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Research article

Assessing the effects of habitat patches ensuring propagule supply and different costs inclusion in marine spatial planning through multivariate analyses

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ABSTRACT

Marine Protected Areas are considered key tools for conservation of coastal ecosystems. However, many reserves are characterized by several problems mainly related to inadequate zonings that often do not protect high biodiversity and propagule supply areas precluding, at the same time, economic important zones for local interests. The Gulf of Naples is here employed as a study area to assess the effects of inclusion of different conservation features and costs in reserve design process. In particular eight scenarios are developed using graph theory to identify propagule source patches and fishing and exploitation activities as costs-in-use for local population. Scenarios elaborated by MARXAN, software commonly used for marine conservation planning, are compared using multivariate analyses (MDS, PERMANOVA and PERMDISP) in order to assess input data having greatest effects on protected areas selection.

MARXAN is heuristic software able to give a number of different correct results, all of them near to the best solution. Its outputs show that the most important areas to be protected, in order to ensure long-term habitat life and adequate propagule supply, are mainly located around the Gulf islands. In addition through statistical analyses it allowed us to prove that different choices on conservation features lead to statistically different scenarios. The presence of propagule supply patches forces MARXAN to select almost the same areas to protect decreasingly different MARXAN results and, thus, choices for reserves area selection.

The multivariate analyses applied here to marine spatial planning proved to be very helpful allowing to identify i) how different scenario input data affect MARXAN and ii) what features have to be taken into account in study areas characterized by peculiar biological and economic interests.

1. Introduction

Human populations and their demands for land, energy, and natural resources are exponentially growing, creating pressures on ecosystems that are not expected by conventional approaches to natural resource management (Leisinger et al., 2002). The Ecosystem-Based Management (EBM) approach (Katsanevakis et al., 2011) was developed to tackle this problem from a holistic point of view, involving management of species habitats and human activities. Ecosystem management is best thought as "the process of ecosystem-based management of human activities" (Grumbine, 1991; Kay and Schneider, 1994) using appropriate management and protection tools, such as Marine Protected Areas (MPAs) (Browman and Stergiou, 2004; Halpern et al., 2010; Rassweiler et al., 2012). MPAs guarantee the conservation of marine biodiversity (Appolloni et al., 2017; Donnarumma et al., 2018; Ferrigno et al., 2017), raising ecosystem services (Franzese et al., 2017, 2015; Picone et al., 2017) and produce economic benefits increasing commercial fish sizes and biomass (i.e Guidetti et al., 2008; Fenberg et al., 2012) and enhancing visitors flows through sustainable practice of marine activities, such as diving and yachting (McCook et al., 2010; Lopes et al., 2015).

In this framework protected areas are the keys for marine environment conservation and improvement of local economies; however they often are not sufficient to achieve their conservation

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objectives (Fraschetti et al., 2005a; Guidetti et al., 2008; Martín-García et al., 2015). Too often relevant sites characterized by high number of species (Russo et al., 2005a, 2005b), presence of important habitats for ecosystem functions (Fraschetti et al., 2005a) and propagule sources, are located in areas of partial or null protection. At the same time, management efforts are often vain since local populations consider protection policies merely as tools for biodiversity conservation, with no economic feedbacks (Badalamenti et al., 2000). This also applies to Italian MPAs, characterized by several management problems, mostly related to political and administrative reasons, such as limited availability of funds, precariousness of management bodies (Francour et al., 2001; Messina, 2005) and inadequate zonings that preclude important zones for economic activities (Badalamenti et al., 2000).

In order to overcome these criticisms, the Systematic Conservation Planning approach was developed (Margules and Pressey, 2000). This is based on the explicit definition and quantification of conservation objectives to be achieved and on minimization of costs linked to the protection (Kirkpatrick, 1983; Smith et al., 2006).

From the stakeholders points of view, “costs” are those deriving from different uses (costs-in-use) of a resource if it had not been included in a reserve. In terrestrial and marine protected areas, where extractive and exploitation activities are forbidden, costs are measured as the highest economic values of activities in absence of protection policies (Naidoo et al., 2006).

In this context conservation features are the items preserved by protection policies, identified according to objectives of the protected area. Other than habitats patches, a typical conservation feature to be taken into account in conservation planning, is the propagule exchange between habitat patches (connectivity), since this is a critical bio-ecological process structuring marine populations and affecting ecosystems resilience (Botsford et al., 2009; Palumbi, 2004; Roberts et al., 2003a; Sale et al., 2005).

Graph theory offers a wealth of powerful tools and algorithms to analyse network connectivity in many ecological fields (Strogatz, 2001; Lesne, 2006; Grubesic et al., 2008) providing a favourable trade-off between how well a model represents reality and the amount of required data (Keitt et al., 1997; Calabrese and Fagan, 2004; Bodin and Norberg, 2007). Within a seascape context, graph theory allows to identify patches of specific habitat that can ensure propagule supply to the other patches of the same habitat.

The selection of protected areas following systematic approach is a complex problem, solvable in some cases only by using mathematical heuristic algorithms. A powerful approach for its flexibility and rapidity is the simulated annealing algorithm, as implemented in MARXAN software (Ball et al., 2009), inspired to the annealing process of metals and glass (Metropolis et al., 1953). The main benefit of this method is that the algorithm indicates a plethora of solutions that can be submitted to stakeholders.

The aims of the present investigation are: (i) to apply an easy method to identify propagule habitats source patches in order to include them in MARXAN input data, (ii) to find a method via community ecology multivariate analyses to assess if and which conservation features and costs are more relevant in protected area selection.

2. Materials and methods

2.1. Study area

The Gulf of Naples habitats map is shown in Fig. 1. In order to simplify its understanding, some explanations with a list of abbreviations and RAC/SPA codes are reported in supplementary materials. The study area covers about 1051 km^2 of the whole Gulf; its morphology changes radically moving from North-West to South-East sectors. The first sector is characterized by a rugged bottom, due to the presence of two deep canyons and a large number of rocky outcrops (mostly remains of submarine volcanic cones) that host most of the precious coralligenous habitats (C). The South-East side is very regular, consisting mostly of a large muddy platform (VTC and DE habitats) that gently degrades until 200 m depth even if a single emergent rocky relief, represented by Vico Equense rocky outcrop (Russo, 1997, 1992), is here present.

On north side and close to the coastline, sandy habitats are present, principally: SFBC, SGCF, GI and SVMC. The latter, in the harbours and in the inner part of the Gulf is also present as high anthropic impacted *facies* (SVMC (STP)).

South-East side coastline and islands are dominated by high rocky cliffs and boulders that determine suitable sites for infralittoral algae habitat (AP) on the shallow part and for coralligenous habitats on the deeper part.

To the south side of the Gulf there is a relevant C-SCA habitat, an important coralligenous *facies* characteristic of the shallow part of the continental slope. Environmentally and economically important species such as *Corallium rubrum* (Linnaeus, 1758) and other alcyonacea as *Paramuricea clavata* (Risso, 1826) are here present (Bo et al., 2009; Bavestrello et al., 2014).

Around all islands, shallow bottoms are mostly characterized by seagrass meadows of *Posidonia oceanica* (Delile, 1813). There also are evidences of *Posidonia oceanica* dead mattes in the inner part of the Gulf, as a result of strongly anthropogenic pressures (Pergent et al., 1995; Costantino et al., 2010).

In order to preserve the great habitats variety characterizing the Gulf four MPAs were also established: the Underwater Parks of Baia (B) and Gaiola (G), the Regno di Nettuno (RN) and Punta Campanella (PC) MPAs. Their protection is ensured through three zoning regimes: no-take zone (A) where all activities that may disturb or damage marine environments are forbidden; buffer zone (B) where impacting activities are strictly regulated; transitional zone (C), where anthropic activities are regulated according to a sustainable development.

2.2. Patches connectivity

In recent years, the number of studies applying graph theory to terrestrial landscapes increased remarkably (Fall et al., 2007; Ferrari et al., 2007; Jordán et al., 2007; Minor and Urban, 2008; Pascual-Hortal and Saura, 2008). In the present study, nodes are habitats patches and links represent the likelihood (p_{ij}) of a meroplanktonic organism to directly disperse between patches i and j (without passing through any other intermediate habitat patch). Values of p_{ij} are quantified using patch areas and Euclidian distance (Treml et al., 2012). Here is assumed that a benthic species, at the end of its meroplanktonic larval stage, is attracted by the adult stage habitat (Pawlik, 1992) within the Gulf. Indeed, Levin (2006) suggests that larval retention in the natal habitat is more frequent than suspected and thus populations could be less open than previously thought.

In order to ensure long-term habitat life, connectivity among patches of the same habitat (Treml et al., 2008) is assessed through Probability of Connection (PC) using ConeforSensinode 2.2 (Saura and Torné, 2009) software.

From graph theory, PC is the likelihood that two points randomly placed within the landscape fall into habitat areas that are reachable from each other (interconnected). Essentially, it is a measure of the likelihood that a patch is a source of propagules.

To assess PC, mixed habitats (i.e. AP-SFBC or C-SGCF) are grouped on the base of the dominant habitat (Table 1). Groups whose dominant habitats are not mentioned by Habitat directive