Challenges facing a network of representative marine protected areas in the Mediterranean: prioritizing the protection of underrepresented habitats

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The high endemism of the Mediterranean Sea provides strong motivation to develop a comprehensive plan for the conservation of its biodiversity and the management of its marine resources. Increasingly, this ecosystem-level approach calls for a comprehensive network of marine protected areas (MPAs) representative of the richness and diversity of this shared basin. Today, Mediterranean MPAs do not represent the diverse geography and habitats in the region. Despite a recent declaration on trawling restrictions in deep waters (>1000 m), there are no true deep-sea Mediterranean MPAs. All but one (98.9%) of the 94 marine areas currently under some type of protection or management are coastal. Moreover, 69 (73.4%) are located along the basin's northern shore, highlighting the lack of MPAs in the south and east coasts. Yet, these underrepresented regions and habitats are ecologically distinctive by virtue of their particular oceanographic and biogeographic conditions. We identify several obstacles to Mediterranean MPA implementation and discuss how they can be overcome through strategic MPA network planning, contending that regional disparities in governance, institutional structures, wealth distribution, social capital, and availability of ecological data are responsible for discrepancies in the establishment and effectiveness of MPAs in this region.

Keywords: biogeography, governance, Mediterranean Sea, MPA networks, oceanography, representation, site selection.

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Introduction

"We voice concern that while 11.5% of the world's land area now enjoys protection, less than 1% of the world's oceans, seas, and coasts have protected status, exposing fisheries and rich storehouses of biodiversity to overexploitation" (IUCN World Parks Congress, 2003).

Worldwide, the establishment of representative networks of marine protected areas (MPAs) is increasingly being invoked as a critical step towards the conservation and management of marine ecosystems. In response, many countries have committed themselves through various treaties to increase the area of marine protection within their jurisdictions. For example, at the 5th World Parks Congress in 2003, 3000 representatives from 144 countries made the commitment to protect 10–20% of their marine areas by 2025 (IUCN World Parks Congress, 2003).

The objectives of MPA establishment often complement a broad range of other national development and economic goals beyond environmental protection. Enhanced food security, decreased poverty, improved governance, increased value to international trade, and sustained economic growth can be regarded as socio-political goals consistent with the more traditional environmental agenda of biodiversity conservation. To this end, the overall objectives of the Millennium Development Goals are indirectly supported by the establishment of networks of well-managed and effective MPAs (UN, 2008).

Recently, the call for the establishment of MPA networks has extended to the high seas, beyond national jurisdiction (WWF, 2003; Roberts *et al.*, 2006). The ecological contributions of such reserves would include awarding protection to sessile deep-sea taxa and to important foraging areas and breeding grounds of highly migratory species (Gjerde and Kelleher, 2005; Norse *et al.*, 2005).

Mediterranean marine biodiversity

The Mediterranean Sea constitutes 0.3% of the global oceans' volume and contains 7% of the world's marine species (Bianchi and Morri, 2000). The high rates of species endemism, in the range of 20–30% (UNEP-RAC/SPA, 1999; Bianchi and Morri, 2000; Briand and Giuliano, 2007), reflect recent geological changes, such as the Messinian Event (Miocene, ca. 6 million YBP; years before present) and Atlantic recolonization (Fredj *et al.*, 1992; Boero, 2003). Moreover, the physiography of the basin has also promoted high species endemism. For instance, the shallow Strait of Gibraltar and the Sicily Channel have encouraged isolation and allopatric evolution of the deep-water fauna in two disjunct basins that are separated from each other and from the Atlantic Ocean (Cartes *et al*., 2004). At smaller spatial scales, the irregularity and complexity of the coastline and topography, which influence local winds and currents, have further contributed to the current biological diversity of the Mediterranean (Abelló *et al*., 2002; Kallianiotis *et al*., 2004).

The Mediterranean Sea has long been considered a priority for conservation because of its ecological richness, with high diversity and endemism, the occurrence of threatened species, and the intense human pressures it has undergone over the centuries (Myers *et al*., 2000; Mittermeier *et al*., 2004; Shi *et al*., 2005). In a recent categorization of global marine biodiversity, Spalding *et al*. (2007) considered a Mediterranean Biogeographic Province with seven distinct ecoregions, designated according to unique ecological and physical characteristics of their coastal and shelf waters: western Mediterranean, Levantine Sea, Aegean Sea, Adriatic Sea, Alborán Sea, Ionian Sea, and the Tunisian Plateau/Gulf of Sidra. For the sake of comparison, our analyses and discussion follow the same biogeographic categorization.

Mediterranean challenges

At the international level, priority sites for protection need to be identified in the Mediterranean and should include representative areas and habitats of special ecological importance. To this end, we review the existing protection and management regimes, and the presence of threatened habitats and species in each of these ecoregions.

Currently, 94 MPAs have been designated in the Mediterranean Sea (Abdulla *et al*., 2008). Yet, the basic question remains: do these sites constitute a representative network of the marine habitats in this shared basin? The answer is simply no, as evidenced by the underrepresentation of deep-sea habitats and southern and eastern Mediterranean coastal sites. Most (98.9%) of the 94 MPA sites are located in the northern part of the basin, with the remainder along the southern Mediterranean coast: one in Morocco, two in Tunisia, and one in Algeria. Therefore, entire regions are not represented in the current system of MPAs. Moreover, all existing MPAs are located on the shallow continental shelf, except the Pelagos Sanctuary, which includes waters of the continental shelf and the pelagic ecosystems of the shelf break and slope (Abdulla *et al*., 2008).

Of the unique ecoregions categorized by Spalding *et al*. (2007), three are restricted to the southern and eastern Mediterranean: the Tunisian Plateau/Gulf of Sidra, Aegean Sea, and Levantine Sea. The large number of distinct ecoregions in the southeastern quadrant of the Mediterranean underscores the ecological uniqueness of this region. The western Mediterranean hosts most of the existing MPAs and is the ecoregion with the most extensive level of protection. The Levantine and Aegean seas contain relatively large numbers of small MPAs, located mainly in Turkey. Currently in the Adriatic Sea, protection is concentrated almost entirely along the irregular eastern coastline. Limited protective measures have been established in the Alborán and Ionian seas. Currently, there are no MPAs located in the Tunisian/Gulf of Sidra ecoregion (Table 1; Abdulla *et al*., 2008).

Mediterranean MPAs can be considered as multiple-use managed areas because only 41 sites include small no-take zones (Abdulla *et al*., 2008). Moreover, MPA designation was based more on the presence of charismatic species and unique features or opportunity, than on a holistic ecological approach (Fraschetti *et al*., 2002, 2005). The marine surface under MPA management (97 410.3 km^2) represents 3.8% of the total surface of the Mediterranean Sea. Without the large-scale Pelagos Sanctuary, the surface under protection decreases to 9910.14 km^2, or 0.4% of the Mediterranean Sea. Finally, if only the no-take zones are considered, the protected surface declines to 220.0 km^2 or 0.01% of the Mediterranean Sea (Table 1; Abdulla *et al*., 2008). Current conservation status is far from the 2010 target of protecting at least 10% of each of the world's ecoregions (Convention on Biological Diversity, 2004). Furthermore, the spacing of the existing MPAs is very broad, with 66% of the MPAs separated by more than 30 km. This spacing may be too wide to ensure ecological functionality of the current network of MPAs, given the spatial scales of larval dispersal of most sessile organisms and effective fish spillover (Shanks *et al*., 2003).

Table 1. Number and percentage of existing MPAs across Mediterranean ecoregions showing total surface area of sea (Abdulla *et al.*, 2008).

Ecoregion	Number of MPAs	Percentage of MPAs	MPA surface area (km ^{2})	No-take zones (km ^{2})
Western Mediterranean	40	42.6	91 175.1	168.4
Levantine Sea	9	9.6	72.0	0.5
Aegean Sea	14	14.9	4 013.1	–
Adriatic Sea	16	17.0	1 181.3	14.2
Alborán Sea	8	8.5	464.4	30.4
Ionian Sea	7	7.4	504.4	6.5
Tunisian Plateau/Gulf of Sidra	0	0	0	0
Total	94	100	97 410.3	220.0

MPAs include multiple-use and no-take zones. Ecoregions are based on the classification of Spalding *et al*. (2007).

Regional ecological importance of underrepresented habitats

Coastal habitats in the southern and eastern Mediterranean

The distinct combination of physiographic (bathymetry), physical (winds and currents), and oceanographic (temperature, salinity, and productivity) conditions in the eastern and southern Mediterranean and the western and northern Mediterranean influences the patterns of species diversity and marine habitat heterogeneity in the basin (Bakun and Agostini, 2001; Agostini and Bakun, 2002; Spalding *et al*., 2007). In particular, the eastern and southern parts of the basin are characterized by ecological habitats of high conservation value, including highly mobile marine vertebrates and sessile invertebrates and seagrass meadows.

Most of the heavily fragmented Mediterranean monk seal (*Monachus monachus*) population is reported in the Aegean Sea (Borrell *et al*., 1997). The coasts of Turkey, Greece, Cyprus, and Libya are the main nesting areas for the loggerhead turtle (*Caretta caretta*), Libya being the most important (Laurent *et al*., 1997) and with few sites elsewhere, whereas the green turtle (*Chelonia mydas*) nests almost exclusively in the eastern Mediterranean, mainly in southeast Turkey and Cyprus (Geldiay *et al*., 1981; Sella, 1981; UNEP/IUCN, 1990; Margaritoulis, 2003; Canbolat, 2004). Unique breeding grounds have been found in Sicilian Channel waters for the great white shark (*Carcharodon carcharias*), a species listed in the Barcelona and Bern Conventions and classified as endangered in the Mediterranean by the IUCN Species Survival Commission (Fergusson, 1996; Abdulla, 2004; Tudela *et al*., 2004). Libyan waters may also contain the last refuge for bluefin tuna (*Thunnus thynnus*) juveniles in the Mediterranean (S. Tudela, pers. comm.). Vermetid reefs affect the spatial complexity of intertidal Mediterranean shores, hosting highly diverse communities (Molinier and Picard, 1953). These biological constructions are created by endemic sessile gastropods, the vermetids *Dendropoma petraeum* and *Vermetus triquetrus*, which are concentrated in the eastern part of the basin (Antonioli *et al*., 1999). Finally, between the Gulf of Gabes (Tunisia) and the Gulf of Sirte (Libya) lies more than 1500 km^2 of seagrass meadows, the largest in the Mediterranean (Green and Short, 2003).

Open sea

The Mediterranean open sea contains habitats of several charismatic marine species. This is largely the result of the oceanographic characteristics of this semi-enclosed sea. The overall Mediterranean circulation structures its pelagic environment and can be characterized by three main features: (i) the anticlockwise along-slope circulation in both the western and eastern basins, whereby inflowing low-density (low temperature, low salinity) Atlantic water tends to become more oligotrophic through the depletion of nutrients by primary production; (ii) the intense, large-scale, and long-lived mesoscale eddies that develop in the southern part of the basin, caused by the instability of the dominant anticlockwise circulation, which create short-lived (time-scale of weeks) enriched zones of primary productivity; and (iii) as the Atlantic surface water becomes more saline through evaporation, it becomes susceptible to winter convection along the northern basin, where cold, dry northerly winds increase the density of the surface water and give rise to the deep-water formation (Bakun and Agostini, 2001). This sinking water induces mixing through the whole water column, replenishing the nutrients in the euphotic zone and promoting intense spring phytoplankton blooms. These productive areas are persistent from year to year, and top predators appear to remain there all year (Millot and Taupier-Letage, 2004).

The pelagic waters of the Mediterranean host sizeable populations of cetaceans, which apparently reside there year-round and reproduce in the basin. These include fin whales (*Balaenoptera physalus*), sperm whales (*Physeter macrocephalus*), Cuvier's beaked whales (*Ziphius cavirostris*), killer whales (*Orcinus orca*; mostly in the Strait of Gibraltar), long-finned pilot whales (*Globicephala melas*), Risso's dolphins (*Grampus griseus*), striped dolphins (*Stenella coeruleoalba*), and short-beaked common dolphins (*Delphinus delphis*; for a review, see Notarbartolo-di-Sciara, 2002). Another cetacean species, the bottlenose dolphin (*Tursiops truncatus*), is found mostly in coastal waters, but may also occur off the shelf, near seamounts and shallow banks (Cañadas and Hammond, 2006).

Although cetacean numbers are larger in the western basin, predictably these large vertebrates can be found in several areas of the eastern basin, including:

(i) a recently discovered winter feeding ground for fin whales in the Strait of Sicily, near the island of Lampedusa (Canese *et al*., 2006);

(ii) sperm whales and Cuvier's beaked whales consistently found along the so-called Aegean Arch, between the southern Peloponnese and the island of Rhodes (Frantzis *et al*., 2003);

(iii) short-beaked common dolphins, today the most endangered cetacean species in the region, are still found in the Strait of Sicily, in several portions of the Aegean Sea (Bearzi *et al*., 2003), and off the coast of Israel (A. Scheinin, pers. comm.).

The Mediterranean pelagic waters are also important for their chondrichthyan fauna (Megalofonou *et al*., 2000; Abdulla, 2004). In particular, white sharks (*Carcharodon carcharias*) are frequent in this region, particularly in the Strait of Sicily, a likely nursery area for the species. White shark sightings in the Mediterranean are in contrast to their rarity in the Northeast Atlantic (Fergusson, 1996).

Deep-sea habitats

Deep-sea communities in the Mediterranean contain a large number of endemic species and unique but extremely vulnerable habitats. The low food input to the deep sea results in scarce resources, a high degree of partitioning, highly diversified diets, and very complex trophic webs. Because deep-water assemblages (>1000 m) exhibit extremely low productivity and growth rates (Peres, 1985), they may be particularly vulnerable to human disturbance (Cartes *et al*., 2004).

Deep-sea species mainly inhabit continental slopes, seamounts, and submarine canyons. Mediterranean marine canyons host unique planktonic communities such as hydromedusae (Gili *et al*., 2000). Gili *et al*. (1998) reported that 45.5% of the world's deep-sea hydromedusae species are found in the Mediterranean and 22% of them are endemic. The western Mediterranean is higher in overall abundance and diversity of deep-sea taxa than the eastern Mediterranean (Sarà, 1985; Sardà *et al*., 2004). These patterns may be explained by the Téthys hypothesis suggesting that Mediterranean ecological communities are relics of the Messinian episode (Peres, 1985). An alternative hypothesis suggests that Mediterranean fauna are satellite populations, dependent on East Atlantic larval replenishment through the Strait of Gibraltar for maintenance of these populations (Bouchet and Taviani, 1992). Past events have therefore contributed to the isolation of deep-sea communities and led to speciation. As a consequence, Mediterranean deep-sea habitats now host this high concentration of species, many of them endemic.

Mediterranean marine conservation

It is clear that the long history of human use and resource exploitation and issues of multijurisdictional governance are politically complex and not easily resolved, and present many obstacles to the establishment of MPAs. Currently, territorial waters in many Mediterranean countries extend only 12 nautical miles (22.3 km), because traditional exclusive economic zone boundaries would prove intractable, given the proximity of the coastlines of the range nations. Therefore, a large proportion of the basin is beyond national jurisdiction, which presents all the special management challenges associated with the management of high seas resources. Concurrently, human impacts on the relatively underdeveloped areas of the southern and eastern Mediterranean are expected to grow at an unprecedented pace in the next decades. Given this anticipated development, the protection of marine habitats in underrepresented biomes (the open sea and deep sea) and geographic regions (on the southern and eastern Mediterranean coasts) is increasingly being recognized as a priority, despite the challenges.

There are many reasons that expanding the network of MPAs to target underrepresented habitats and subregions is possible. A large portion of the region is well studied; there is a multinational commitment to increasing marine conservation investment; and many legal frameworks exist to facilitate region-wide, cooperative MPA planning (Chevalier, 2005). In addition, there are policies that could enhance the efficacy of a region-wide representative network. For instance, on the high seas, a ban on trawling beneath 1000-m depth has been introduced by the General Fisheries Commission for the Mediterranean (GFCM), which affords *de facto* protection to demersal and sessile organisms in these deeper Mediterranean waters.

A 2004 study by the Mediterranean Science Commission (CIESM), the International Union for the Conservation of Nature (IUCN), and the World Wildlife Fund (WWF) has identified deep-sea sites that require protection (WWF/IUCN, 2004). An important criterion for identifying potential deep-sea MPAs is the number of endemic species. Although 26% of all Mediterranean species are endemic (Fredj and Laubier, 1985; Fredj *et al*., 1992), an estimate is not available for the deep sea. Moreover, these regional patterns of community-wide endemism in the deep sea may not be deciphered for some time. Given the paucity of ecological data, the distribution of physiographically and physically distinct habitats may provide a starting point for identifying potential MPA sites. For instance, bathymetric features (shelf breaks, slopes, and seamounts) can serve as a proxy to provide an oceanographic context for the selection of representative habitats (Gleason *et al*., 2006). In particular, the most unique deep-sea ecosystems in the Mediterranean are associated with specific physical features (cold seeps, brine pools, and seamounts) and biogenic structures (deep-water coral mounds; Cartes *et al*., 2004). Tudela *et al*. (2004) proposed a system of representative deep-sea MPAs based on a distribution of 35 unique deep-sea biocenoses in the Mediterranean (Miller *et al*., 2004). On this basis, the GFCM identified three of these deep-sea sites as of particular ecological interest.

Currently unprotected areas merit special attention within the larger regional MPA framework. As part of a regional marine conservation agenda for the Mediterranean, we advocate the formation of a set of MPA networks in Mediterranean subregions where MPA coverage is minimal. Establishing an MPA network is a step beyond the more traditional approach of establishing MPAs opportunistically, as single independent entities. Networks allow a whole that is greater than the sum of its parts. Through interconnections and interdependencies, the individual elements of the network contribute positively to each other's integrity by decreasing overall vulnerability. Marine foodwebs extend beyond individual MPA boundaries, and fishers depend on different species and geographic regions at different times of the year. Tourism revenues from one easily accessible MPA with charismatic species can help subsidize the maintenance costs of another, more remote MPA that has other values not easily captured through current market mechanisms. Many biophysical and socio-economic connections overlap national boundaries, and regional cooperation can promote national interests.

The way forwards

It must be emphasized that the absence of scientific data is not an excuse to postpone the conservation and protection (no-take zones in MPAs) or management (multiple-use zones in MPAs) of marine resources. Many developing countries cannot afford to implement comprehensive research on all marine habitats and species within their national jurisdiction. Under these circumstances, a different approach may be necessary, whereby the information required for the design and designation of MPAs arises through rigorous quantitative research in a few representative sites, combined with comprehensive surveys of traditional knowledge (Johannes, 1998). However, the current portfolio of Mediterranean protected areas highlights the need to implement MPA networks designs based on coherent ecological criteria.

To employ best practice principles of design and to achieve viable MPA networks in underprotected areas of the Mediterranean, we propose action at different nested scales. First, systematic surveys of marine biodiversity in key sites are required to identify understudied regions (e.g. southern and eastern Mediterranean) and biomes (e.g. the open ocean and deep sea), and to establish biodiversity research priorities. Once these subregions have been identified and described with respect to biodiversity, ecosystem functioning, and existing threats, an integrated network of Mediterranean protected area sites can be designed within each subregion. Once these key sites have been identified, effective conservation will require choosing appropriate MPA tools to address threats and developing management plans in conjunction with local resource users and conservationists. This approach will ensure that protection is afforded to underrepresented species and habitats within biogeographically and oceanographically distinct regions of the basin, and will improve the balance between European and non-European MPAs.

To determine the location of specific MPA sites within these interlinked networks, we envision an integrated, spatially explicit marine conservation approach aimed at conserving both marine biodiversity and fishery resources by preserving critical ecosystem processes and functions. Moreover, the goal is to integrate protection of mobile species and conservation of sensitive habitats, using approaches founded an interdisciplinary understanding of natural history, ecology, and oceanography (Agardy and Wilkinson, 2003; Wilkinson *et al*., 2004; Pederson *et al*., 2005). This exercise expands previous MPA initiatives and explores how these concepts can be applied to the Mediterranean realm.

This integrative and comprehensive approach requires multiple ecological criteria for considering the relative importance of potential MPA habitats such as: (i) the value of a site to the conservation of species of "special concern" for conservation, fisheries, and cultural reasons; (ii) the importance of a site for trophic relationships and foodweb dynamics; and (iii) the significance of the site to the conservation of ecosystem biodiversity.

Understanding the natural history, habitat preferences, and dispersion of top-level marine predators will help guide the selection of MPAs appropriate to protect the breeding areas, foraging grounds, and migratory routes of these species. In particular, several species of conservation concern occur in the Mediterranean Sea. Additionally, endemic, locally breeding species may constitute especially suitable focal taxa for assessing the efficacy of marine zoning efforts, in part because one can measure changes in the biology of these species (e.g. feeding rates and diet composition), following reserve implementation.

Protecting foodwebs may help buffer marine resources against environmental variability, uncertainty, and poor management decisions. MPAs designed to protect trophic relationships and energy transfer should target biologically productive areas where large numbers of marine predators aggregate. Metrics of overall seabird and cetacean standing stocks (abundance) and aggregation (patchiness) can be used to pinpoint important foraging grounds. Additionally, the distributions of focal species with high energetic requirements (e.g. diving seabirds and large cetaceans) can be used as bioindicators of the physical processes that promote ocean productivity (e.g. fin whales tracking dense euphausiid aggregations). Additionally, the protection of the foodwebs and foraging areas of these top predators may lead to other ecological benefits. For example, MPAs delineated to protect the foodwebs that support seabirds and cetaceans may also benefit economically valuable species that rely on the same prey resources but are inherently more difficult to survey.

MPAs may also help maintain marine biodiversity by protecting productive "hotspots" and "transition zones" characterized by strong physical gradients. In particular, community-level metrics (e.g. species richness and diversity) may be useful bioindicators of regions known to support a diverse community of predators exploiting the same prey resources (e.g. baleen whales, finfish, and seabirds foraging on euphausiids), and ecotones (e.g. fronts and water mass boundaries) separating distinct species assemblages. In other words, areas of high species richness or diversity are indicative of localities where different predators aggregate to forage on a common resource or of ecotones separating distinct species assemblages (e.g. as exist in oceanographic fronts).

The need to increase the number of protected habitats and the quality of protection in underrepresented Mediterranean areas is apparent. Although more than 20 coastal sites in the south and east of the Mediterranean and 35 deep-sea sites have been identified, and states of the Mediterranean have been recognized as unique or important habitats in need of protection (Miller *et al*., 2004; Tudela *et al*., 2004), little progress in protection has occurred in the past 15 years. However, a systematic approach to establishing MPA networks in underrepresented and largely unprotected Mediterranean subregions may well provide the impetus for more effective conservation in large parts of the basin. This approach must acknowledge that vital marine resources are declining rapidly; in certain circumstances, where technical and financial capacity is lacking, imperfect management advice is preferable to no management advice (Johannes, 1998). At the same time, there is a need to further our understanding of the potential causal factors for the discrepancy in protection between European and non-European MPAs, that may include aspects of governance, institutional structures, wealth distribution, social capital, and the knowledge environment. Identifying these constraints will help overcome the challenges facing effective marine conservation throughout the Mediterranean, especially in non-European waters and on the high seas.

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