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Marine protected area design patterns in the Mediterranean Sea: Implications for conservation

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ABSTRACT

Mediterranean marine protected area (MPA) design patterns regarding geographic distribution, size, spacing and shape were analysed as a proxy of the region's MPA's ecological effectiveness and a first step towards an ecologically coherent MPA network.

Results for legally designated MPAs and ecologically functional MPAs accounting for overlaps are presented. Geographically, Mediterranean MPA area is very unevenly distributed, with four-fifths concentrated in just three countries of the north-western part of the basin. Average distance between functional MPAs lies within recommended ecological thresholds, which suggests adequate potential connectivity of the Mediterranean MPA system. Mediterranean designated MPAs are larger than MPAs worldwide on average, although they are generally smaller than international guidance suggests at different levels: ecoregion, country and designation category. On average, Mediterranean designated and functional MPAs have relatively high compactness, which makes them prone to spillover and adequate viability, and less vulnerable to edge effects.

1. Introduction

The CBD Aichi Target 11 states the need to effectively protect at least 10% of the marine and coastal habitats of particular importance for biodiversity by 2020 using MPAs or other effective area-based conservation measures (CBD, 2010), MPAs being the main global strategy for the conservation of marine biodiversity (Day et al., 2012). However, marine biodiversity does not equally benefit from such spatial protection measures, with sessile, territorial and limited-range organisms benefitting most (Roberts et al., 2010; Andrello et al., 2013; Metcalfe et al., 2015). MPA ecological effectiveness, defined as species self-replenishment and colonization through dispersal, depends, among other variables, on MPA design factors such as size, shape, spacing and location (Shanks et al., 2003; OSPAR, 2007; Roberts et al., 2010; Sciberras et al., 2013).

MPA size is the best studied MPA design factor, although with somehow contradicting results. Some authors have found that (no-take) MPA size is not relevant to render ecological benefits when compared to control areas (Halpern, 2003; Rife et al., 2013), whereas others have deemed this variable fundamental for both no-take and multiple use MPA ecological effectiveness (Shanks et al., 2003; Gaines et al., 2010; Edgar et al., 2014). MPA size influences viability of protected biodiversity by conditioning individuals' persistence in the MPA, especially of those species that are sessile and short-distance dispersers, and the degree of external impacts on protected features (Shanks et al., 2003; Roberts et al., 2010). Shanks et al. (2003) suggested a bimodal dispersal strategy of short (<1 km) and long distance dispersers (>20 km) according to the feeding nature of dispersing species' propagules in the plankton. They suggested designing coastal MPAs of a size between 12 km^2 and 50 km^2 to allow short-distance dispersers to settle within the limits of the MPA. Roberts et al. (2010) found that 81% of a sample of adult organisms of 72 marine species with different ecological requirements and phylogenetic origins present in UK waters could gain good protection from MPAs with a median minimal size of 20 km^2 and a mean size ranging from 80 km^2 to 315 km^2. Additionally, they argue that these sizes could provide adequate protection to short-distance dispersers. Edgar et al. (2014) found that minimal MPA size (>100 km^2) was important for the ecological effectiveness of MPAs, especially for large marine predators such as sharks and jacks. They linked broad ecological effects of MPA size to complementary MPA features like age, degree of isolation, enforcement or regulation stringency.

Other MPA design factors such as spacing, shape or location have deserved less attention than size, although they also have important implications for conservation. Spacing between MPAs conditions persistence of long-distance dispersers and is a basic component of MPA network connectivity (Roberts et al., 2010). MPA shape influences organism

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spillover from MPAs (Roberts and Hawkins, 2000), and determines variable external pressure on protected features through edge effects (Foster et al., 2014), which are especially relevant in marine environments due to their high connectivity (Jameson et al., 2002). In turn, MPA geographic distribution is important for proper representation of protected biodiversity at regional scale (OSPAR, 2007; Gabrié et al., 2012). MPA size, shape, spacing and location factors are also considered basic criteria for the establishment of ecologically coherent networks of MPAs (OSPAR, 2003, 2007; HELCOM, 2010; UNEP-MAP, 2013).

The Mediterranean Sea is considered a heavily pressured global marine biodiversity hotspot due to its high numbers of endemic and threatened species (Coll et al., 2010, 2012; Micheli et al., 2013). In recognition of the importance of Mediterranean marine biodiversity, the Contracting Parties to the Barcelona Convention (UNEP-MAP, 1995a) established the List of Specially Protected Areas of Mediterranean Importance (SPAMI's List) on which designated MPAs meeting the ecological criteria in the Protocol concerning Specially Protected Areas and Biological Diversity in the Mediterranean can be added (UNEP-MAP, 1995b). Additionally, the Mediterranean Marine Protected Areas Network (MedPAN) was created in 1990 in order to streamline the region's MPA's management efforts and networking activities. Since 2008, the MedPAN Organisation aims to promote the establishment, operation and sustainability of a Mediterranean network of MPAs (MedPAN, 2016). Previous studies looked at MPA design patterns in the region with data from 2007 (Abdulla et al., 2008) and 2011–2012 (Gabrié et al., 2012). Since then, the Mediterranean MPA network has experienced substantial expansions leading to some countries already meeting international MPA coverage targets in their inshore and/or offshore waters (Rodríguez-Rodríguez et al., 2016a). Therefore, it is important to assess current MPA design patterns as proxies of MPA ecological effectiveness in this marine biodiversity hotspot (Coll et al., 2010, 2012).

Previous studies have considered design factors on legally designated MPAs that account for official MPA boundaries regardless of boundary overlaps and their ecological implications (Gabrié et al., 2012) whereas others have accounted for MPA boundary overlaps and fostered a more ecologically meaningful, functional spatial approach through “protected polygons” (Foster et al., 2014). Here, we present “theoretical” data on legally *designated* MPAs as well as more spatially and ecologically meaningful data on *functional* and *viable* MPAs that consider “real” MPA boundaries and ecological design thresholds, respectively. Accordingly, this study has the following objectives:

1) Assessing *designated* MPA size (size of each designated MPA, regardless of overlaps) and *functional* MPA size (size of individual protected polygons, accounting for overlaps) at different levels: the whole Mediterranean Sea, by ecoregion, by country and by designation category;
2) Analysing *designated* and *functional* MPA shape through compactness, for the whole Mediterranean Sea and by ecoregion;
3) Analysing *functional* MPA area distribution across the basin by ecoregion;
4) Determining the minimal spacing between protected polygons (*functional* MPAs) and ecologically *viable* protected polygons bigger than 20 km^2 in the Mediterranean Sea and by ecoregion;
5) Discussing marine biodiversity conservation implications of current Mediterranean MPA design patterns against proposed ecological design targets.

2. Methods

2.1. Common spatial and statistical methods

The May 2015 version of the digital MPA layers of the Database of Marine Protected Areas in the Mediterranean (MAPAMED, 2015) was used. It included the following MPA designation categories: Natura 2000 sites, National sites (various designations), Ramsar sites, Specially Protected Areas of Mediterranean Importance (SPAMIs), the Pelagos Sanctuary, and Biosphere Reserves (data from April 2014). These layers were intersected with the Mediterranean Sea shape from the Mediterranean marine ecoregions layer (Marineregions.org, 2015) based on the biogeographical representation by Spalding et al. (2007), to select purely marine Mediterranean protected area. As such, only the seaward area of coastal or estuarine protected areas was considered. All spatial calculations were done in the ETRS89-LAEA projection using ArcGIS v.10 (ESRI, 2010). For the analysis of differences, Kruskall-Wallis tests were performed for a significance value of 0.05 after checking the normality of the original and log10-transformed variables.

2.2. Geographic distribution

The original, designated MPA layers were merged and dissolved into a functional MPA layer to portray just the external boundaries of individual protected polygons, with or without overlaps with other officially designated MPAs. We used the “Single part” option in Arc-GIS to dissolve official MPA boundaries into its physically discontinuous protected polygons (i.e., a designated MPA consisting of four separated polygons was split into its four individual constituents). To assess MPA geographic distribution at the ecoregion and country scales, the functional MPA layer was intersected with the Mediterranean ecoregions layer (Marineregions.org, 2015) and with the hypothetical Exclusive Economic Zone layer of Mediterranean countries covering the whole Mediterranean Sea area (Marineregions.org, 2014; Rodríguez-Rodríguez et al., 2016a).

2.3. Spacing

Spacing among MPAs was assessed by determining the minimum straight distance between the boundaries of the nearest protected polygons from the functional MPA layer for the whole Mediterranean Sea and by ecoregion using the Near tool in ArcGIS. Some polygons had a minimal mutual distance of 0 m because they had a vertex in common. The same analysis was repeated only considering protected viable polygons of a minimal size of 20 km^2 which represents a minimal threshold of ecological viability of MPAs for short distance dispersers (Shanks et al., 2003; Roberts et al., 2010).

2.4. Size

Designated MPA size was obtained by computing areas on the original MPA layers and on the merged MPA layer intersecting the Mediterranean ecoregion (Marineregions.org, 2015) and country layers (Marineregions.org, 2014), respectively. Our results were compared with a (non-exhaustive) number of global and regional studies on designated MPA size to put them in the broader context. To calculate functional MPA size, the functional MPA layer was intersected with the ecoregion and country layers and resulting areas were calculated.

2.5. Shape

To calculate the theoretical MPA shape, each designated MPA's area (in km^2) and perimeter (in km) were computed for the whole Mediterranean, for Mediterranean ecoregions, and for MPA designation categories from the merged, originally designated MPA layer. The Pelagos Sanctuary was excluded as an MPA category due to its unique character in terms of number, size, management regime and designation category, as done previously (Gabrié et al., 2012). Then, MPA “compactness” was calculated according to the following formula: $C = (4\pi A / p^2)^{0.5}$ where C is the compactness; A is the area of the site; and p is its perimeter. According to this algorithm, a circle receives a maximal score of one, which decreases as the MPA shape becomes less circular (OSPAR, 2007). To calculate functional MPA shapes, the previous process was repeated using the functional MPA layer.