the modelling approach implemented in conservation planning, monitoring activities and management.

Key-words: MSFD, Habitat distribution modelling, MaxEnt, Ligurian Sea

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1. Introduction

Coralligenous habitats are considered an important bioconstruction that confers great structural and functional complexity hosting more than 20% of the Mediterranean species. Besides their importance, little is known of their ecological needs to achieve adequate management. The Marine Strategy Framework Directive (MSFD) defines monitoring goals for coralligenous environments as well as their good environmental status (GES) assessment in the Mediterranean Sea by 2016. Effective implementation of these policies requires a sound understanding of the extent and distribution of benthic biological assemblages as a starting point. In addition, developing low cost methods to monitor and evaluate challenging ecosystems at multiple scales is a necessity and advance to achieve these goals. Remotely sensed data have the potential to provide a broad-scale synoptic view of benthic environments and provide temporal data that may be used to assess events in community dynamics (Zapata-Ramirez et al., 2013). Recent developments in marine habitat mapping using remote sensing tools (e.g. multibeam sonars and georeferenced photo or-underwater video) and the integration with distribution modelling techniques have resulted in an increased availability of environmental data (Brown et al., 2011; Reiss et al., 2014). MaxEnt, in particular, is now a common distribution modelling (DM) tool used by conservation practitioners for predicting the distribution from a set of records and environmental predictors (Phillips and Dudik, 2008; Elith et al., 2011; Fourcade et al., 2014). These models estimate the fundamental ecological niche in the environmental space (i.e. species response to abiotic environmental variables gathered by remote sensing techniques) and project it onto the geographical space to derive the probability of presence for any given area or, depending on the method, the likelihood that specific environmental conditions are suitable for the target species (Mellin et al., 2010; Fourcade et al., 2014). Effective modelling allows us to visualise spatial patterns and identify natural or anthropogenic processes as well as environmental variables governing species distribution and abundance (Mellin et al., 2010; Fourcade et al., 2014). In this context, predictive modelling based on species/environment relationships provides a potentially useful way to synthesise information from scattered samples into coherent maps of distributions of species and habitats, ecological goods, and services (Reiss et al., 2014). More specifically these tools can be applied (i) to explore the possible effects of climate change on benthic species distribution patterns (Elith et al., 2011; Reiss et al., 2014), (ii) to assess habitat distributions in areas that, due to their complexity, are difficult to study and therefore have limited data availability (Fourcade et al., 2014), and (iii) to estimate the most suitable areas for a species and infer probability of presence in regions where no systematic surveys are available (Martin et al., 2014). Only a limited number of coralligenous environments sites have been mapped to a certain extent, including interpretations of the different associated habitats using MaxEnt (Martin et al., (2014). Modelling techniques can contribute to solve this gap using the available information of species presence and environmental data from Multibeam Echosounder (MBES) records, producing Habitat Suitability (HS) maps, which describe, in high resolution, the predicted spatial distribution of the vulnerable habitats, threatened sessile species and essential fish habitats (EFH). Therefore, we aimed to analyse the performance of the Maximum Entropy approach (MaxEnt freeware) for modelling the distribution of coralligenous habitats located at Portofino Marine Protected Area (MPA) and to identify how environmental variables based on high resolution bathymetry influence their distribution.

2. Materials and methods

a. Data sources

Portofino MPA (http://www.portofinoamp.it) has a surface of 3.74 km2. The coast is characterized by a narrow continental shelf with a very steep slope reaching a maximum of 80-90m depth. Multibeam bathymetry data was collected using a Multibeam system SONIC 2024 (Selectable Frequencies 200-400kHz) during 2010 and were provided by the Ligurian Region (Dipartimento Ambiente, Regione Liguria). Bathymetric and backscatter data were exported as 32-bit rasters with a cell size of 1m. With these data a wider area in the circalittoral zone was selected, where coralligenous formations occurred. In the study area depth ranged from -20m to -90m (total surface area considered for the model 5.287 Km2, of which 2.57K2 m fall inside of the MPA). We combined a suite of techniques that segment the acquired MBES data in terms of seabed morphology and composition. To determine sea-bed morphology, we applied standard layers using the Benthic Terrain Model (BTM) extension on ArcGis 10.2 platform (ESRI, Redlands, CA, USA). Geomorphometric attributes (e.g. slope, aspect, curvatures) were measured for each bathymetric datasets, with a particular emphasis given to attributes expressing the complexity of the seafloor, such as Bathymetric Position Index (BPI) and Vector Ruggedness Measure (VRM). In order to determine the seabed composition of the study area, we carried out a combination of morphometric and textural analyses of both bathymetric and backscatter data performing a an unsupervised Iterative Self-Organizing Data Analysis Technique (ISODATA) classification using ENVI 5.1 software (EXELIS VIS, Boulder, CO, USA) (see Zapata-Ramírez et al. 2013) with which we finally obtained 7 morphosedimentary classes (Mid slope, Lower bank shelf, Upper slope, Cliffs, Caves and Overhangs, Shallow slope and Bank shelf). Since coralligenous environments occur on a variety of geomorphologies, including near vertical walls and terraced slopes, we assessed multiple sites within the MPA locations to assess variation in the structural groups relative to this factor. Using these data, the importance of seafloor morphology in structuring coralligenous habitats was studied across the MPA .

During 2013-2014 field trips were designed using a random-stratified approach identifying the checkpoints (300 points) within the GIS and correlated with the GPS locations and taking in account several parameters such as: MPA Zonation, Complexity (rugosity/slope), the 7 morphosedimentary classes and the accessibility from land that could help to guaranty future monitoring activities. From each of these checkpoints, a diver or VideoRay Pro 4 ROV system for areas deeper than 40m were used together with two calibrated Go-pro Hero (3D system) to collect images, - One Go-pro Hero 2 to gather video, lasers and strobes for the divers or ROV. The diver or ROV swam over the bottom recording benthos composition with video and still photographs for ∼15 minutes (as proposed in

Zapata et al., 2013). The video was pointed directly at the seabed and held between 1.0 and 1.5 m from the substratum. In addition we used an Underwater acoustic positioning system (USBL) to record the position of the diver and the ROV and related with the boat position. All sample data were stored using ArcGIS software, in order to facilitate the habitat distribution modelling

b. Habitat suitability models using Maximum entropy model (MaxEnt)

We built the habitat suitability models using i) presence data with the checkpoints collected in the study area and, ii) environmental variables (EVs) extracted from multibeam sonar measures of geophysical substrate properties (depth, slope, aspect, rugosity, and morphosedimentary classes). These bio-physical variables were then modelled using the machine-learning method (MaxEnt) to predict the distribution of coralligenous formation at the MPA. The default model parameters were used as they have performed well in other studies (Phillips and Dudık, 2008; Fourcade et al., 2014). The importance of each variable in the model was assessed using a jack-knifing procedure that compared the contribution of each variable (when absent from the model) with a second model that included the variable. The final habitat suitability maps were produced by applying the calculated models to all cells of the total surface area (5.286405 km2) in the study region, using a logistic link function to yield a habitat suitability index (HSI) between zero and one (Phillips and Dudık, 2008). Model accuracy between the test data and the predicted suitability models was assessed using a threshold-independent procedure that used a receiver operating characteristic (ROC) curve with area under curve (AUC) for the test localities and a threshold-dependent procedure that assessed misclassification rate following the methodology proposed by Phillips and Dudık, (2008).

3. Results

To model the distribution of coralligenous habitat at Portofino MPA, a total of 88 presence records were used for training, 29 for testing and 10088 points to determine the MaxEnt distribution (background points and presence points). MaxEnt model was successful in predicting the distribution of Coralligenous habitats, with AUC score 0.984 for the training data set and 0.964 for the test data

(Figure 1) and were significantly different from that of a random prediction of AUC= 0.5 (Wilcoxon rank-sum test, p,0.01). This indicates that EVs chosen are relevant to distinguish the distribution of coralligenous in the study area. Slope (39%), Morphosedimentary classes (24.1%) and Rugosity (17.3%) were the three main contributors to the model, followed by Bathymetric Position Index (13.2%); Depth (5.9%) and Curvature (0.4%). The interpretation of the Jackknife tests shows that Morphosedimentary classes was the most influential EV in determining HS as well as the one that had most useful information not contained in other EVs and was most effective in the contribution to the HS. By intersecting the known distribution of coralligenous habitats with the environmental layers, it was possible to gain insight into the species niches. (Figure 1). According to the models, in Portofino MPA, coralligenous habitats are most likely to be found on the steep rough walls (cliffs) where facies of octocorals in particular Paramuricea clavata is well represented, in caves and overhangs where facies of semi dark communities and associations of *Corallium rubrum*, *Parazoanthus axinellae* and *Leptopsammia pruvoti* occurs and, in less proportion, in upper slope where facies of scattered octocorals such as Eunicella singularis are characterized. The majority of records were found in areas where slopes were well represented as it is highlighted in the percentage of the contributors in the model. Figure 2 shows a representative area of steep slopes located at Isuela, a stack formation along the cliff and where facies *of P. clavata* is well distributed.

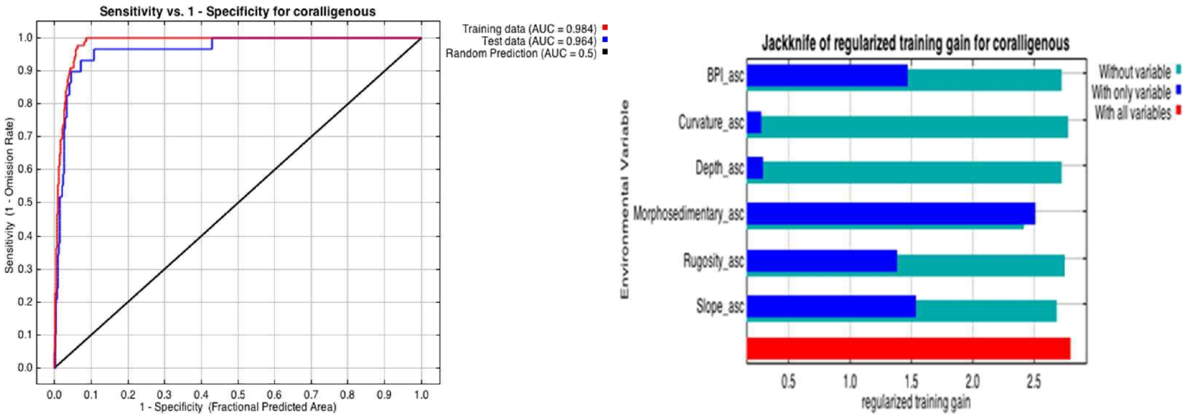

Figure 1. On the left ROC curves for the training (red) and test (blue) sets of coralligenous occurrence. The AUC index can take values between 0 and 1, where 0.5 represents a distribution indistinguishable from random; a lower value indicates performance worse than random and 1

indicates perfect discrimination. On the right result of the jackknife test of variable importance of coralligenous training data.

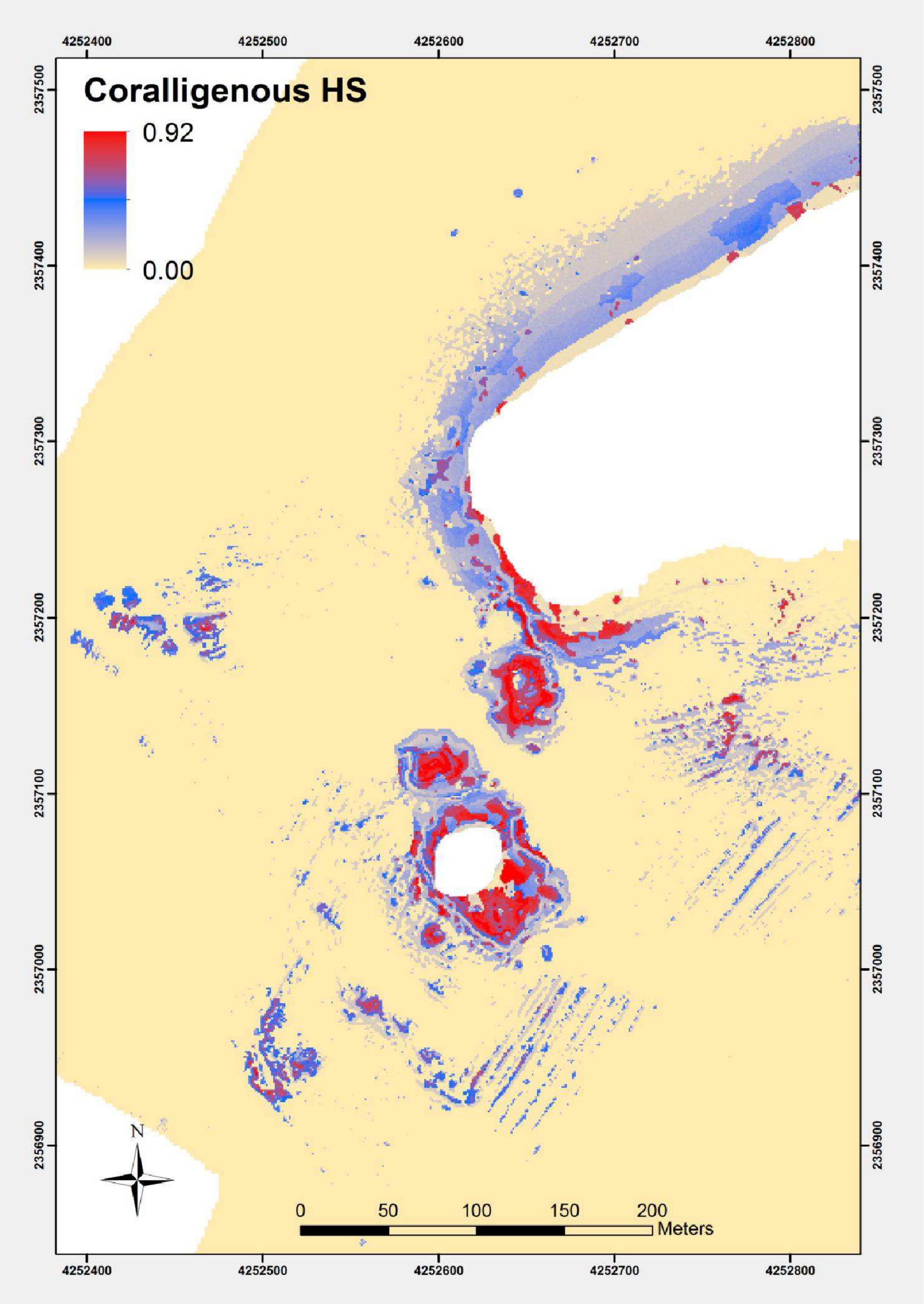

Figure 2. Predicted occurrence probability for coralligenous formations at Portofino MPA. Yellow background indicates that coralligenous is not present, blue indicates low probability and red high probability of presence. The map shows a close up of the study area known as a Isuela, a stack formation along the cliff.

4. Conclusions

The results show that the MaxEnt model is a useful technique to characterize and give a better understanding of the distribution patterns of coralligenous habitats in relation with environmental factors extracted from multibeam sonar measures. The approach provides both high-resolution, full coverage surveys of selected areas that can be precisely revisited during monitoring activities as well as broader scale features of the terrain, such as slope, surface roughness and aspects that provide notion of the habitat structure and regarding sea floor integrity. In addition, optical information help us examining the correlations between populations and underlying bathymetric processes that determine their distribution that also provides the foundation to monitor future changes. The results presented here fits in the regional spatial mapping of coralligenous environments (MSFD:2008/56/EC), allowing the production of high quality bathymetric and habitat maps as one of the first requirement for a sustainable management. Therefore, providing measures to achieve or maintain Good Environmental Status (GES) by 2020. The presented methods are simple and cost-effective becoming an optimal solution for extended monitoring by the combination of innovative and new tech tools.

Acknowledgments

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Chapter 5

Modelling the distribution of rocky shore indicator species and its relation to the geomorphology and anthropogenic pressures at Portofino MPA.

Abstract

The prediction of the distribution of indicator species on rocky shores communities is fundamental for an effective implementation of the Marine Strategy Framework Directive (MSFD) and to support decision-making. We tested a method within tight resource limitations, to model five species outlined in MSFD at Portofino MPA using Maximum Entropy modelling (MaxEnt) technique .The aim was to detect how the geomorphological expression and the anthropogenic stressors affect their distribution. Our results indicated that slope, rugosity and depth are the most contributing variables for *Cystoseira amentacea* distribution. While sites close to anthropogenic stressors are favourable for more competitive species (e.g: *Ulva lactuca* and *Mytilus galloprovincialis*). An integrated snapshot description of the indicator species along the MPA is presented. We concluded that the method could be an effective standardized tool for managers, useful for monitoring activities, to detect areas of possible restoration actions and to evaluate the Good Environmental Status at MPAs.

Keywords: Reefs, Costal Geomorphology, Anthropogenic stressors, Indicator species, Models, Portofino MPA.

SUBMITTED

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1. Introduction

Occurring at the interface between land and sea, rocky shores are characterized by a wide range of environmental conditions at the extreme edge of both the terrestrial and marine domains (Martínez et al., 2012a; Bermejo et al 2015) and by a complex morphology, that provide essential micro-habitats to a diverse number of biological organisms (Peglow, 2013; Thorner et al., 2013; Hollenbeck et al., 2014). In general terms, studies of rocky shore ecological communities have revealed much about species interactions and the physical-chemical controls that influence them (Benedetti-Cecchi et al., 1999; Bulleri et al., 2002; Crowe et al., 2013; Chappius et al., 2014; Bermejo et al., 2015). Furthermore, due to their sessile environment, rocky shore benthic species are important indicators for anthropogenic and environmental impacts (Ballesteros et al., 2007). They are particularly sensitive to pressures such as coastal development, pollution, climate change (e.g: sea level rise, storm dynamics, temperature increase) and biological invasions, that affect the ecological stability and spatial allocation of their species (Gappa et al., 1993; Diez et al., 1999; Mangialajo et al., 2007, 2008; Arévalo et al., 2007; Martínez et al., 2012b; Parravicini et al., 2012, 2013; Hollenbeck et al., 2014). Likewise, geology is fundamental to shape rocky shore and to determine sub-habitats (Thorner et al., 2013; Bermejo et al., 2015) and information about different geomorphological expressions; such as rugosity for instance, relevant to elucidate the mechanisms driving assemblages patchiness that cannot be explained by biological and physical process alone (Peglow, 2013). Unfortunately, less attention has been focused on the relationship of the species that inhabit these communities with the geomorphological expressions of the coast and changes in the topography of the substrate (Gómez-Pujol et al., 2006; Thorner et al.,2013; Ramos et al.; in press). In addition, there is a lack of studies that discuss the combination of all these factors (biological, geomorphological and pressures), restricting our understanding of the processes influencing rocky shore species distribution in a more integrated context. This situation could be primarily attributed to an inability to resolve fine scale features due to the low resolution and accuracy of conventional methods of in situ surveys. Hence, they require a good technology to extract fine-scale spatial data on habitat extent and status (Peglow, 2013; Thorner et al., 2013). As a result, there is a growing demand, from the Marine Strategy Framework Directive (MSFD) (MSFD, 2008/56/EC; European Commission, 2008), for standardized approaches, useful to predict and to understand the consequences of different factors affecting the distribution and the status of marine environments (Mariani et al., 2014; Piroddi et al., 2015). Fortunately nowadays, with the advances in marine mapping technology there is a proliferation of seascape characterization, species distribution modelling (SDM) and classification techniques (Brown et al., 2011, 2012; Rice et al., 2012; Levin et al., 2014; Zapata-Ramirez et a., 2014; Buhl-Mortensen et al., 2015) that permits the prediction of occurrence of the species as function of a set of selected environmental variables (EVs). These approaches provide an excellent framework for understanding how different factors contribute with their distribution over large areas (1 km – 100 km) in a small scale and in a simple and comprehensive way. The results of these efforts have been applied among others to: i) produce models in order to complement or overcome gaps in the biological information (Martin et al., 2014); ii) detect changes in the morphology with which to identify the environmental variables (EVs) that contribute to the distribution of the species (García-Alegre et al., 2014; Zapata-Ramirez et al., 2014); iii) illustrate how human impacts interact with their distribution (Bandelj et al., 2009; Martinez et al., 2012; Parravicini et al., 2012, 2013) and iv) identify optimal sites for restoration initiatives (Elsäßer et al., 2013; Valle et al., 2015). Furthermore, the models could be a support tool for efficient management decisions, providing simple visual elements, crucial for a successful communication to various stakeholders (Brown et al., 2012; Marshall et al., 2014). Thus, delivering information critical to support the integrated European Maritime Policy, (Zapata-Ramirez et al., 2014; Marshall et al., 2014; Reiss et al., 2015; Piroddi et al., 2015) and for reaching a ‘Good Environmental Status’ (GES) by 2020 across Europe’s marine environment, as required by MSFD.

The objectives of this paper were: i) to develop methodologies, within tight resource limitations, that can help to analyze and define the complex inter-relationships between the geomorphological expression and marine biodiversity on rocky shores, ii) to assess how the distribution of the considered species responses to the anthropogenic pressures (i.e.: distances to harbours, to sewage outfalls, to river effluents and human population density) and iii) to provide information about indicators of biogenic structures or 'reefs', outlined in the MSFD, particularly on Descriptor 1 (Biological diversity).

2. Materials and methods

2.1 Study area

The study was conducted at Portofino MPA, Italy. The area contains one small (0.1 km2) 'no entry-no take' area (A zone or integral reserve), and 18 management units which form an 'entry regulated-take regulated' zone (B) and two buffer zones (C) (Fig. 1). Despite the limited extension (18 km2), the MPA encompasses a wide range of environmental conditions and habitats. The area is characterized by cliffs that exhibit steep environmental gradients cut by tectonic lineation that influence the geomorphology (Corradi et al., 1984; Faccini et al., 2008). In addition, other conspicuous features like stacks, shore platforms, pocket beaches, caves and notches compose the MPA landscape and showing a large geomorphological variability. In particular, the promontory extends in N-S direction. The western side it is almost rectilinear between Camogli and Punta Chiappa for about 3 km. This zone is characterized by boulders, inlets and pebbly beaches. The eastern side runs parallel to the western one and shows a high coastal morphological variability represented by bays, sandy beaches and boulders for about 8 km. The southern side presents general E-W orientation, extends for a length of about 6.5 km and it is mostly characterized by cliffs, shore platforms, caves and small inlets (Fig. 1). These characteristics, combined with other factors such as the wave exposure, the exposition to hydrodynamic forces, the elevation above the sea level and the rock's micro topography itself, make available different physical conditions over short distances that allow the coexistence of several organisms, competing for the space and source availabilities. This is particularly true in the intertidal zone, a very narrow zone in the Mediterranean Sea characterized by a micro-tidal range (+/- 0.5 m), where benthic communities are regularly exposed to air and/or wave action. The typical assemblages of exposed shores are belts of Cystoseira amentacea, a protected species by European Legislation (Barcelona and Bern Conventions). However, despite the ecological importance of the rocky intertidal communities at the MPA, no study analyzed the large spatial patterns of these communities and their relationship with the topography complexity. Only few studies focused on their relationship with human impacts on a large scale and performed a first assessment of their distribution in the MPA (Mangialajo et al., 2007, 2008; Asnaghi et al., 2009).

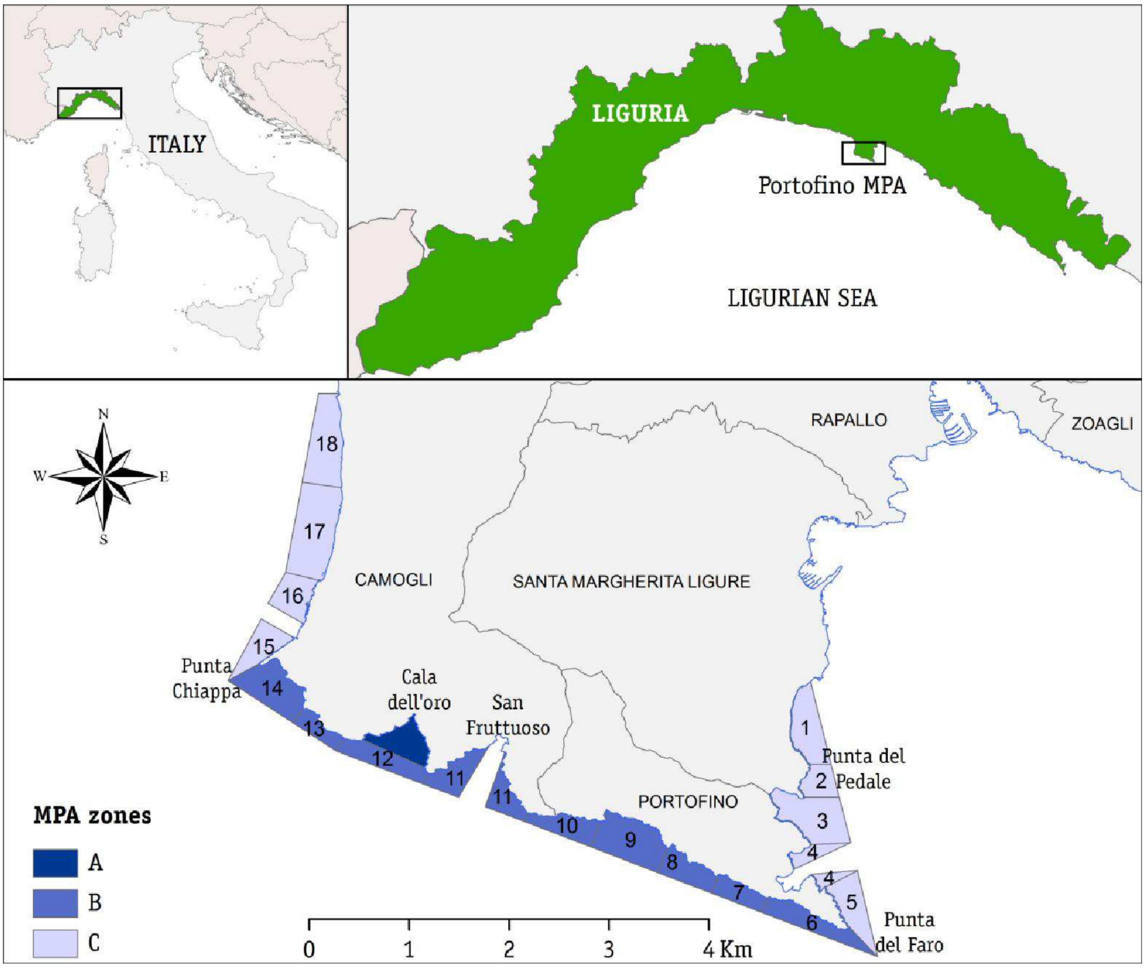

Fig. 1. Study area showing the different MPA management zones.

2.2 Environmental variables (EVs)

2.2.1 Geomorphological expression

LIDAR (Airborne laser scanning), has been increasing and extensively used in the last decade to collect high resolution bathymetry data for habitat mapping initiatives at rocky shores (Valle et al., 2011; Peglow, 2013; Thorner et al., 2013; Hollenbeck et al., 2014,) among other uses (i.e Wilsey et al., 2012; Rarity et al., 2014; Bosman et al., 2015). Nevertheless, LIDAR acquisition remains expensive and difficult to achieve by MPA managers, that usually operate on a limited budget. Despite some LIDAR data is available for the Liguria Region, these data have not been released for management purposes. As a consequence, there is the necessity to test and implement more affordable cost-effective methods, which could take advantage of the available information. Bearing this statement in mind, and the limitations that this fact could represent, we used a Digital Elevation Model (DEM) resulting from a fusion between a terrestrial DEM originated by an aerial photograph of the study area, and a marine DEM, derived by a Multibeam Echosound system (MBES) .

The terrestrial DEM was based on the DTM (Digital Terrain Model) produced on data collected by the Liguria Region from 2006 to 2010 with a resolution of 5 meter (the best current elevation data available). The DTM has been developed from a topographic map (scale 1:5000) produced from aerial photos. The elevations from 0 to 5 meter were analysed in this study. Below the sea level, we used multibeam data collected with a Multibeam system SONIC 2024 (Selectable Frequencies 200-400kHz) during 2010 and provided by the Ligurian Region (Dipartimento Ambiente, Regione Liguria, ARPAL). Both data sets were merged and homogenized in ArcGis 10.2 (Esri, Redlands, CA, USA) using the tool ‘topo-to-raster’. The complete data set was projected from Monte Mario (fuso 2) to ETRS-89 LAEA spatial reference system and exported as 32 bit grid with a cell size of 5m.

The Benthic Terrain Model (BTM) extension on ArcGis 10.2 was used to extract the sea-bed morphology features: rugosity, aspect, the Bathymetric Position Index (BPI), slope and curvature. Rugosity was created using a 3 × 3 cell neighbourhood window method that calculates the average change in elevation of a central cell from 8 bordering cells. Aspect, and thus the consequent exposure to prevailing waves and current, was divided into Northness and Eastness components. The angles were converted in radians and the sine and cosine were calculated. Sine represents the grade of exposition to East (or Eastness) of a cell, whereas the cosine corresponds to the grade of exposition to North (or Northness). In this way a continuous range of orientation values (from -1 to 1) were obtained avoiding that values numerically far may be oriented in the same bearing. BPI was built in order to obtain the description about crest, depressions, slope and flats areas on the terrain. The algorithm measures the relative elevation of a location, to the overall landscape by evaluating differences between a focal point and the mean elevation of the surrounding cells (Lundblad et al., 2006). Specific details of the computation methods applied are provided by Wilson et al. (2007). In order to have different fine windows scales, second derivatives of bathymetric highs from slope of the slope (Degrees of degrees) and rugosity of rugosity were also used as predictors with which to detect more local details and features in the bathymetric surfaces.

Afterwards, and in order to correlate the geomorphology and the species distribution, we built a classification dictionary (Fig. 2) of the seabed following the methodology proposed by Lundblad et al., (2006). In this approach we used two classification schemes: i) a broad scale with which to identify large morphological structures like crest and depressions and ii) a more descriptive fine scale with which to identify small features like steep slopes and mid-slopes crest. We standardized the BPI values by subtracting the mean value and dividing by the standard deviation, then, the result was multiplied by 100 and the values converted to integers. This step is necessary since morphological trends tend to be spatial auto-correlated (i.e. location that are closer are more related than locations that are farther apart) (Wright et al., 2004). The final classification scheme indicates a geomorphological classification based on the two standardized BPI (fine and broad scale) and the slope values. The resulting classification map was used as a potential indicative of the relationship between broad geomorphological features and the rocky shore species through identifying distinct seabed zones in the study area.

2.2.2 Anthropogenic pressures

Georeferenced information on harbours, river effluents , sewage outfalls and presence of buildings at Portofino MPA (Fig. 3) were gathered by the Liguria Region and downloaded by the website www.cartografia.regione.liguria.it

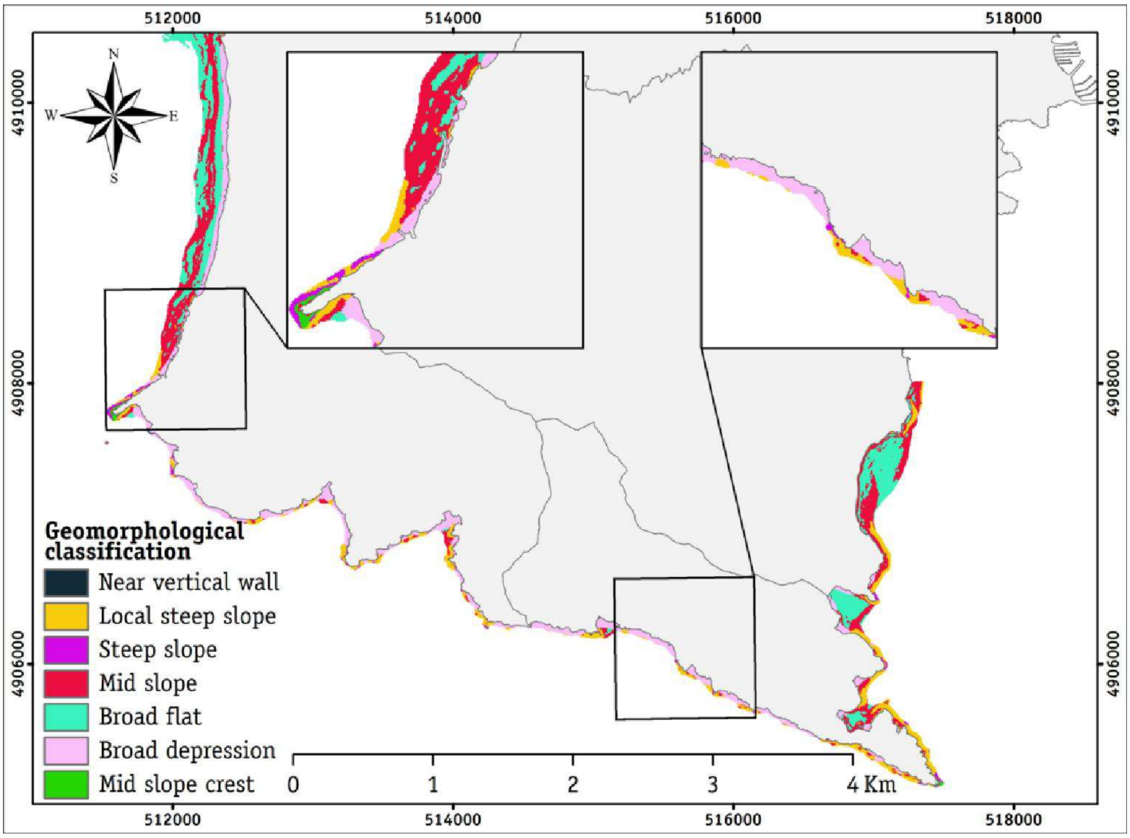

Fig 2. The map shows the different geomorphological zones resulting from the application of the sea bed classification dictionary, following the methodology proposed by Lundblad et al., (2006).

To calculate the relationship between the anthropogenic variables and benthic communities, we modelled the spatial extent of the four pressures considered above, evaluating their distance from each sampling point. We calculated the distances from the four harbours located around the MPA (Camogli, Portofino, Santa Margherita Ligure and Rapallo) using a “coast surface” tool in ArcGis 10.2 which allowed to measure distances along the coastline. Finally, the distances from the four harbours were averaged, in order to estimate the combined impact of the four harbours in each cell.

In addition, distances from rivers effluents (river mouth) and from sewage outfalls were calculated. All these distances were computed using the "Euclidean distance" tool in ArcGIS 10.2. We used building presence as proxy of the population density that surrounds the MPA. We transformed the polygonal layer of presence of building in to a point layer in order to have a point each 25 square meters of built surface. Then, we computed the density of these points using the "Point Density" tool in ArcGIS 10.2. In this way, we calculated for each cell of the study area the density of building in a neighbourhood of one Km from the coastline. All the anthropogenic pressure grids had a cell seize of 5 m.

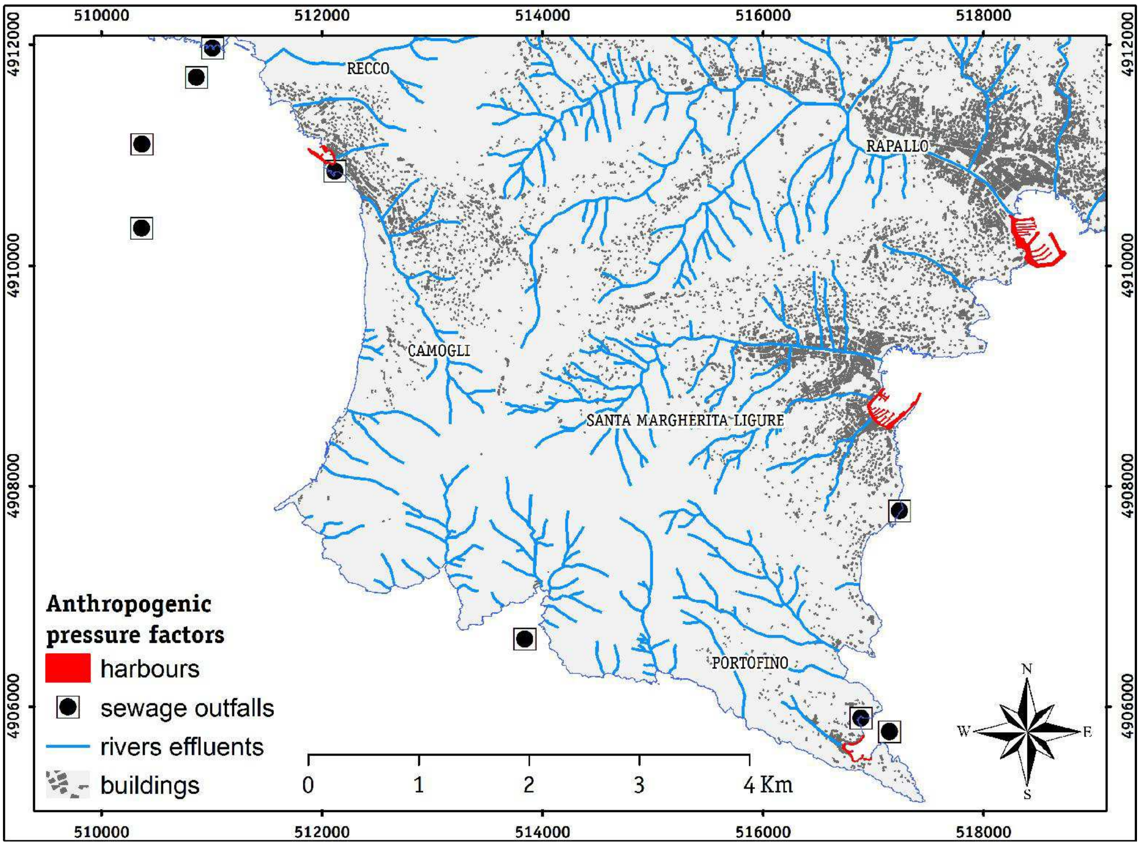

Fig 3. The map shows the distribution of the different anthropogenic pressures located at Portofino MPA.

2.3 Data inventory

In particular, the study examined broad distributional patterns of several rocky shore species such as *Cystoseira amentacea* var. stricta (Montagne, 1846) (hereafter C. amentacea), *Cystoseira compressa*

(Gerloff & Nizamunddin 1975), *Mytilus galloprovincialis* (Lamarck 1819), *Corallina elongata* (Ellis & Solander 1786) and *Ulva lactuca* (Agardh 1822). The rationale behind of the chosen species is that they have been recommended as key indicators to assess the ecological status of coastal waters (Arévalo et al., 2007; Ballesteros et al., 2007; Bandelj et al., 2009; MESMA, 2010; Pinedo et al., 2013; Mariani et al., 2014; Chappuis et al., 2014; Bermejo et al., 2015; Devescovi, 2015) due to that their distribution has been closely related to the spatial boundaries of different stressors (OSPAR, 2008).

Species presence information was extracted based on the inventory data set compiled by the CARLIT method performed in June 2013. The CARLIT method was designed in the framework of the Water Directive (2000/60/EU) to assess the ecological status of coastal shallow waters (Ballesteros et al., 2007). The method is well known and has been already applied in North-Western Mediterranean and in the Adriatic Sea (Ballesteros et al., 2007; Mangialajo et al., 2007; Sfriso et al., 2011; Bermejo et al 2013; Nikolić et al., 2013). In detail, the entire coastline of Portofino MPA (about 14 km) was divided in 50 m sectors where the most abundant intertidal communities (*Cystoseira* spp., coralline algae, mussels, etc.) were visually estimated and recorded. Furthermore, some physical characteristics of the coast were recorded, such as morphology (high cost/low cost/boulders), exposure to waves (exposed/calm) and slope of the substrate (vertical/sub-vertical/horizontal). In particular, we sampled 337 sectors sailing a few meters from the coastline in a boat provided by Portofino MPA. For the aim of this study, we calculated the coordinate of the central point of each sector where the species were recorded. The presences of the species were used to run the SDM and to detect its relation with the EVs, the geomorphological expression and the anthropogenic pressures Finally, measures of all the anthropogenic pressures and geomorphological expression variables in each sampling point were extracted, using multi values to points in ArcGIS.

2.4 Modelling technique and validation

We used a non-parametric maximum entropy model called MaxEnt to predict the occurrence of the chosen species (*Cystoseira amentacea, Cystoseira compressa, Mytilus galloprovincialis, Corallina* *elongata, Ulva lactuca*) and to evaluate how their distribution is related with the geomorphological expression and the anthropogenic pressures (here referred as EVs) . In particular, MaxEnt has been considered to be more resilient to the effect of anthropogenic disturbances (Elith et al., 2011) and is increasingly used in benthic environments (Downie et al., 2013; Bucas et al., 2013; Bergstrom et al., 2013; Martin et al., 2014; Zapata-Ramirez; 2014; Reiss et al., 2015). As MaxEnt is a presence only modelling approach we used: i) the presence records of each one of the mentioned species assigned to the georeferenced central point of each sector where they were observed and ii) the geomorphological and anthropogenic EVs above described Habitat suitability models (HS) for each species were produced and the ten-fold cross-validation was used to evaluate the model performance along with a jackknife test procedure to measure the importance of each predictor. In addition, following the methodology proposed by Phillips and Dudık (2008), the area under the curve (AUC) was used to compare the performance of each model, calculating the values between 0 and 1, where values below 0.7 indicate poor prediction, between 0.7 and 0.9, good prediction, and those above 0.9 indicate very good prediction. A cut-off at the HS value of 60% was applied on the final resulting HS maps. The value was calculated taking in to account the error of omission (false negatives) and commission (false positives), and was fair enough for the modelled species with which to have a most accurate confidence and view of the patterns distribution. Once the HS maps were produced for each specie, we selected and kept the pixels where HS was higher than 0.6, all other pixels were assigned as null value (HS = 0). Then we overlaid the resulting layers, selecting at each pixel the dominant specie (i.e. the one which showed the highest HS value). This last exercise was conducted in order to map as a whole the selected indicators species and to provide a general integrated snapshot view of the rocky shore intertidal communities located in Portofino MPA.

3. Results

3.1 CARLIT method observations

In situ sampling of the intertidal communities through the CARLIT method, allowed us to identify that *Cystoseira amentacea* belts are almost only present on the southern side of the Portofino promontory, while on the western and eastern side the species are scattered and substituted by other species, above all *Corallina elongata* and *Mytilus galloprovincialis.* According to the geomorphology expression of the coast that were visually estimated during the field trip activities, *C. amentacea and Cystoseira compressa* were present mainly on exposed coasts and mainly on sub-vertical substrates. Similar patterns were observed for *M. galloprovincialis* and *C. elongata*. While *Ulva lactuca* was found on exposed and calm stretches of the coast, particularly in inlets on vertical substrates, such as at the artificial walls of the harbours.

3.2 Modelling distribution patterns and importance of variables of contribution

The first classification model showed similarly patterns in the broad geomorphological expression and in the species distribution (Fig 2; 4). In this sense, there was a tendency of the species to be located at the same shore height, particularly near broad depression, local steep slope and mid slope zone but not spatial relations were observed, for instance, in flat areas and in accordance with the *in situ* CARLIT observations. Even though depth and/or slope, were the most relevant EVs contributing to the HS distribution of all the species (Table 1), different EVs influence the distribution of the species at more fine scales. The MaxEnt models of the evaluated species generally performed well on cross-validation data providing ‘excellent’ predictions (AUC >0.9) (Table 1).

The western side (between Camogli and Punta Chiappa) and the eastern side (between Santa Margherita and Punta del Faro) had significantly different geomorphological expressions compared with the southern side of the MPA (Fig 2). Values of rugosity and slope were strikingly similar showing a decrease in these areas. In addition, lowest positive BPI values were associated with the presence of boulders indicating that particular areas in the terrain are higher than the surrounding topography.

Table 1. Analysis of the variable of contributions of each one of the EVs used to performed the MaxEnt models and their AUC values.

	C. amentacea		*C. compressa*		*C.elongata*		*U.lactuca*		*M.galloprovincialis*	
Variables	**% contribution**	**Permutation importance**	**% contribution**	**Permutation importance**	**% contribution**	**Permutation importance**	**% contribution**	**Permutation importance**	**% contribution**	**Permutation importance**
Depht	16.3	35.3	46.8	79.1	53.4	67.2	68	93.6	44.3	75.5
Slope	45.8	32	21.2	10.5	17.8	15.1	4.4	2.4	9.8	7.1
Rugosity	19.4	10.7	4.1	0.4	5.7	0.7	0	0	2.5	0.4
BPI	5.8	3.5	9.6	2.9	9	4.3	15.8	2.5	8	2.5
Curvature	0.2	0.5	0	0	0.7	1.1	0.3	0.2	1	0.6
Eastness	0.6	0.8	0.6	0.3	2.2	2.5	0.4	0	3.2	1.1
Northness	0.8	1	3	1	1.8	0.9	0.3	0.1	1.1	0.7
Slope_Slope	1.4	3.6	0.1	0.1	0.3	1.2	0.4	0	0.6	1.7
Rugosity_rugosity	0.1	0.3	3.9	1	1.9	1.2	0	0	0.5	0.6
Sewage_distance	1.1	1.1	5.7	1.8	1.2	0.3	7.4	0.9	5.8	1.8
Building_density	0.6	2.9	2.9	1.8	2.8	1.2	0.1	0	1.8	0.3
Distance_rivers	0.4	1	0.6	0.3	0.9	0.8	2.7	0.2	10.8	2.3
Distance_ports	7.4	7.4	1.5	0.9	2.4	3.7	0.1	0	10.6	5.4
AUC	93.7		94.2		98.6		96.9		95.2	

In particular, the western side is characterized as well by both positive and negative BPI values, suggesting that the terrain is highly variable presenting big boulders in moderate slopes values. Species located at these zones such as *Cystoseira compressa, Corallina elongata* and *Mytilus galloprovincialis* exhibited similar correlation trends (Fig 4) between slow values of slope and rugosity and experienced similar relationship with the proximities to the environmental stressors and the oceanographic conditions, such as wave exposure and sediment deposition regimes.

On the contrary, the geomorphological EVs were more relevant to determine the distribution of *Cystoseira amentacea* (Table 1; Supplementary FS.1). The specie was found predominantly in areas with high slope values and rugosity (particularly in sub-vertical substrates). The shifts in the distribution pattern also coincided with the increase of distance to the anthropogenic stressors. It was found that the community decreases along the gradient of nutrients enrichment, in particular, close to rivers and sewage outfalls.

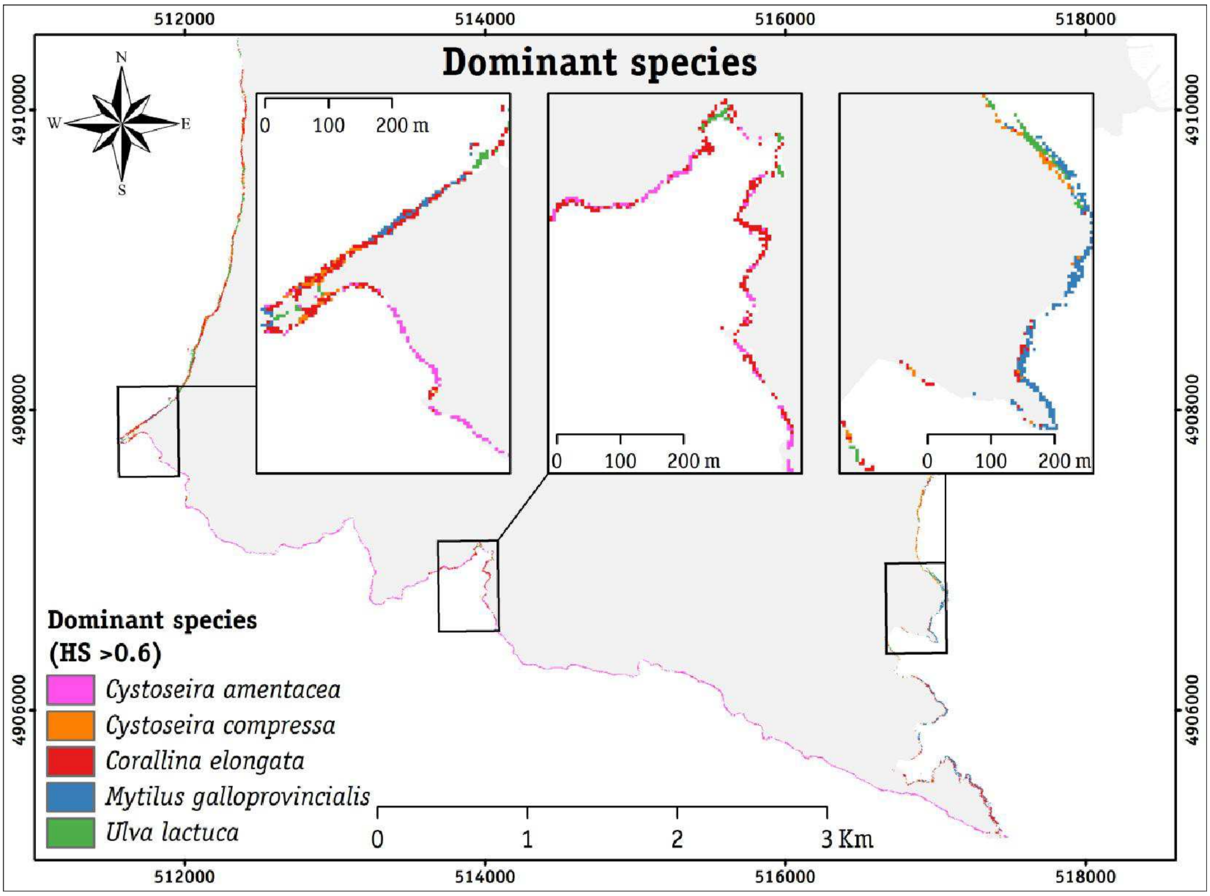

Fig. 4. The map represent the distribution of the dominant species along Portofino MPA.

Among the geomorphological expression, depth was the primary predictor in explaining the occurrence of *C. compressa, C. elongata, Ulva. lactuca* and *M. galloprovincialis*. Unexpectedly, slope showed to be the most relevant EV that contributed with the distribution of *C. amentacea* (45.8 % of contribution), where a threshold effect was evident with the increase of slope values (30 ° - 60°). More specifically, models showed that in the case of *C. amentacea*, slope, rugosity and depth (45.8 %, 19.4 % and 16.3 % respectively). While in the case of *U. lactuca*, depth, BPI and distance to sewage outfall were the most relevant ones (68 %, 15.8 % and 7.4 % respectively). In the case of *M. galloprovincialis* (Table 1), depth, distance to rivers and distance to harbours (44.3 %, 10.8 %, 10.6 %

respectively) explained the variation and the distribution at the MPA. Examples of the Jackknife result tests are presented in the supplementary material (Fig S1).

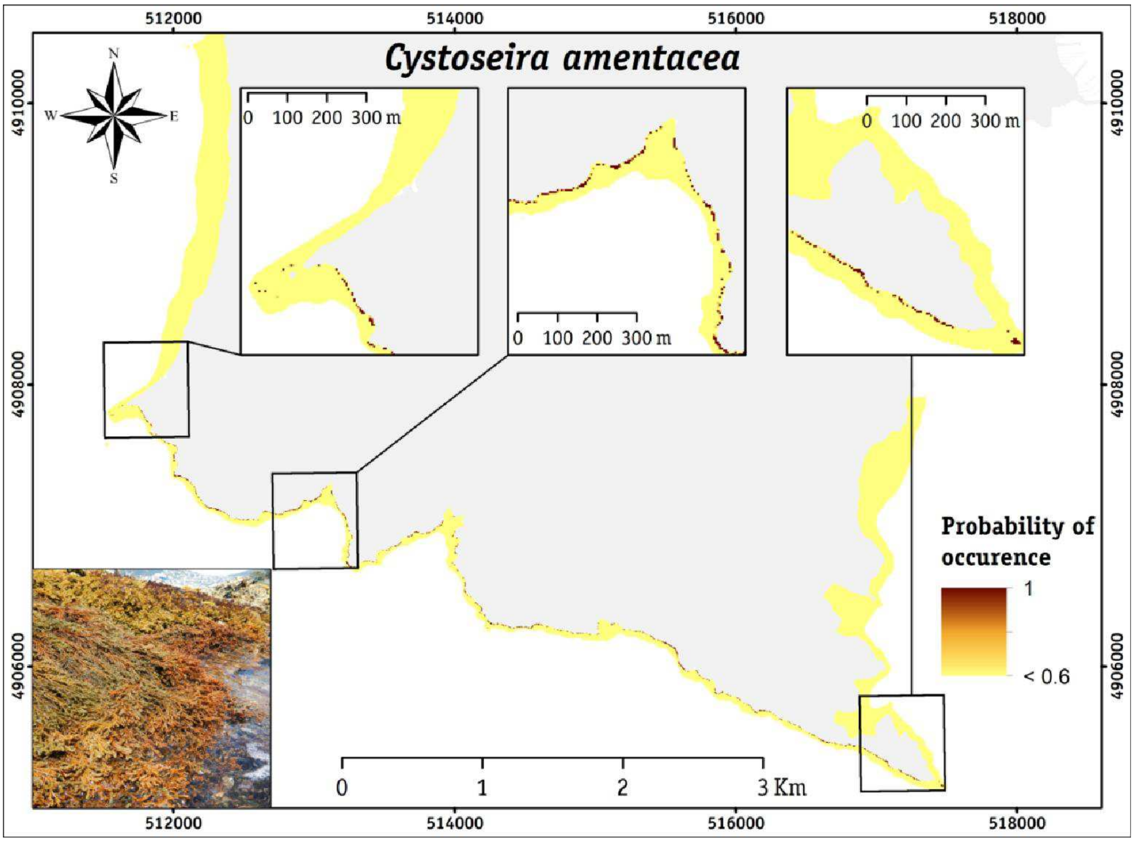

Fig. 5. Distribution of the HS model values of *Cystoseira amentacea*. The areas with HS values lower than 0.6 are equally represented in light yellow. The dark brown denoted the high probability of occurrence.

Some combinations of environmental and anthropogenic EVs were relevant in the distribution of the species simultaneously. As a result, the produced maps suggested that specific locations might be affected by changes in the water quality and therefore related with the species located at these areas. For instance, pressures related with distance from sewage outfalls played a pivotal role on the distribution of *M. galloprovincialis* (Fig. 6), *C. compressa* (Fig. 7) and *U. lactuca* (Fig. 8), while distance from rivers showed some important role in the distribution of *U. lactuca* and *M. galloprovincialis.* Meanwhile, building density and distance from ports seems to have a relevant influence to determine *C.elongata* distribution. On the contrary, a decrease of *C. amentacea* was observed in relation to the proximity to the anthropogenic stressors (Fig. 3).

Specific trends were observed in the inlet “San Fruttuoso”, located in the southern side of the MPA (Fig. 1) and used as navigation corridor. In this subzone, a proliferation of opportunistic and stress tolerant species was determined, with no strict link to the geomorphological expression and possible due to freshwater uptakes related with river discharge and increased in sedimentation flux (Fig 3). In addition, an increment on the distribution of *C. elongata* was found dominating the vertical walls close to this subzone (Fig. 9). Correspondingly, other navigation corridors at the MPA with freshwater input also showed similar high HS values of opportunistic and stress tolerant species, in particular *Ulva lactuca* (Figure 4).

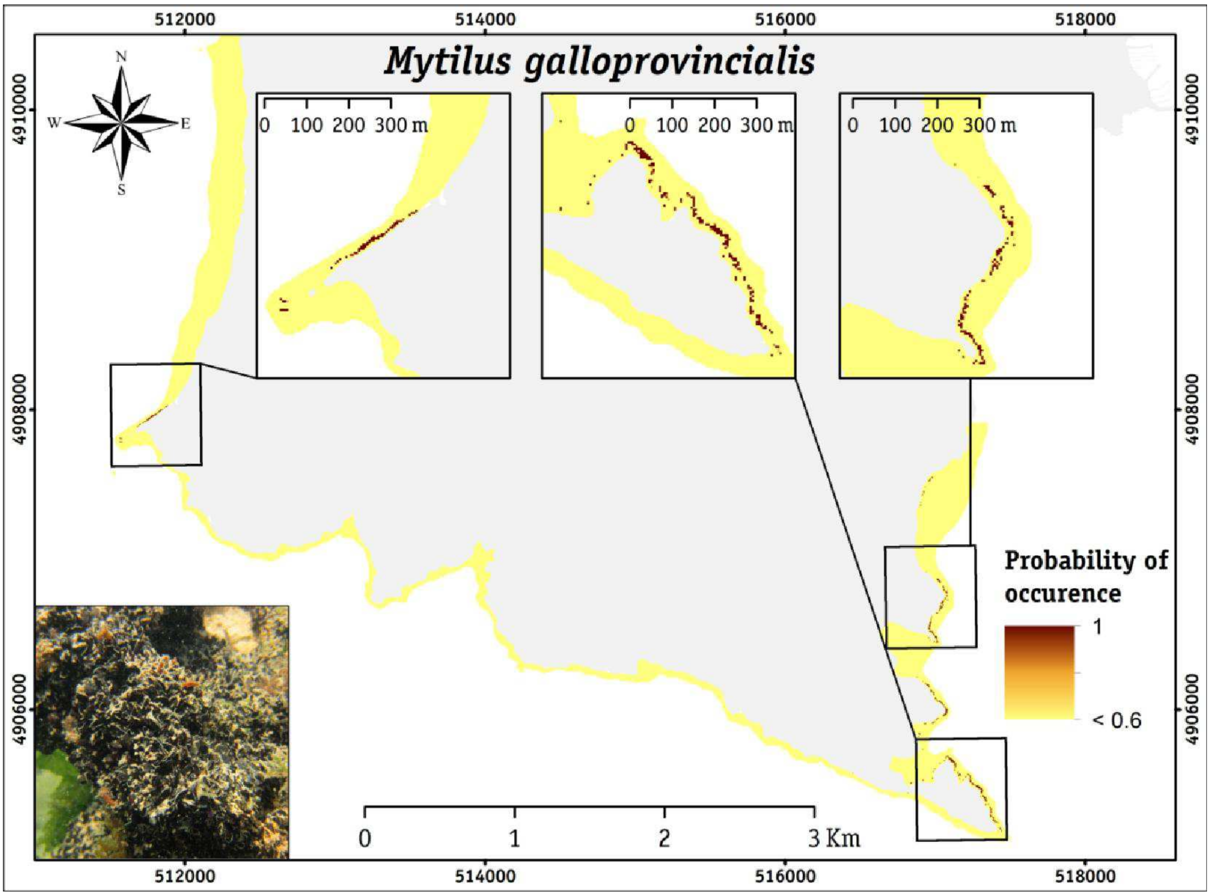

Fig. 6. Distribution of the HS model values of Mytilus galloprovincialis. The areas with the HS values lower than 0.6 are equally represented in light yellow. The dark brown denoted the high probability of occurrence.

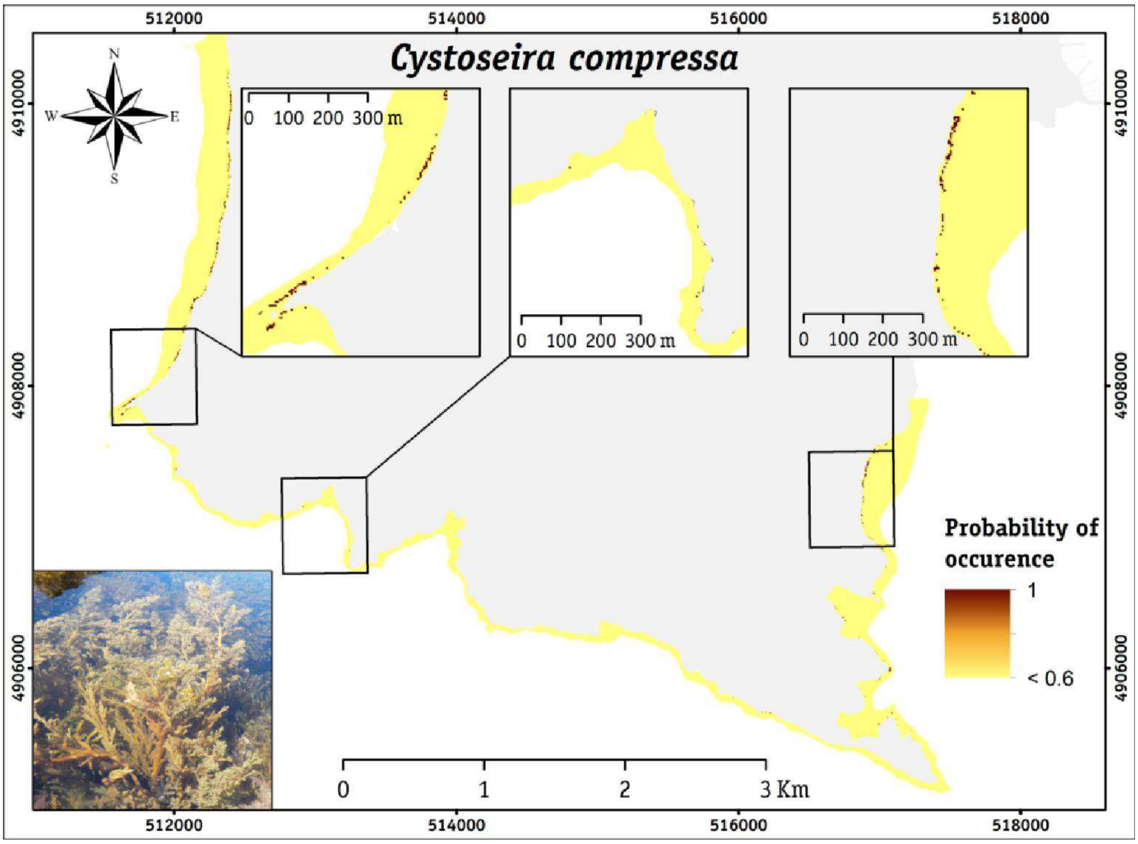

Fig.7. Distribution of the HS model values of *Cystoseira compressa*. The areas with the HS values lower than 0.6 are equally represented in light yellow. The dark brown denoted the high probability of occurrence.

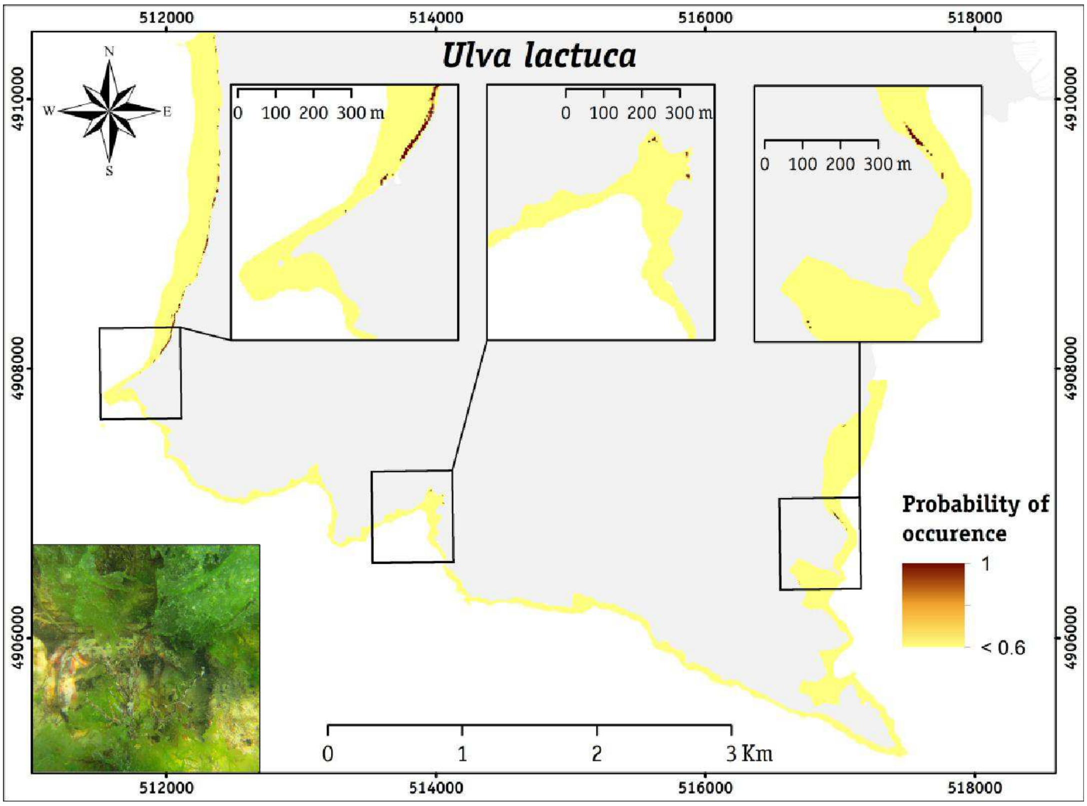

Fig. 8. Distribution of the HS model values of *Ulva lactuca*. The areas with the HS values lower than 0.6 are equally represented in light yellow. The dark brown denoted the high probability of occurrence.

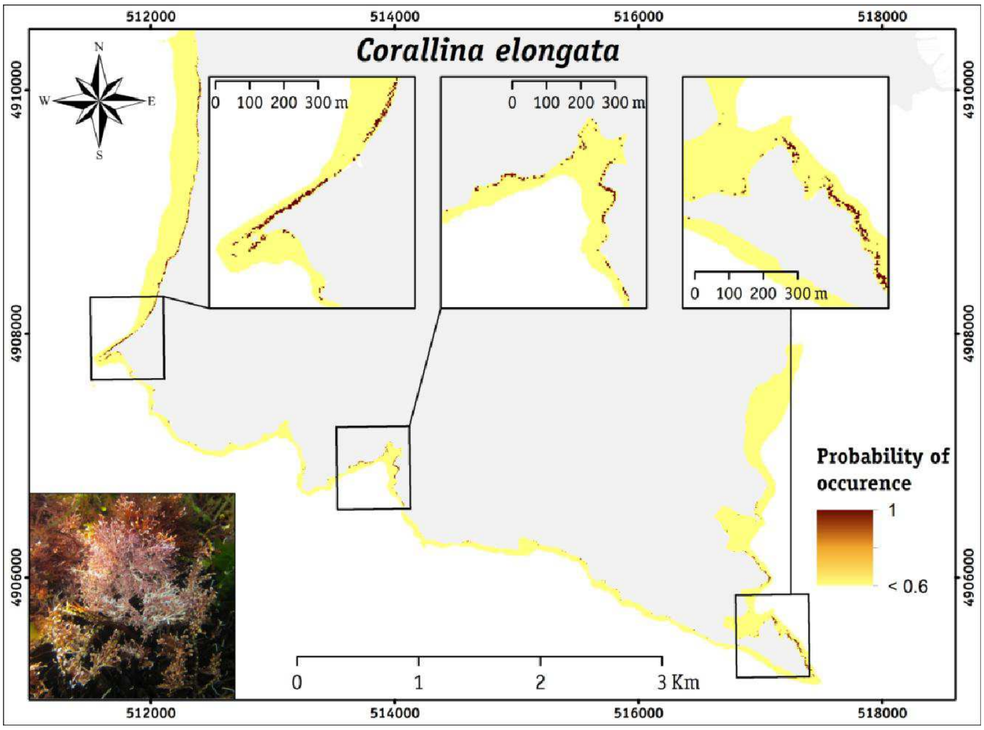

Fig. 9. Distribution of the HS model values of HS *Corallina elongata*. The areas with the HS values lower than 0.6 are equally represented in light yellow. The dark brown denoted the high probability of occurrence.

4. Discussion

Despite the limitations about the resolution of the data here employed, the produced HS models are in agreement with the real distribution of the species visually observed on the field. Thus, by combining and extracting information from standard and well known methodologies like CARLIT with recent advance in MBES technologies and SDM approaches, we have explained and predicted the occurrence of five different rocky shore indicator species located at Portofino MPA and its relation with different EVs. In a general scene, our results found a major tendency of the dispersion of the species in areas with more stability of the seafloor, such as near vertical walls, steep slopes and mid slope crests, in contrast to flat areas and sandy deposits. The influence of these factors suggest that similar process and patterns operate over broad geographical scales (Fraschetti et al., 2005; Chappuis at al., 2014; Ramos et al., in press) are relevant in the prediction for the species at rocky shore communities. It has been recognized that, in particular, the geology of the promontories determines the nature and the distribution of habitats at broad scales (Harris et al., 2013), and that, the geomorphology of the substrate may drive community structure by mediating physical stress mechanisms (Thorner et al., 2013, Peglow, 2013). In Portofino promontory, our findings suggested that species like *C.amentacea* tend to be distributed at more structured highly complexity areas, such in the southern side (slope 45.8%, rugosity 19.4% and BPI 5.8 respectively) where more sheltered conditions from the harsh currents and the eddy formations exist (Doglioli et al., 2004) and where an upwelling effect provides nutrients (De Gaetano, 2010). Ramos et al., (in press and reference therein) stated that in particular, the slope may cause differences in drainage and evaporation, while rugosity could influence composition through indirect effects on herbivore activity. Factors such as water flow, shading, indirectly represented by the BPI (Hill et al., 2014) and high values of slope, were also well presented in these areas (Fig 2).

On the contrary, exact opposite trends occurred in the eastern and western side. These areas are most exposed to currents and to the high flow variability due to the formation of instability like eddies (Doglioli et al., 2004) that strongly influence the sediments dispersion (De Gaetano, 2010) and therefore, their resuspension. Other regional factors that were not measured on the present study, such as low light incidence, tidal range and wave exposure may also contribute to limit the distribution of the indicator species on these areas of the coast line. The presence of large boulders in the eastern and western side, particularly close to Punta Chiappa could contribute to the presence of the association of *C.compressa* and Mytilus, the latter, dominating in smaller areas between clasts, that presented larger, *in situ* semi-rugose silt/sandstone areas. The presence of boulders and their relation with the association *Cystoseira-Mytilus* has been also observed in the Black Sea (Gozler et al., 2010; MESMA, 2010), where mussel beds on boulders were the most important biotope occurring on the shallow sublittoral rock. Although greater structural complexity supports more diverse intertidal communities (Pinedo et al., 2013; Descovi, 2015) such the ones present in the southern side of the MPA, specific lithologies, such as conglomerates (i.e boulder of different size), have various responses to wave action and sedimentary structures (Thorner et al., 2013; Peglow, 2013). They create distinctive multi-scale sheltering profiles that allow the presence and distribution of the observed association of the species. On the other hand, it is also well known, that macroalgae play an important role in trapping sediment (Wilding and Nickell, 2013) useful for the feeding filter behaviour of *Mytilus* and their recruitment (Pitacco et al., 2014). Therefore, both characteristics (boulders and presence of *Cystoseira* forests) increase habitat complexity, enhancing biodiversity by attracting new colonists that can take advantage of newly opened feeding grounds (Wilding and Nickell, 2013). *C.elongata* was also well distributed in the southern and western side as well dominating the vertical walls close to the bays and the inlets (Fig. 9). Similar distribution patterns were also observed by Chappuis et al., (2014), who stated that their presence is probably related with the ability to grow and remain for a long period of time in harsh conditions.

Although we observed similar patterns on the species distribution among the areas and regarding the natural geomorphological expression variability along the promontory, some patterns were also correlated with the presence of different anthropogenic stressors that act locally (Fig 3). For instance, *U.lactuca* distribution showed important links related with the distance to sewages (7.4 % of contribution). *Ulva* has been reported dominating places with high nutrient levels, frequently related with polluted areas elsewhere in the Mediterranean Sea (Soltan et al., 2001). In fact, they have been often considered to be indicative of recent or ongoing perturbation (Arévalo et al., 2007; Airoldi and Bulleri, 2011) and frequently referred to as ‘invasive’. In particular, sewage outfalls (Archambault et al., 2001, Parravicini et al., 2012, 2013) as well as terrestrial, catchment-derived inputs (Arevalo et al., 2007) have been pointed out to provide the necessary amount of nutrients to enable the genus *Ulva* to dominate the substratum. Similar tendencies as the ones shown by Soltan et al., (2001) and Arevalo et al., (2007), were well presented in the area of “San Fruttuoso” for instance. In this sense, *U. lactuca* dominated nearby areas of freshwater uptakes (Fig.3 and 8), then this ephemeral species is replaced by *C. elongata* presented at intermediate levels of nutrient enrichment and dominating the vertical walls close to the bay (Fig 9), to finally, with an increase of the outfall pressure distance, being replaced by *Cystoseira species* (Fig 5 and 7). Our results showed that the relationship between the evaluated species and the building density is not evident for all the species (low values of percentage of contribution in the majority of the cases in Table 1). The patterns of species distribution we observed in the field were similar to the findings obtained by Mangialajo et al., (2008) in the same study area. Indeed, *C. amentacea* belts were lost close to urban areas, while *C.elongata* and *C. compressa* increased. Descovi (2015) also found that *C. compressa* was more abundant in areas where ports were present, and related these patterns with the rapid growth and high recruitment ability that could contribute to its persistence in areas with considerable levels of pressure. Generally our resulting maps are in accordance with common distribution patterns observed in other Mediterranean areas. For instance, Pinedo et al., (2013 and reference therein) found a decrease of *C. amentacea* when the concentration of nutrients in the water column was higher and, on the contrary, an increase of more tolerant species, like *Ulva* spp. and *M. galloprovincialis*, with *C. elongata* dominating the areas in between . Arévalo et al., (2007) also found similar patterns on the communities' distribution in a locality of the Catalonian coast. Their results showed the presence of *Ulva* spp.*, C. elongata* and *M. galloprovincialis* at the same areas, similar to the distribution we observed in the western and eastern side of Portofino MPA (Fig. 4). In particular, the authors explained that there is a substitution of *Cystoseira* for *C. elongata* that prevents the colonization through spatial exclusion, as also observed in Portofino MPA by our study and by Mangialajo., et al (2008). Although we have not collected *in situ* oceanographic measures (such as temperature, chlorophyll contain, salinity, total organic content), we showed that the geomorphological expression may be associated with localised water flows and therefore with the nutrients availability as suggested by Hill et al., (2014). The findings could imply that variation on species distribution could be generated by a combination of biological, hydrodynamic and anthropogenic pressures, modulated by the complexity of the bottom geomorphology. In addition, develop indicator measures of ecological status, also needs to locate and assess the pressures acting locally (Holon et al., 2015). As we previously highlight, our results are roughly estimation of the local pressures, as we have only tackled the distance effect and not *in situ* measurements of the stresses were conducted in the study area. Accordingly, the maps here presented have to be considered with caution and should be indirectly associated as proxies of the pressures evaluated. Nonetheless, the obtained results indicate that the EVs and the “indicator species” here selected, have proved to be appropriate to assessed the current status of rocky shores at Portofino MPA. Finally, our finding suggest that SDM could provide insights about the role of different EVs affecting the distribution of indicator species, thus enhancing a better understanding of the mechanisms driving assemblages patchiness at more large scale. The methodology here proposed, with further refinement through the application of more high spatial resolution data, could be a standard cost-effective tool for managers, useful for the evaluation of the GES and to better inform management decisions at MPAs.

5. Conclusions

We have provided an assessment of the current distribution of rocky shore indicator species at Portofino MPA, along with targets designed to provide awareness of whether the MPA is achieving GES. In particular, the results here presented provide insights for future monitoring of human impacts and/or ecological dynamics and their relationship with the decline or recovery of the important engineering species like *Cystoseira amentacea,* protected key-stone species outlined in the list of conservation priorities. In addition, the implementation of SDM techniques suggest an excellent framework for understanding general coastal geomorphological expression and anthropogenic pressures in a classified way over large areas in a small scale. Data gaps can be identified to direct monitoring efforts, and once LIDAR data is available, potential improvements could be added to the methodological framework, thus improving accuracy and model performance. The results show that the implementation of the proposed method provides simplistic and comprehensive inputs and could be an effective tool to inform decision-making and to support conservation objectives.

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Modelling the distribution of rocky shore indicator species and its relation to the geomorphology and anthropogenic pressures at Portofino MPA

Paula Andrea Zapata Ramirez; Fabrizio Gianni and Michele Marconi

Supporting Information captions

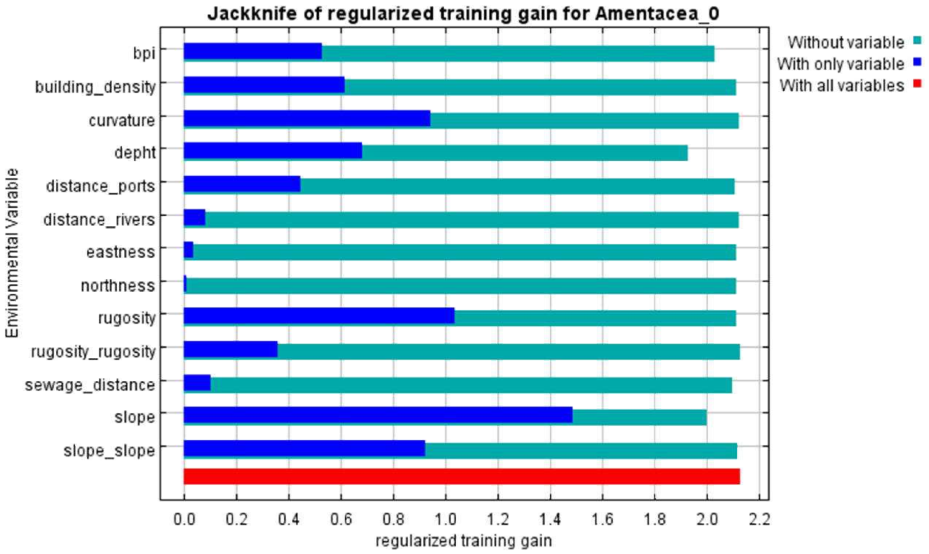

Figure S1: Variable of contribution to final *Cystoseira amentacea* MaxEnt model output of each environmental factor determined using a jack-knife test.

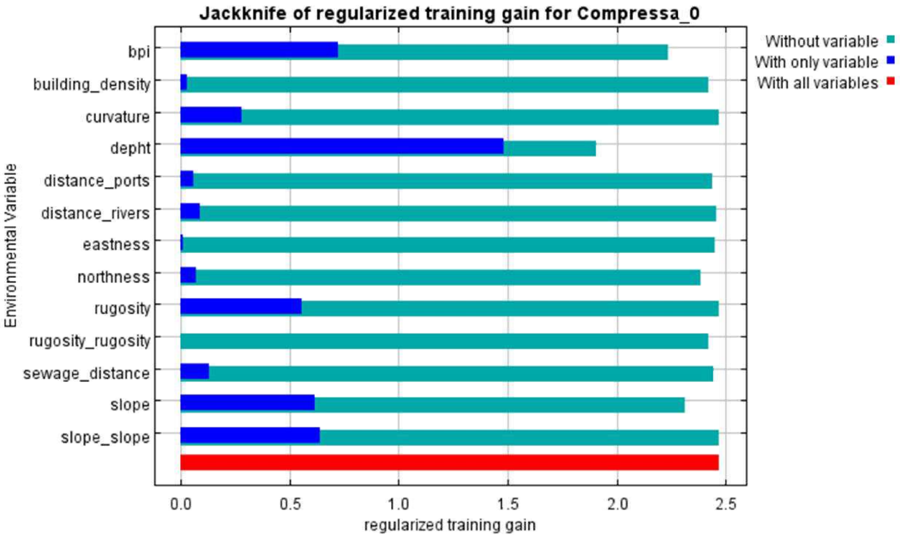

Figure S2: Variable of contribution to final *Cystoseira compressa* MaxEnt model output of each environmental factor determined using a jack-knife test.

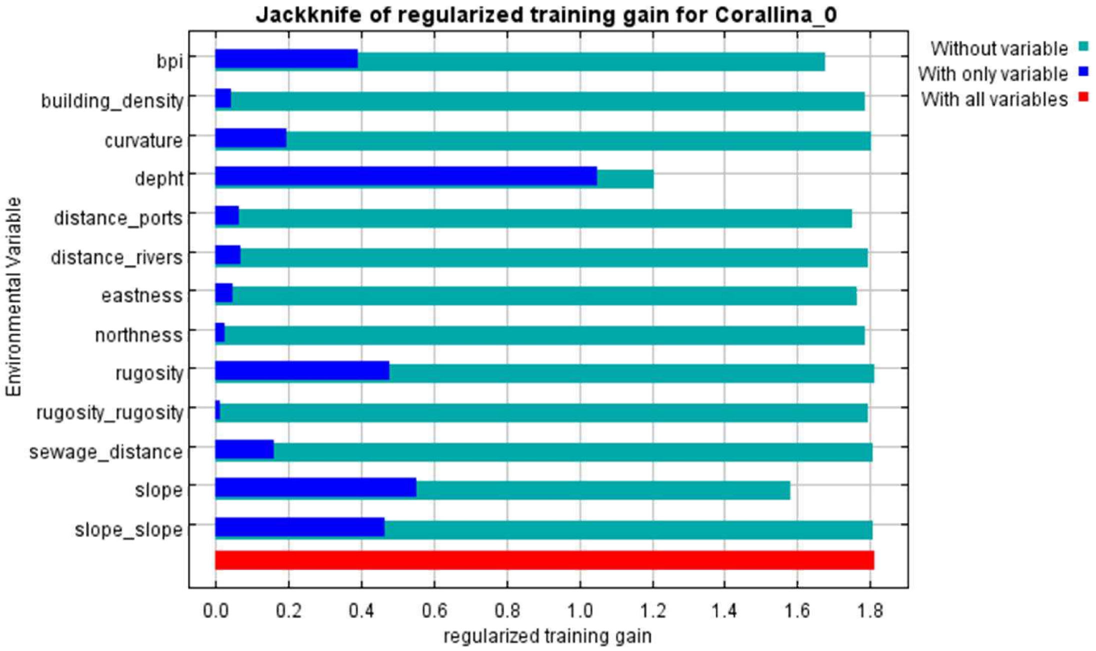

Figure S3: Variable of contribution to final *Corallina elongata* MaxEnt model output of each environmental factor determined using a jack-knife test.

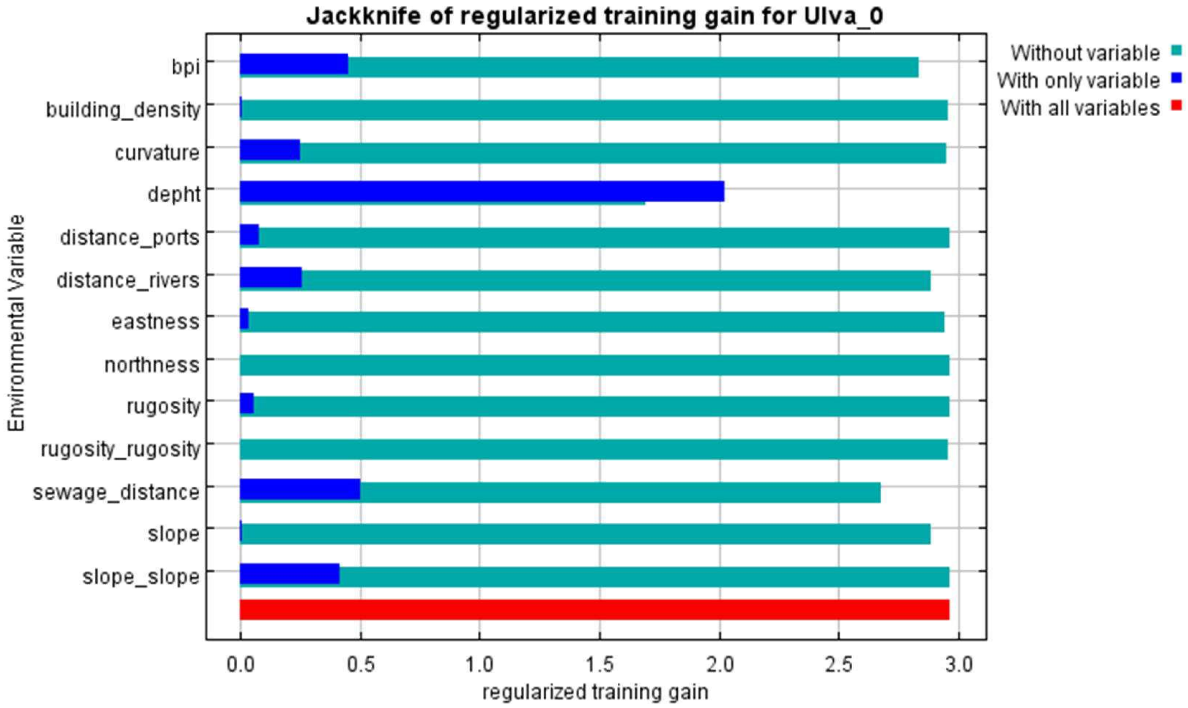

Figure S4: Variable of contribution to final *Ulva lactuca* MaxEnt model output of each environmental factor determined using a jack-knife test.

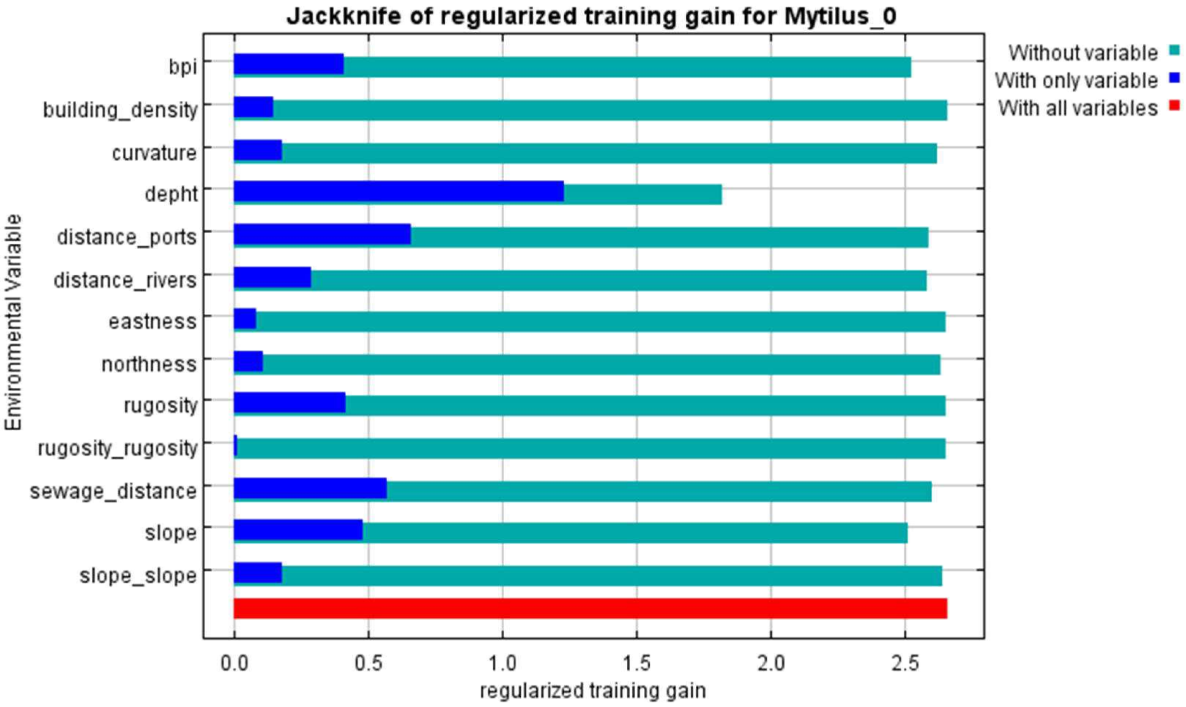

Figure S5: Variable of contribution to final *Mytilus galloprovincialis* MaxEnt model output of each environmental factor determined using a jack-knife test.

Chapter 6

Guidelines for monitoring measures of coralligenous assemblages within a Management context

1. Remark

This document provides a methodological framework for the implementation of monitoring measures for coralligenous assemblages with the aim to provide statistically sound data for management purposes. The method is based on existing standard monitoring assessment currently used in marine benthic habitats.

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This document provides a methodological framework for the implementation of monitoring measures for coralligenous assemblages. The method is based on existing standard monitoring assessment currently used in marine benthic habitats. It should be used together with other monitoring activities at MPAs to assess effectiveness of community based marine management and Marine Spatial Planning (MSP). The objective of this guideline is to identify and recommend the most appropriate, efficient, and internationally-recognized monitoring methods which can be used in the field and with which to provide statistically sound data for management purposes.

2. Why is it important to monitor coralligenous environments ?

Coralligenous habitats provide several essential ecological, economic and cultural services and their sustainable management and exploitation is one of the most important concerns of the last decade throughout the Mediterranean basin. Their importance has been also recognised under different international, European and national conservation frameworks (e.g. Habitats Directive; European Water Framework Directive) and as protected habitats in the EC Regulation No. 1967/2006 concerning management measures for the sustainable exploitation of fishery resources. Despite their importance, however, there are missing consensual methodologies for their monitoring and little is known about their distribution and status. This situation could be related to the difficulties associated with their exploration, their spatial heterogeneity and the lack of technical and financial capacity to collect and use the data.

Consequently, governmental bodies are increasingly obliged to implement and establish monitoring programs and protocols for the assessment with which achieve or maintain a Good Environmental Status (GES) by 2020. Therefore, Marine Strategy Framework Directive (MSFD) offers a crucial opportunity to Member States to build and standardised novel innovative methodological assessments and to incorporate a cost-benefit analysis, based on today's state-of-the-art technological developments into current monitoring practices.

Faced with the challenge of implementing MSFD goals, policymakers are tackled with the problem of 'the need to know *versus* the need to act'. Effective implementation of the MSFD directives relies on a comprehensive geospatial framework with which to understand the processes that determine the observed distribution patterns of habitat/species in marine ecosystems as a starting point. This information should contain spatially continuous and broad scale data on the distribution of both biological and physical resources and their interaction, with which to make informed and ecologically relevant decisions. Several pressures can be responsible of structural changes in the coralligenous habitats and the present approaches are at the moment the most effective to monitor them.

3. How remote sensing, habitat mapping and distribution modelling tools are useful for coralligenous management ?

Remote sensing (RS) and Habitat Mapping (HM) techniques are now fundamental tools for the monitoring and management of marine ecosystems (Brown et al., 2011; Buhl-Mortensen et al., 2015). These approaches offers repeatable, quantitative assessments and have the potential to provide a broad-scale synoptic view over spatially extensive areas, providing temporal data that may be used to assess events in community dynamics (Zapata-Ramirez et al., 2013) and in long term monitoring practices. Additionally to the HM practice and results, the implementation of Distribution Modelling (DM) procedures have resulted in an increased availability of environmental data (Brown et al., 2012; Reiss et al., 2015) with which to explore the relationships between abiotic and biotic patterns, allowing the predicted distributions to be mapped across an entire region. From this perspective, the integration of RS, HM and DM methods can be used as a management tool, providing information on:

(i) the exploration of possible effects of climate change on benthic species distribution patterns (Elith et al., 2011; Reiss et al., 2015), (ii) to assess habitat distributions in areas that, due to their complexity, are difficult to study and therefore have limited data availability (Fourcade et al., 2014; García-Alegre et al., 2014), (iii) to estimate the most suitable areas for a species and infer probability of presence in regions where no systematic surveys are available (Martin et al., 2014), (iv) to illustrate how human impacts interact with their distribution (Bandelj et al., 2009; Martínez et al., 2012; Zapata-Ramirez et al., submitted) and (v) to identify optimal sites for restoration initiative (Elsäßer et al., 2013; Valle et al., 2015). As a result, the integration of these techniques have proved to be a cost-effective and productive endeavour to achieve management objectives and to provide coherent maps of distributions of species and habitats, ecological goods, and services with which to assess the status (Piroddi et al., 2015) of MPAs.

Accordingly, our aim is to offer an easy and understandable guideline with which to identify and recommend the most appropriate RS techniques, HM and DM tools and data that should be used to address coralligenous management questions. We presented a framework with simple steps useful to build a strong baseline exploitable also to forecast future conditions and evaluate management actions of these habitats. The method is based on current standard monitoring assessment used in similar benthic habitats such as "reefs" (e.g. European Projects: HERMES, HERMIONE, CoralFish, SEDCoral, MAREMAP, MESH, MAREANO program, CODEMAP) as described in the European Habitats Directive (92/43/EEC). They have proven to be a cost-efficient and widely applied internationally-recognized method which provide relevant information for management purposes. As a result, the guideline for coralligenous assemblages management presented here, are likely to be applicable in a variety of other benthic habitat contexts where management actions are needed.

4. How to do it

Figure 1 summarises the basic steps of the methodological process for data collection and processing based in RS, HM and DM techniques.

5. Costs

The resource requirements vary significantly between different monitoring methods and the general expenses could be between medium to high. Time and cost, therefore, need to be considered across six main categories (Table 1).

6. What are the benefits of the implementation of this methodological framework on management implications ?

The methodological framework here presented will help to provide recommendations to managers and policymakers about how to best protect coralligenous resources, how to create or redefine different zones or levels of protections at MPA's and how to forecast future changes due to global warming and/or anthropogenic activities.

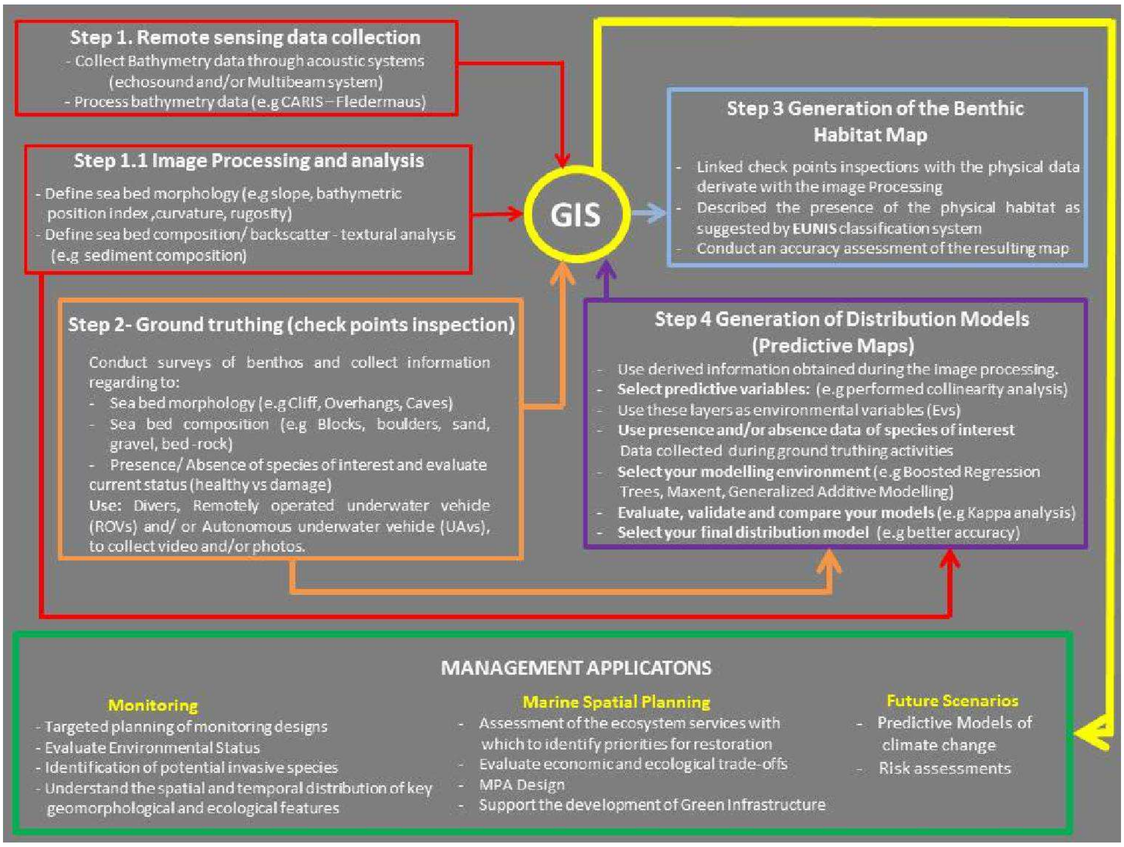


Figure 1. Key Step by Step Graphic Guide.

Table 1. Common Resources Required and Estimated Cost.

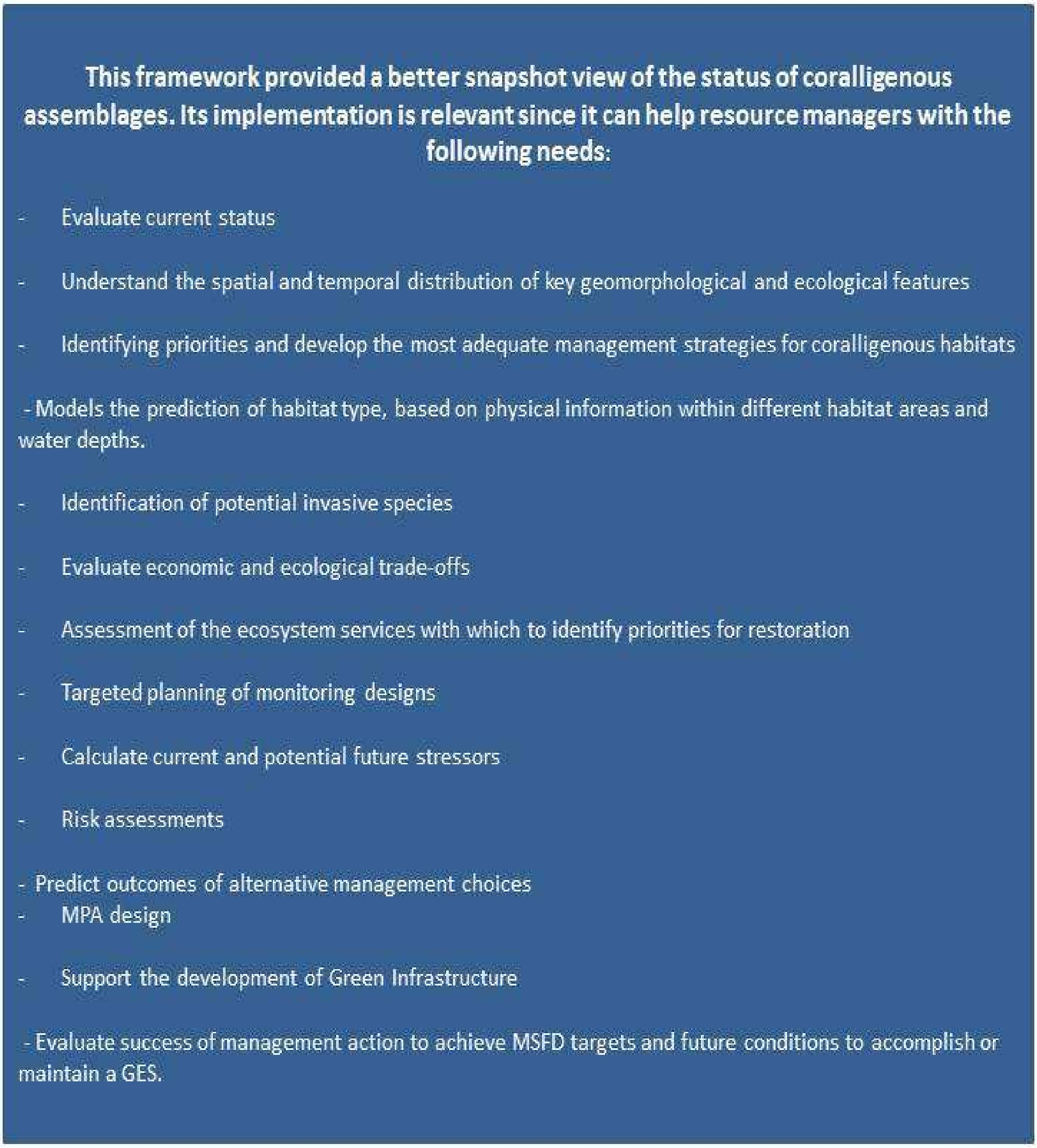
ACTIVITY	MEDIUM COST	HIGH COST
Set-up costs (e.g. hardware and software requirements)	ArcGIs 10.2 The R Project for Statistical Computing (Open source)	CARIS HIPS and SIPS Hypack Fledermaus - QPS Computers
Cost of acoustic acquisition	Single beam: low resolution	Multibeam: high resolution
Image acquisition	Divers with High resolution cameras / low resolution camera such as Go-Pro	AUVs – ROVs with high resolution cameras
Geo-Positional System	Divers connected with GPS in the surface	Ultra-Short Base line transponder (USBL system)
Field survey costs	The cost of this category will depend of the number of sampling days	The cost of this category will depend of the number of sampling days.
The time required for image processing, derivation of habitat classes and modelling	The cost of this category will depend on the amount of models and the expertise level of the researchers	The cost of this category will depend on the amount of models and the expertise level of researchers

We believe that the implementation of these recommended guidelines are timely and in alignment with the MSFD objectives and could strengthen management efficiency to make the best decisions at local scale that also could take into consideration the broader regional contacts and in that way, help to achieve or maintain the GES of coralligenous habitats by 2020.

7. Skills and Training

It is crucially important that those who commission surveys and monitoring for the coralligenous ensure that the habitat survey team has the required ecological and technological expertise. Regardless of the skill levels of field surveyors, some training for the methodological framework here presented will often be required, as survey objectives and methods can vary considerably. In the absence of widely recognized training in RS, HM and DM, at least for the implementation of the first step here presented can be challenging. Therefore, expert knowledge will be compulsory and essential to assist the success implementation of the methodological framework with which to obtain the baseline distribution maps. However and due to that usually MPAs managers often operate on a limited budget, in such cases, consideration should also be presumed to establish collaborations with research centers, universities or other government agencies which may have better technical, building capacity and resources to produce higher quality tested models and maps.

Once these baseline maps are produced, they will provide simplistic and comprehensive inputs, easy to be exploited by managers and stakeholders providing clarity and coordination among plans, useful to implement monitoring actions and with which to make informed management decisions and increase social awareness towards conservation needs.



This framework provided a better snapshot view of the status of coralligenous assemblages. Its implementation is relevant since it can help resource managers with the following needs:

- Evaluate current status

- Understand the spatial and temporal distribution of key geomorphological and ecological features

- Identifying priorities and develop the most adequate management strategies for coralligenous habitats

- Models the prediction of habitat type, based on physical information within different habitat areas and water depths.

- Identification of potential invasive species

- Evaluate economic and ecological trade-offs

- Assessment of the ecosystem services with which to identify priorities for restoration

- Targeted planning of monitoring designs

- Calculate current and potential future stressors

- Risk assessments

- Predict outcomes of alternative management choices
- MPA design

- Support the development of Green Infrastructure

- Evaluate success of management action to achieve MSFD targets and future conditions to accomplish or maintain a GES.

8. Portofino MPA case study

The methodological framework here presented was developed and tested at Portofino MPA, here we provide the main maps and models produced in the study case.

Bathymetric data was provided by the Ligurian Region, the data was collected in 2010. This data creates an extremely accurate digital representation of seafloor topography. The spatial analysis functions of a GIS allow the extraction of several derived products from bathymetric data, such as slope, bathymetric position index (BPI), curvature, hill-shade and rugosity (Figure 2).

Through a set of standard algorithms based on image classification and segmentation process, these derived products, and the relationships between them, can be examined to classify the benthic landscape (Figure 3). In general terms, pixels with close proximity and having similar spectral characteristics are grouped together into a segments that exhibit certain shapes, spectral, and spatial characteristics that are grouped to classify the area of interest (AOI).

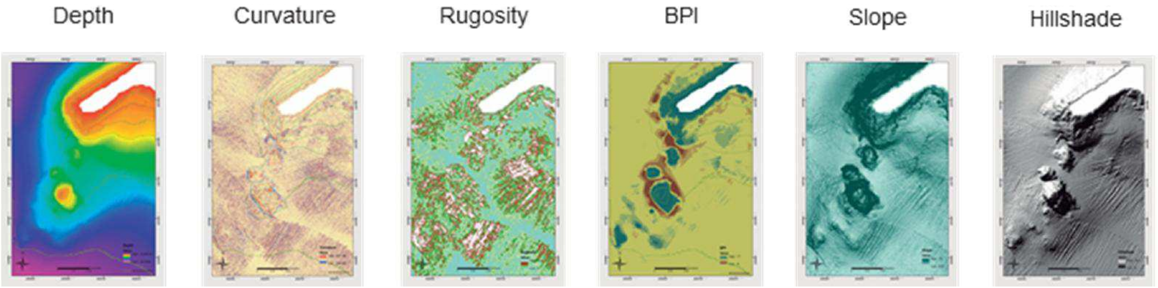


Figure 2. Bathymetric derived products

8.1 Portofino MPA habitat map

The map (Figure 3) show a rough estimation of the different seabed zones within the study area and with respect to the topography and kind of sediment distribution, providing an indication of where to find different habitat types during ground truthing activities.

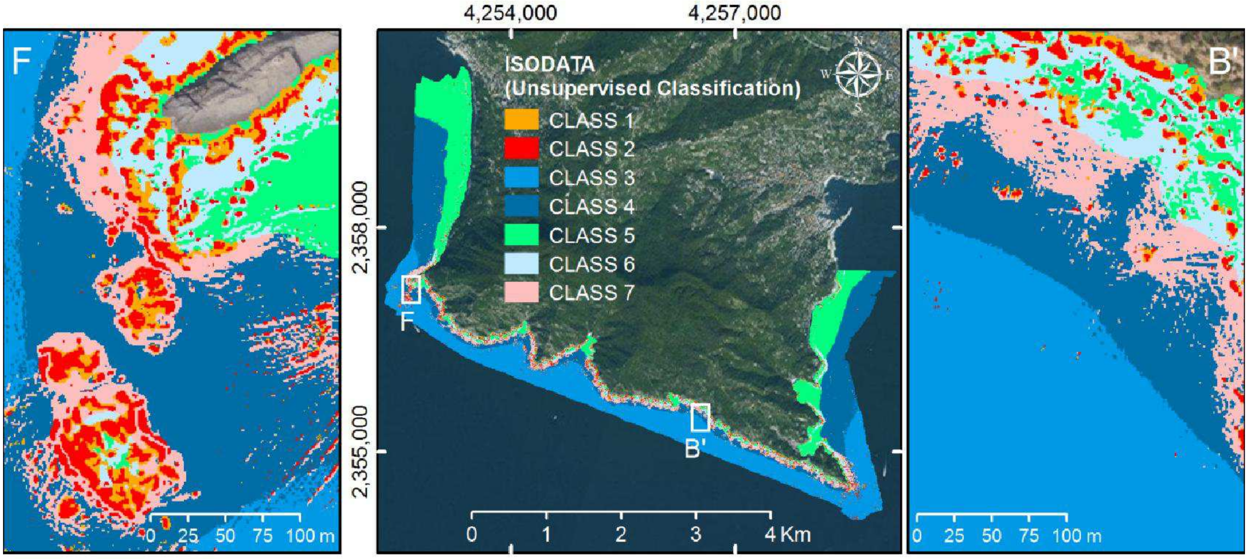


Figure 3. Portofino Habitat Map. On the left, a general map displaying the results of the entire MPA. On the right, the figure shows a close up of the study area recognized as "Isuela", a stack formation along the cliff (Zapata-Ramirez et al., submitted)

8.2 Ground truthing verification

We selected *in situ* transects that crossed areas that were spectrally separated in the classification map (Figure 3) and in order to produce an integrated, geo-referenced dataset. We accounted the accessibility from land that could help guarantee future monitoring activities as well as potentially more impacted areas. Once in the field, we recorded ground-truth variables as sea floor indicators and based on a combination of the main sediment types, the presence absence of the geomorphological features resulted from the image classification process and the presence of the benthic habitat as suggested by EUNIS classification system. The figures below shows two conceptual models: Figure 4) the morpho-sedimentary structures and facies-biotic associations at "Isuela" and Figure 5) the schematic representation of caves and overhangs at "Altare".

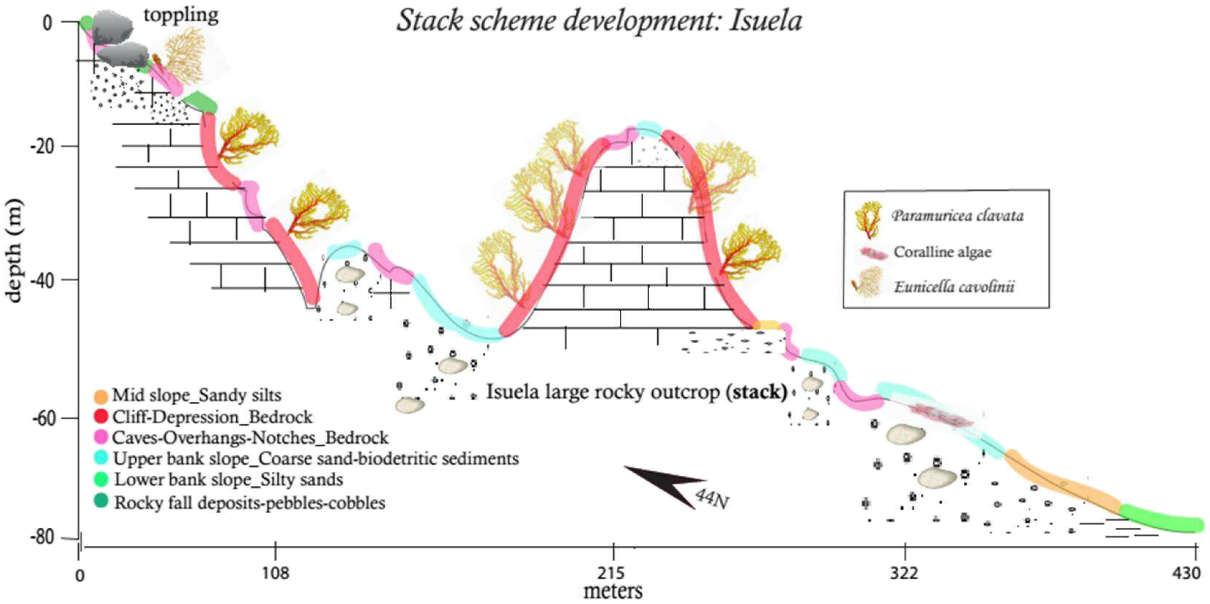


Figure 4. The schematic diagrams show the main coralligenous assemblage at "Isuela "and their relation with the morphology of the seabed, the water depth and the sediment grain size.

Spatial and quantitative analyses were applied to this dataset in order to characterize the morphology and distribution of coralligenous assemblages at the selected transects. An integration of the ground truthing and the classification map was conducted. Then training and ground validation field data collection and the map were refined and tested.

8.3 Final Habitat Product released with known accuracy results

As coralligenous occurs at the circalitoral zone (Peres and Picard, 1964; Laborel, 1987), we cut the shallow area (-0 to -20m) of the habitat map classification. Finally, total surface area considered for the habitat map and distribution models were 5.45 Km2, of which 2.57 Km2 fall within the MPA.

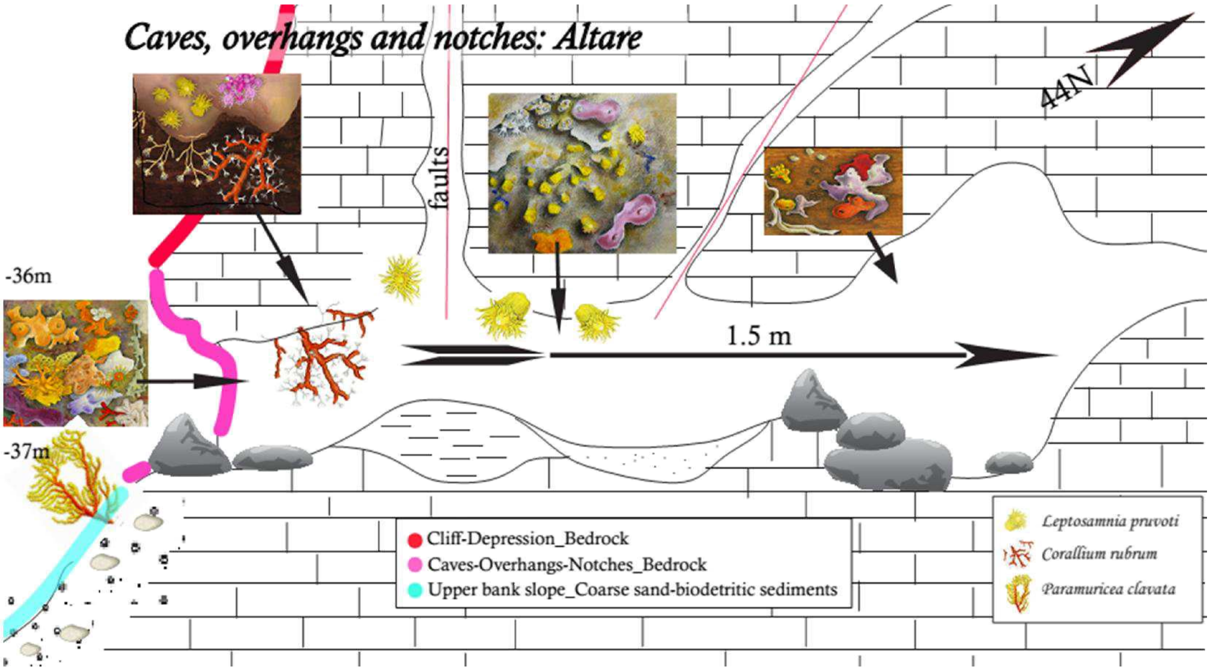


Figure 5. The schematic diagram show the coralligenous assemblages associated with the morphology of the seabed, in particular with rims where several overhangs between 18-40m depth occur at "Altare".

Accuracy of assessment of the classification map (Figure 6) produced an overall accuracy of 76.40%. The classification of the habitat map and the spatial analyses shows that coralligenous preferentially grow on steep slopes/ cliff depressions (Figure 4), while on caves and overhangs structures, semi dark communities such as the red coral develop (Figure 5).

Due to the proximity between coralligenous and cave environments at Portofino MPA, we consider that *Corallium rubrum* (Figure 5) should be also included among the aspects of coralligenous assemblages. These *facies* develop in the same sites, hence the integration for monitoring activities between the two habitats and their connections to management strategies, protection and conservation would be more effective.

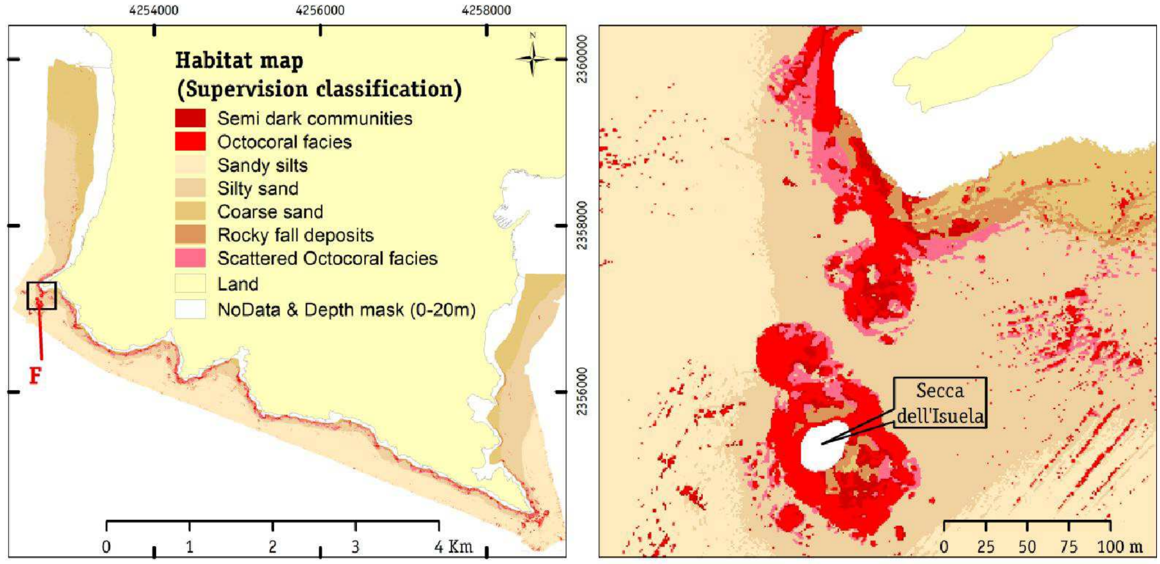


Figure 6. Final Habitat Map Product released with known accuracy of Portofino MPA. On the left, a general map displaying the results of the entire study area and on the right, a zoom in one of the sampling sites (“Isuela”) (Zapata-Ramirez et al., submitted).

8.4 Distribution Models

There is now a variety of Distribution Modelling (DM) techniques based on presence–absence or presence-only data and the list of available methods to select is growing continuously (Reiss et al., 2015). As a result, a key decision should be to choose the most appropriate method to use to model the interest habitat. Methods which tend to under predict distribution patterns might be useful for species protection applications such as MPAs, as a consequence, here we presented two possible solutions that performs equally well and describe the distribution in a similar way in Portofino MPA.

8.4.1 Presence only algorithm approach

- The maximum entropy model (Maxent)

The final model has a mean AUC: 0.97 and narrow confidence which indicate a good model (Figure 7). The model indicate Slope (> 53.2 %) as the most important variable of contribution for the model prediction follow by Rugosity (19.4%) and Bathymetric Position Index (BPI) (17%).

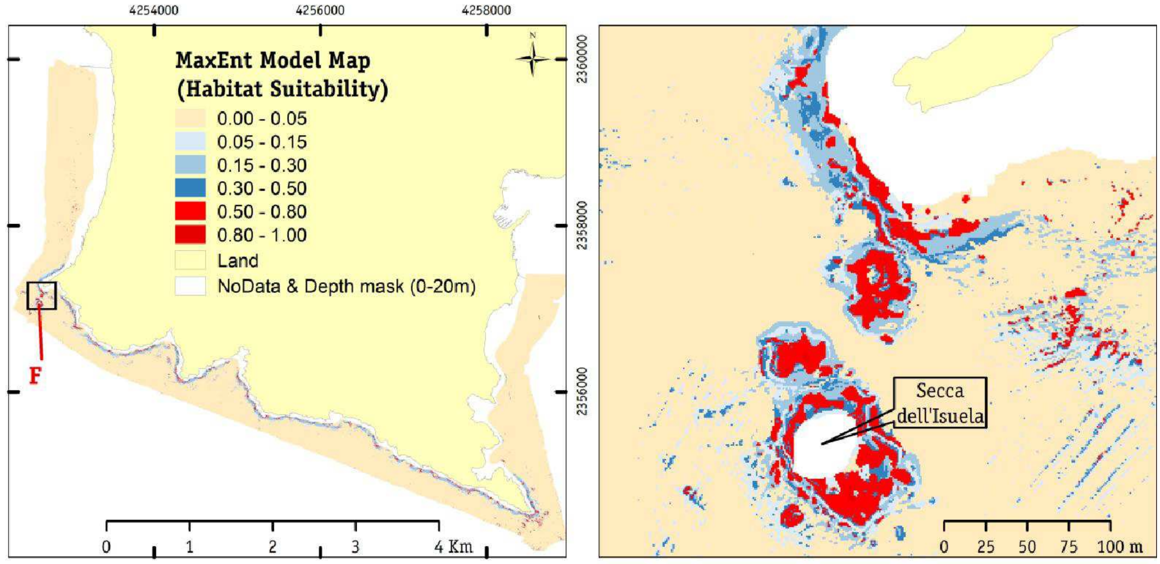


Figure 7. Distribution model (MaxEnt) revealing the predicted occurrence of the coralligenous assemblages located at Portofino MPA. On the left, a general map displaying the results of the entire study area and on the right, a zoom in one of the sampling sites ("Secca dell' Isuela"). Pink background indicates that coralligenous is not present (probability < 0.05), blue shades indicate low probability (< 0.50) and red high probability of presence (> 0.50). (Zapata-Ramirez et al., submitted).

8.4.2 Presence – absence algorithm

- Boosted Regression Trees (BTR) also called stochastic gradient boosting

A final model (Figure 8) selected using 10 fold cross validation utilized 9950 trees for the same area, Isuela, achieve an excellent (AUC 0.98) prediction. As in Maxent prediction model, Slope contributed the most (> 66.7 %) to the prediction, but in this case followed by Curvature (15%) and Depth (14%).

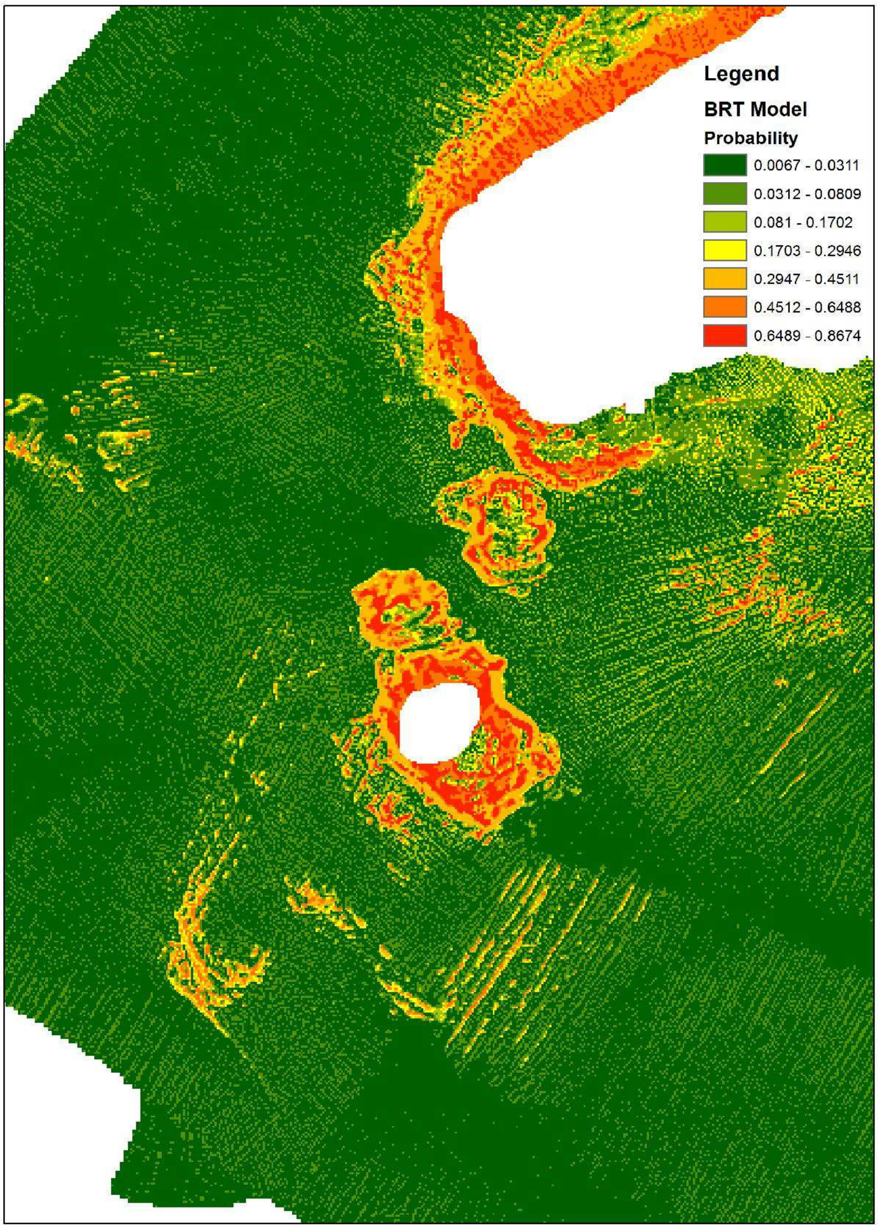
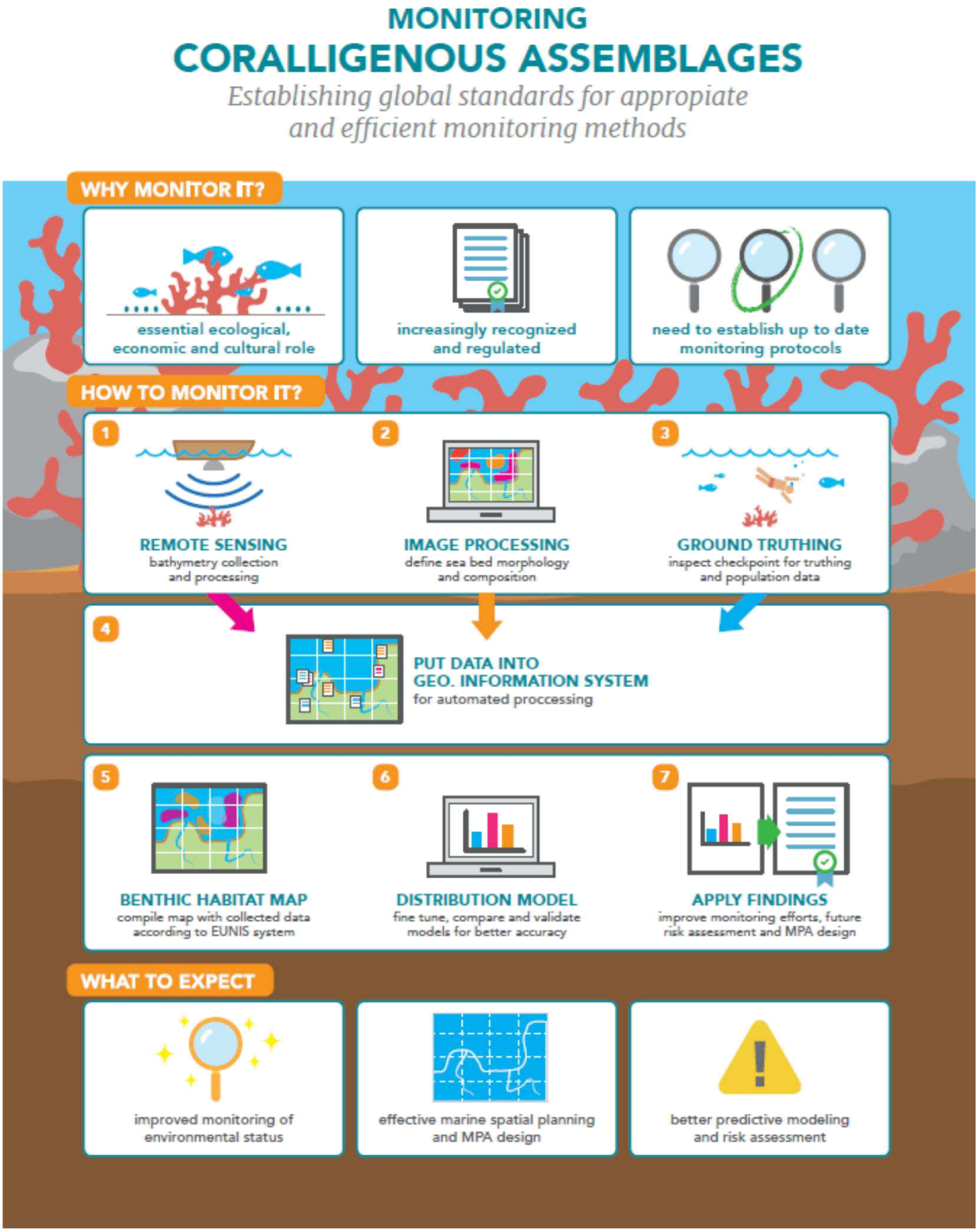


Figure 8. BRT Distribution model showing the presence of coralligenous assemblages at “Isuela” (Zapata-Ramirez et al., in prep).

8.4.3 Results

Both models fit complex functions between responses and predictive variables and generated very similar broad predictions. The two models shows that coralligenous assemblages are most likely to be found on the steep rough walls where slope values is usually high. However, the models weighted the environmental variables differently and consequently the spatial predictions differ slightly. These differences emphasize the important role of critical expert evaluation of spatial predictions before they can be used reliably for monitoring and to inform decision-making.



MONITORING

CORALLIGENOUS ASSEMBLAGES

Establishing global standards for appropiate and efficient monitoring methods

WHY MONITOR IT?

essential ecological, economic and cultural role

increasingly recognized and regulated

need to establish up to date monitoring protocols

HOW TO MONITOR IT?

1 **REMOTE SENSING** bathymetry collection and processing

2 **IMAGE PROCESSING** define sea bed morphology and composition

3 **GROUND TRUTHING** inspect checkpoint for truthing and population data

4 **PUT DATA INTO GEO. INFORMATION SYSTEM** for automated proccessing

5 **BENTHIC HABITAT MAP** compile map with collected data according to EUNIS system

6 **DISTRIBUTION MODEL** fine tune, compare and validate models for better accuracy

7 **APPLY FINDINGS** improve monitoring efforts, future risk assessment and MPA design

WHAT TO EXPECT

improved monitoring of environmental status

effective marine spatial planning and MPA design

better predictive modeling and risk assessment

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European Projects :

CODEMAP: http://www.codemap.eu/

CoralFish: http://www.eu-fp7-coralfish.net/

HERMES: http://www.eu-hermes.net/

HERMIONE: http://www.eu-hermione.net/

MAREANO: http://mareano.no/en/about_mareano

MAREMAP: http://www.maremap.ac.uk/index.html

MESH: http://www.emodnet-seabedhabitats.eu/default.aspx?page=2003

SEDCoral: http://archive.noc.ac.uk/SEDCORAL/SEDCoral_results_Darwin.html

Synthesis of the results, general outcomes and conclusions

As stated in the introduction of this study, the application of RS and DMs is widely recommended as the ideal approach to management and to achieve MSFD conservation goals, yet the availability of real data concerning the distribution of species and habitats is often scarce, in particular in deep environments and problems may arise when trying to choose appropriate management targets without having spatially extensive biophysical data from field inventories with which to meet conservation targets. For this reason, this study investigated the performance of different RS and DMs techniques at Coralligenous and at Rocky shore environments as management tools to assess their status and to support management actions and Marine Spatial Planning (MSP) decisions. This is motivated by the recognition that optical and acoustic sensors commonly available on underwater mapping platforms have complementary strengths and are non-destructive methods. General results shows that predictions based on combined methods, provide more realistic estimates of the core area suitable for different environments providing both high-resolution, full coverage surveys of selected areas that can be precisely revisited during monitoring activities as well as broader scale features of the terrain, such as surface roughness, slope and aspect that provide notion of the habitat structure and regarding sea floor integrity. The use of underwater cameras is often applyed to ground-truth remote sensing techniques such as aerial photography, satellite imagery, and multibeam sonar. In addition, the images collected helps to examine the correlations between populations and the underlying bathymetric processes that determine their distribution (Chapter 1).

The produced maps provide information about where the habitat/species could be present and how they are related to the geomorphological context and/or the anthropogenic pressures (Chapter 3 and 5). Even though the different methodologies and models applied could describe the distribution correspondingly well, the findings show that there were in some cases minor misclassifications on the resulting maps (Chapter 3 and 6). These results emphasize the role of critical expert evaluation of spatial predictions before they are used to guide policy and to take informed acological relevant decissions. Results also highlight that similar methods can be analysed in multiple ways to map and characterize benthic habitats depending on cost, time, end goals and human resources (Chapter 1, 2 and 6).

Results also provided an assessment of the current distribution of rocky shore indicator species at Portofino MPA, along with targets designed to offer awareness of whether the MPA is achieving GES. In particular, the results here presented provide insights for future monitoring of human impacts and/or ecological dynamics and their relationship with the decline or recovery of the important engineering species such *Cystoseira amentacea*, protected key-stone species outlined in the list of conservation priorities

Although this research includes data over a limited temporal window, and therefore restricts the examination of spatial distribution over temporal scales, the outputs of these baseline predictions could be useful for evaluation of temporal and spatial changes in the future, resulting from natural environmental disturbances such as climate change and/or anthropogenic impacts addressing several of the high priority recommendations of European Commission and EU Nature 2000 Network under the Habitat Directive (EUROPEAN COMISIÓN: SEC, 2011). In particular, the results presented fit the aims of MSFD (2008/56/EC), by generating spatial mapping of coralligenous environments, building a key baseline for their monitoring and providing measures to define GES.

The application of the standardized methodological framework suggested as a guideline on the PhD thesis, could strengthen management efficiency and will help to make the best decision at local scale that also take into consideration the broader regional contacts and in that way, help to achieve or maintain a GES for 2020 (Chapter 6).