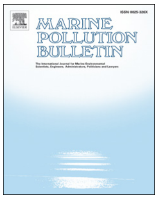
Marine Pollution Bulletin 131 (2018) 218–232

Contents lists available at ScienceDirect

Marine Pollution Bulletin

journal homepage: www.elsevier.com/locate/marpolbul



A predictive approach to benthic marine habitat mapping: Efficacy and management implications

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ARTICLE INFO

Keywords:
Fuzzy clustering
Random forest
Marine Protected Area
EUNIS
Coralligenous reefs
SWOT analysis

ABSTRACT

The availability of marine habitats maps remains limited due to difficulty and cost of working at sea. Reduced light penetration in the water hampers the use of optical imagery, and acoustic methods require extensive sea-truth activities. Predictive spatial modelling may offer an alternative to produce benthic habitat maps based on complete acoustic coverage of the seafloor together with a comparatively low number of sea truths. This approach was applied to the coralligenous reefs of the Marine Protected Area of Tavolara - Punta Coda Cavallo (NE Sardinia, Italy). Fuzzy clustering, applied to a set of observations made by scuba diving and used as sea truth, allowed recognising five coralligenous habitats, all but one existing within EUNIS (European Nature Information System) types. Variable importance plots showed that the distribution of habitats was driven by distance from coast, depth, and lithotype, and allowed mapping their distribution over the MPA. Congruence between observed and predicted distributions and accuracy of the classification was high. Results allowed calculating the occurrence of the distinct coralligenous habitats in zones with different protection level. The five habitats are unequally protected since the protection regime was established when detailed marine habitat maps were not available. A SWOT (Strengths-Weaknesses-Opportunities-Threats) analysis was performed to identify critical points and potentialities of the method. The method developed proved to be reliable and the results obtained will be useful when modulating on-going and future management actions in the studied area and in other Mediterranean MPAs to develop conservation efforts at basin scale.

1. Introduction

Habitat mapping is a prime necessity for environmental planning and management since it can provide an inventory of environmentally sensitive areas, identify hot spots of ecodiversity, detect changes in biotic cover, allow boundary demarcation of multiple-use zoning schemes, and help quantifying ecosystem services (Bianchi et al., 2012; Ichter et al., 2014). On land, high quality habitat maps are obtained thanks to aerial photography, satellite imagery and an array of multispectral and hyperspectral sensors while ground-truthing can be achieved by means of field surveys (Sankey et al., 2017).

In the sea, light attenuation in the water column limits the use of optical methods to the intertidal or shallow depths (Kachelriess et al., 2014). Acoustic methods (such as single- or multibeam echosounders and side scan sonar) supply the best alternative, as sound can reach greater depths (Mayer, 2006).

Acoustic methods can discriminate between reefs and sedimentary areas but give little information on the biotic communities inhabiting these substrata (Markert et al., 2013). The analysis of backscatter images is promising in this respect (Lamarche and Lurton, 2017), but requires a large amount of sea-truthing to associate acoustic regions (or facies or classes) to different biotic assemblages (van Rein et al., 2011). Field surveys for sea-truthing are more expensive than on land, as they require purposely equipped vessels and autonomous or remotely operated videos and scuba diving (Clements et al., 2010). Scuba diving provides the most accurate method to describe and identify benthic communities living on reefs (Bianchi et al., 2004) but has severe limitations in term of operational time and/or depth (Parravicini et al., 2010). All these constraints explain the paucity of detailed marine habitat maps. Spatial distribution models (Guisan and Zimmermann, 2000) applied to the marine ecosystems can represent an alternative to predict the distribution of marine communities on the basis of physical

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https://doi.org/10.1016/j.marpolbul.2018.04.016
Received 9 October 2017; Received in revised form 9 March 2018; Accepted 9 April 2018

attributes such as depth or distance from coast. Physical parameters can be more easily obtained, and require a reduced number of sea-truthing surveys (Martín-García et al., 2013). Spatial distribution models allow obtaining large-scale and efficient mapping also when sea-truthing data are limited. They showed effective in understanding the distribution of benthic organism categories (Holmes et al., 2008), subtidal rocky habitats (Mielck et al., 2014) and seagrass beds (Kelly et al., 2001).

Coralligenous reefs are endemic Mediterranean habitats and important coastal ecosystems for distribution, biodiversity, biomass, and role in the carbon cycle (Laubier, 1966; Bianchi, 2001). They represent an iconic submerged seascape (Bianchi et al., 2005; Giaccone, 2007), exhibit great structural and functional complexity (Paoli et al., 2016, 2018), and provide multifarious ecosystem services to humans (Paoli et al., 2017), but are vulnerable to either global or local impacts (Gatti et al., 2015a, 2015b, 2017; Montefalcone et al., 2017). Coralligenous reefs have therefore been included among the ‘special habitat types’ that should be assessed under the Marine Strategy Framework Directive of the European Union (Bavestrello et al., 2016).

Coralligenous reefs are characterised by a basal bioconstructed layer mostly formed by calcareous red algae (Oprandi et al., 2016) and typically exhibit a canopy of erect macroalgae or sessile invertebrates that grow in dim light conditions and in relatively calm waters, typically between 20 and 120 m (Ballesteros, 2006). They are therefore too deep for optical methods but their distinct assemblages cannot be distinguished by acoustics. The habitat classification developed by the European Nature Information System EUNIS (Davis et al., 2004; Tunesi et al., 2006) recognises 15 such habitat types, differentiated by depth, exposure, substrate, and characteristic and accompanying species (Bellan-Santini et al., 2002). EUNIS habitats characterised by macroalgae are called ‘associations’, those characterised by macroinvertebrates are called ‘facies’. However, in the European Red List of marine habitats, Mediterranean coralligenous habitats are classified as Data Deficient (Gubbay et al., 2016), thus evidencing the urgent need for thorough investigations and accurate monitoring plans (Ballesteros, 2008; Sartoretto et al., 2017).

In this paper, the coralligenous habitats of a Marine Protected Area have been mapped through a predictive model applied to a set of underwater observations, made by scuba diving and used as sea truth, and to acoustic data offering a complete coverage of the seafloor. Results allowed: i) calculating the surface area occupied by each of the distinct coralligenous habitats identified; ii) quantifying their occurrence in zones with different level of protection; and iii) discussing management implications. The application of the spatial prediction method has been criticized through a SWOT (Strengths, Weaknesses, Opportunities and Threats) analysis (Gao and Peng, 2011).

2. Material and methods

2.1. Study area

The study area is represented by the coastal marine tract located around Tavolara Island, in NE Sardinia, Italy (Fig. 1).

From a geomorphological perspective, high cliffs, interrupted by narrow coastal plains and coastal lagoons, compose the mainland (Rovere et al., 2013). Two major islands characterise the continental shelf: Tavolara and Molara. From a lithological perspective, the entire study area is composed of granitic bedrock of Hercynian origin (304–251 Mya). The only exception is Tavolara Island, composed almost entirely of Jurassic (201–145 Mya) limestone. Seafloor morphology is similarly characterised by granitic inselbergs and limestone pinnacles and further complicated by beachrocks that run parallel to the coastline at various depths (Orrù and Pasquini, 1992).

Since 1997, Tavolara and Molara, together with most of the surrounding region, have been included in the Marine Protected Area of ‘Tavolara - Punta Coda Cavallo’, extending for about 15,000 ha and divided in three zones subjected to different levels of protection (Rovere et al., 2013): zone A (no entry – no take), of ca 600 ha, is limited to a small site at the south-east of Tavolara and the islet of Molarotto to the east of Molara; zone B (general reserve, human activities strictly regulated), of ca 3400 ha, is split in four parts around Tavolara, Molara and Molarotto, Capo Ceraso, and Capo Coda Cavallo; zone C (partial reserve or buffer zone, most human activities allowed but regulated) comprises the remaining ca 11,000 ha, between Capo Ceraso to the north and Cala Finocchio to the south (Fig. 2).

Most infralittoral bottoms of the Marine Protected Area are covered by an extensive seagrass (*Posidonia oceanica*) meadow (Navone and Bianchi, 1992; Gattorna et al., 2006), whereas rocky outcrops of different nature (granite, limestone, beachrock conglomerate) harbour distinct epibenthic communities according to depth and slope (Navone et al., 1992; Bianchi et al., 2010).

2.2. Data sources

Early acoustic surveys in the Marine Protected Area of Tavolara - Punta Coda Cavallo were carried out in 1989 using single beam echo sounders (Elac Laz 5100, 60 kHz, and Furuno 612, 100 kHz) and side scan sonar (Klein 150 kHz), and allowed producing a first geomorphological map at the scale of 1:25000 (Navone et al., 1992). In 2011, a new seabed survey was carried out using multibeam (Kongsberg-GeoSwath Plus 250 kHz) and side scan sonar (Klein 3900–445/900), which allowed perfecting and updating the previous map (Deiana et al., 2013; Rovere et al., 2013). From these surveys, detailed bathymetry and georeferenced information about potential coralligenous reef occurrence were obtained (the full set of acoustic data is available at the Marine Protected Area of Tavolara - Punta Coda Cavallo: www.amptavolara.com). Only rocks between 25 m and 55 m (maximum depth explored) were considered in this study (Fig. 2).

Direct observations by scuba diving (Bianchi et al., 2010) were used as sea-truths of acoustic surveys and provided the relevant biological information. Positioning accuracy of divers was in the order of a few tens of metres, which is considered adequate at the scale 1:25000 of the final map (Rovere et al., 2013). Dives were carried out in 21 sites (capital letters A to U in Fig. 2). Depending on local morphological complexity, up to 6 stations were surveyed in each site, differing for depth, slope and proximity of the sedimentary bottom. In total, 57 stations were surveyed, each station consisting of a reef portion of about 2 m^2 (Gatti et al., 2012). Diving surveys allowed realising an inventory of 59 conspicuous sessile species (Table 1).

2.3. Species clustering

A presence-absence matrix of 59 species × 57 stations was used to classify different species groups by means of cluster analysis (Halkidi et al., 2001), using specifically a fuzzy clustering technique (Dunn, 1974; Bezdek, 1981). Fuzzy *c*-mean (FCM) is an unsupervised clustering algorithm that has been widely applied since the introduction of the fuzzy set concept (Zadeh, 1965; Rezaee et al., 1998).

FCM is able to determine the grade of membership for each object in the cluster, starting from the identification of the most characteristic point in each cluster, which can be considered as the ‘centre’. In the specific case, the centre is represented by the typical species composition of each coralligenous habitat. In particular, FCM minimizes within-cluster variance D_v (distance or square error) expressed as:

$$D_v = \Sigma_{k=1}^{K} \Sigma x_j \in S_k \ |X_j - C_k|^2$$

where C_k is the mean point of all points in the cluster k, K is the number of clusters, S_k is the set of points in the k_{th} cluster, and x_j is the standardized vector for site j (Sadri and Burn, 2011). The FCM algorithm identifies an initial set of k groups and then calculates the mean point, or centroid, of each set. The next step is the construction of a new partition by associating each point with the closest centroid. Then, the