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Inequitable protection of multidimensional biogeochemical regions in the Mediterranean Sea

Joan Giménez [a,b,c,d,*], Rubén Venegas-Li [e,f], Tessa Mazor [g], Salit Kark [h], Noam Levin [i,j]

[a] MaREI Centre, Environmental Research Institute, University College Cork, Cork, Ireland
[b] School of Biological, Earth, and Environmental Sciences, University College Cork, Cork, Ireland
[c] Institut de Ciències Del Mar (ICM-CSIC), Passeig Marítim de La Barceloneta 27-49, 08003, Barcelona, Spain
[d] Estación Biológica de Doñana (EBD-CSIC), Américo Vespucio 26, Isla de La Cartuja, 41092, Seville, Andalucia, Spain
[e] Centre for Biodiversity and Conservation Science, School of Earth and Environmental Sciences, The University of Queensland, Brisbane, QLD, Australia
[f] School of Biological Sciences, Monash University, Clayton, VIC, Australia
[g] The School of Biological Sciences, The University of Queensland, Brisbane, QLD, Australia
[h] The Biodiversity Research Group, The School of Biological Sciences, Centre for Biodiversity and Conservation Science, The University of Queensland, Brisbane, QLD, Australia
[i] Department of Geography, The Hebrew University of Jerusalem, Mount Scopus, Jerusalem, 91905, Israel
[j] Remote Sensing Research Centre, School of Earth and Environmental Sciences, The University of Queensland, Brisbane, QLD, Australia

A R T I C L E I N F O

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A B S T R A C T

In many cases, protected areas are placed opportunistically and do not fully capture the representation of ecological components for achieving biodiversity conservation goals. In marine systems, where threats and biodiversity are inherently multidimensional and include vertical depth gradients, the designation of protected areas can be more challenging than in the terrestrial realm. Here, we aimed to evaluate the representation equality of biogeochemical regions at different depths in the Mediterranean Sea as a surrogate for biodiversity. We conducted a gap-analysis evaluating the current extent and coverage of protected areas in the Mediterranean Sea biodiversity hotspot to achieve an equitable representation and conservation strategy for the basin. We used biogeochemical regions across different depths, which allow more complex 3D marine spatial planning that includes spatial complexity of marine systems. A total of 60 biogeochemical regions distributed across three bathomes (spaces determined by depth; *i.e.* epipelagic, mesopelagic, and bathypelagic zones) and the seafloor were assessed. We found that biogeochemical regions in the Mediterranean Sea were not equally protected across bathomes, and that global conservation targets were not met. The bathypelagic bathome had the lowest representation in the Mediterranean Sea marine protected area (MPA) network, as well as the lowest protection equality. The sub-basins with highest protection included the Algero-Provençal basin and the Tyrrhenian Sea. These two sub-basins were the only ones that passed the Aichi protection target of 10%, while all others were lower than the target. The Ionian Sea was identified as the most highly diverse sub-basin regarding biogeochemical regions but with the least protection and with low conservation equality, making this sub-basin a high priority for conservation. Amongst countries, non-European Mediterranean countries had lower values of protection and conservation equality metrics. In general, the bathypelagic bathome was found as the least protected, the most fragmented, and with the lowest protection equality, thus its protection should be enhanced through all the Mediterranean Sea. Decision makers in the Mediterranean can apply the gap-analysis approach presented here as a useful starting point for improving protection equality in the region, incorporating these metrics in the evaluation of new proposed protected areas and sites for conservation.

1. Introduction

The Mediterranean Sea is an important biodiversity hotspot with high levels of endemism (Cuttelod et al., 2009; Coll et al., 2012). However, it is also one of the regions in the world with higher cumulative human impact levels (Halpern et al., 2008, 2015; Coll et al.,

* Corresponding author. Institut de Ciències del Mar (ICM-CSIC), Passeig Marítim de la Barceloneta 27-49, 08003, Barcelona, Spain.
E-mail address: gimenez.verdugo@gmail.com (J. Giménez).

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2010). To mitigate this threatening condition, and as part of efforts to achieve regional and global biodiversity protection targets (*e.g.* Aichi targets), the number of marine areas managed for biodiversity protection in the Mediterranean Sea has increased in recent decades (MedPAN and UNEP/MAP-SPA/RAC, 2016).

Despite the increasing number of Marine Protected Areas (MPAs), most of these have been placed in near-shore areas, and mostly in European countries (Micheli et al., 2013; MedPAN and UNEP/MAP-SPA/RAC, 2016; Mazaris et al., 2018). Such bias in MPA placement likely translates into the MPA network not being representative of the biodiversity of the whole basin. Representative and ecologically coherent MPAs networks are key concepts of systematic conservation planning (Danovaro et al., 2020; Margules and Pressey, 2000), needed within a holistic marine conservation strategy avoiding single-species and inequitable approaches (Hyrenbach et al., 2000; Agardy, 2010; Mazaris et al., 2018). The MPA network in the Mediterranean Sea is likely to expand as part of the efforts to achieve greater conservation targets (*i.e.* EU Biodiversity Strategy aims to protect at least 30% of the sea by 2030). Therefore, evaluating the representativeness of the current MPA network in the Mediterranean Sea could help identify shortcomings in protection, and guide future conservation efforts.

Ideally, biodiversity should be represented in protected area networks at finer scales, such as intraspecific genetic variation (Crandall et al., 2000; Moritz, 2002; Hendry et al., 2010) or ecological management units (Esteban et al., 2016; Giménez et al., 2018). Yet, genetic and species distribution data is often scarce, especially for less studied habitats such as those occurring in the deepsea (Glover et al., 2018; Manea et al., 2020). In fact, real three-dimensional (3D) species distribution models in the ocean that capture the presence of species along the water column are just starting to emerge (Duffy and Chown, 2017). Consequently, biodiversity conservation planning is frequently done using surrogates of species diversity such as habitats, ecosystems, or biogeographic regions (e.g. Mazor et al., 2014; Sutcliffe et al., 2015). Those surrogates are considered proper proxies as representative reserve systems can be designed using abiotic domains when information on biodiversity is limited (Sutcliffe et al., 2015; Hanson et al., 2017). These broad regions are considered important in seascape management as they can act as ecological domains that include different species assemblages (Spalding et al., 2007). The lack of political boundaries in habitats, ecosystems, or biogeographic regions can also promote a transboundary conservation planning strategy (Kark et al., 2009, 2015; Mazor et al., 2013).

For the Mediterranean basin, several regionalization proposals are now available (*e.g.* Berline et al., 2014; Nieblas et al., 2014; Rossi et al., 2014; Mayot et al., 2016), and consensus areas have been identified from the synthesis of these regionalizations (Ayata et al., 2017). However, these regionalizations mostly follow a two-dimensional approach as they are derived from data obtained at the surface of the ocean and extrapolated to deeper areas where environmental conditions may be very different. Thus, species diversity in deeper waters and along the water column might not be well represented by two-dimensional regions defined based on conditions from the surface of the sea. This limitation has been overcome by Reygondeau et al. (2017), who proposed an objective and quantitative 3D biogeochemical regionalization of the Mediterranean Sea based on physical, chemical, and biological properties at different depths. In total, they proposed 60 biogeochemical regions for the Mediterranean Sea, distributed across 3 bathomes (*i.e.* spaces determined by depth) and the seafloor. This 3D bioregionalization provides a useful tool to evaluate the representation of habitats at particular depths that could be used to guide future conservation initiatives such as the expansion of the marine protected area network of the Mediterranean Sea.

Here, we aim to apply the 3D regionalization from Reygondeau et al. (2017) of the Mediterranean Sea to evaluate the protection and the representation equality of biogeochemical regions as proxies of biodiversity, at different depths in the existing MPA network for the region. Our gap-analysis is performed across three scales (basin-wide, sub-basin-, and countrywide) to assess disparities between zones and countries and guide future conservation efforts in the entire basin in a 3D context. This analysis is timely and particularly important, considering the bias in the location of current MPAs in the region, and that the MPA network in the basin will likely expand in the near future.

2. Material and methods

2.1. Biogeochemical regions as proxies of biodiversity

We used the most updated biogeochemical regionalization in the Mediterranean Sea (Fig. 1 modified from Reygondeau et al. (2017)) as a proxy to examine the spatial representation of habitats within the marine protected areas network in the Mediterranean Sea. These biogeochemical regions were originally defined using annual climatologies of 16 environmental parameters (e.g. temperature, salinity, chlorophyll-a, pH, bathymetry, NO_2, PO_4) at a 0.2° spatial horizontal resolution. These environmental parameters supported the characterisation of the basin by specific oceanographic features according to geography (e.g. shelf break, river runoff), hydrodynamics (e.g. gyral system, frontal structure, coastal upwelling) or Low Nutrient Low Chlorophyll (LNLC) areas (Reygondeau et al., 2017). In the vertical dimension, the information was discretized in 26 levels non-linearly distributed from surface to the seafloor, allowing for a 3D regionalization. The distribution of the biogeochemical region boundaries detected by Reygondeau et al. (2017) are closely related to dynamic oceanographic feature of the basin, so encompassing the mesoscale activity. These regions are also proxies for habitat types (Reygondeau et al., 2017), therefore we used them as surrogates for biotic features. These biogeochemical regions were built in a 3D framework dividing the basin into three bathomes (*i.e.,* epi, mesopelagic, bathypelagic) and the seafloor.

2.2. Representation of biogeochemical regions within protected areas

We estimated the representation (coverage percentage) of marine biogeochemical regions within protected areas in the Mediterranean Sea across three scales: i) basin-wide, ii) sub-basin-wide, and iii) countrywide. By using these three scales, we aimed to assess disparities between zones and countries and guide future conservation efforts in the entire basin in a 3D context.

The proportion of protected areas within each biogeochemical region was calculated in ArcMap 10.3.1 overlaying the Mediterranean MPA GIS database developed and jointly administered by the MedPAN association and RAC/SPA (MedPAN, 2017). All marine protected area categories available in MAPAMED were included in the analysis (*i.e.* Biosphere reserves, Fishing restricted areas (FRA), National MPAs, Natura 2000 sites, SPAMIs, and World Heritage sites), except for Ecologically or Biologically Significant Areas (EBSAs), Critical Cetacean Habitats (CCH), Particularly Sensitive Areas (PSSA), and RAMSAR sites, due to the absence of implemented protection or the non-marine focus of these sites. We have treated all MPAs equally in regard of their level of protection as MPA enforcement is difficult to verify through the revision of their management plans and national legally binding texts (Mazaris et al., 2018). In addition, the existence of a management plan by itself does not guarantee the application of those management plans (Mazaris et al., 2018; Claudet et al., 2020), so we have assumed that all MPAs are equally efficient to protect biodiversity along the entire water column and seabed. Moreover, our aim was not to assess MPA efficiency but to evaluate conservation equality of biogeochemical regions to guide new sites allocation in the post-2020 agenda.

The European Union, through the recommendation of the General Fisheries Commission for the Mediterranean (GFCM), prohibited fishing operations of trawlers and towed dredges at depths beyond 1000 m (Micheli et al., 2013), nevertheless we have not considered these deep areas as protected, as other activities are still permitted, and fishing is

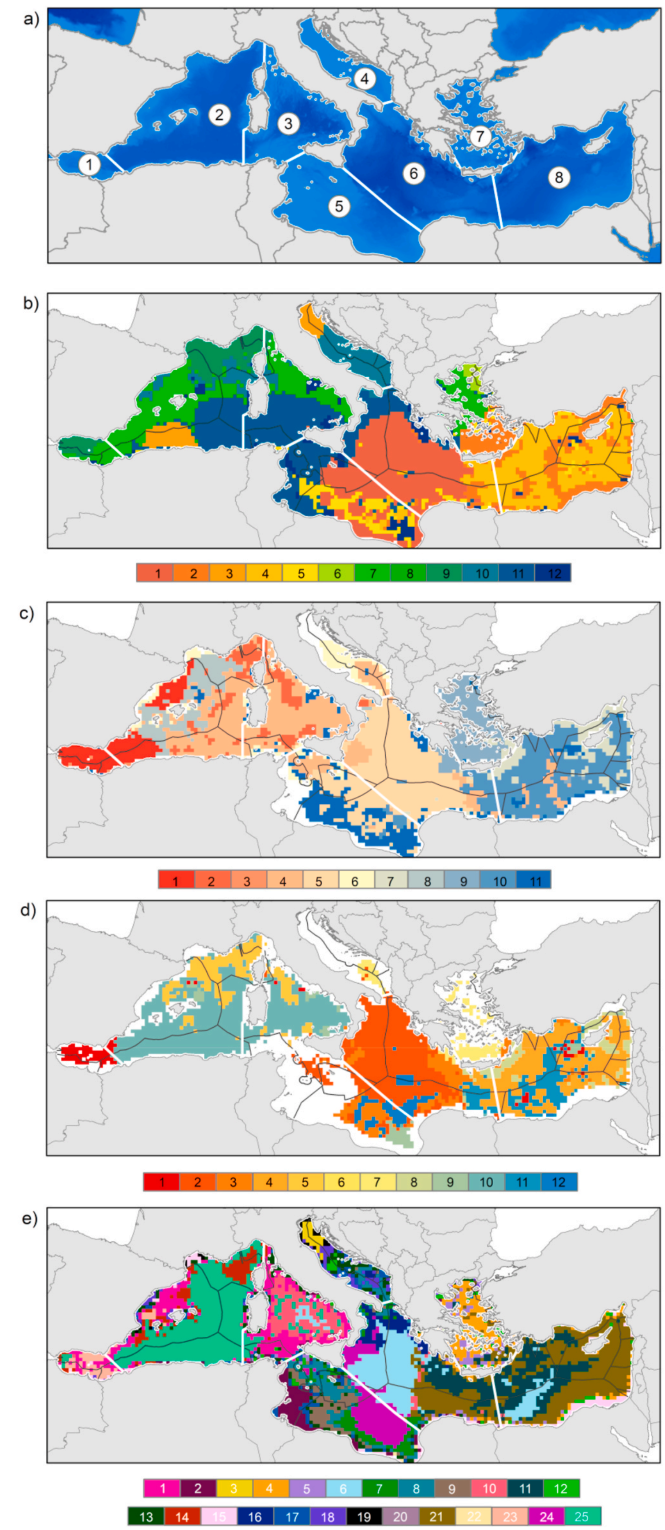

Fig. 1. Biogeochemical regions of the Mediterranean Sea. a) Bathymetry and sub-basins of the Mediterranean from Notarbartolo di Sciara and Agardy (2010) delimited by white lines; 1: Alboran Sea, 2: Algero-Provençal Basin, 3: Tyrrhenian Sea, 4: Adriatic Sea, 5: Tunisian Plateau/Gulf of Sidra, 6: Ionian Sea, 7: Aegean Sea, 8: Levantine Sea, b) epipelagic bathome, c) mesopelagic bathome, d) bathypelagic bathome, and e) sea floor. Data extracted from Reygondeau et al. (2017). Black lines represent marine boundaries between countries. Different colours represent different biogeochemical regions for each bathome. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

not the only threat to these habitats (Coll et al., 2010; Katsanevakis et al., 2015).

For the analysis at the sub-basins scale, we used the division proposed by Notarbartolo di Sciara and Agardy (2010) who subdivided the Mediterranean basin into eight sub-basins (Fig. 1). These zonation allow us to encompass all the sub-basins within the four main subdivisions of the Mediterranean Sea established by the 2008 EU Marine Strategy Framework Directive [MSFD, 2008/56/EC], which is relevant to those Mediterranean riparian nations that are European Union member states. Finally, for the biogeochemical regions representation analysis at a country level, we used the Exclusive Economic Zones downloaded from marineregions.org.

2.3. Protection metrics

Classical metrics such as mean and median area protection were combined with recently developed metrics to assess Protection Equality (PE) within a systematic approach (Barr et al., 2011; Chauvenet et al., 2017b). PE measures how equally features (e.g. biogeochemical regions) are protected within a zone (e.g. bathomes). The PE metric is adapted from the Gini coefficient used in economics to measure income equality (Lorenz curve (Allison, 1978)). Here, we calculated the Protection Equality proportional (PE_p) and the Protection Equality fixed (PE_f) metrics using the R package ProtectEqual (Chauvenet et al., 2017a). PE_p measures ecological representation as a determined percentage of each feature under protection (*i.e.* what fraction of each feature is protected), while PE_f does it as a determined amount of each feature (*i.e.* absolute protection independent of how much of each feature is available) (Chauvenet et al., 2017b). With the PE metrics, a value of zero signifies perfect inequality, whereas a value of one represents perfect equality. Both metrics (PE_p and PE_f) were then calculated to increase transparency when reporting, and to allow comparison with other studies using one versus the other. These metrics are more informative than solely reporting the amount or percentage of area protected (Chauvenet et al., 2017b). Ecological representation is a key aspect of conservation planning (Kirkpatrick, 1983; Margules and Pressey, 2000), so evaluating the conservation equality of biogeochemical regions is important to conserve different biogeochemical conditions that will likely host different ecological communities.

2.4. Fragmentation metrics

Habitat fragmentation (Crooks et al., 2017) and edge effects (Woodroffe and Ginsberg, 1998) have been shown to increase extinction risks for terrestrial mammals, to reduce biodiversity and to negatively impact key ecosystems functions (Haddad et al., 2015). While the effects of habitat fragmentation on marine biodiversity are poorly understood (Yeager et al., 2020), the fragmentation of seagrass meadows in the Mediterranean Sea was found to be strongly impacted by human activity (Montefalcone et al., 2010). Seagrass fragmentation has also been reported (in California) to negatively affect fish density (Yeager et al., 2016). In order to examine the extent of habitat fragmentation of the biogeochemical regions, we used the ecological Fragstats software (McGarigal, 1995) to calculate the spatial fragmentation of the patches of each of the biogeochemical regions within each of the bathomes and seafloor, separately. We calculated the metrics of area, number of patches and mean distance from the nearest neighbour. Fragstats performs its spatial analysis using raster grids, and for the sake of this analysis, we defined neighboring grid cells, as the 8 cells surrounding each grid cell (see van Bemmelen et al., 1993).

3. Results

3.1. Biogeochemical regions representation in MPAs in the entire Mediterranean basin

We found that none of the bathomes or seafloor achieves the 10% representation target stated in the Aichi 11 targets (Table 1, Fig. 2b). The highest protection was present in the epipelagic bathome and seafloor (6.91%). Of the three bathomes, the bathypelagic is both the one with the lowest representation (5.48% protected) in the MPA network of the Mediterranean, as well as the one with lowest protection equality (PE_p = 0.221, PE_f = 0.204) (Table 1, Figure S1). None of the bathomes or seafloor has high protection equality (PE), which ranges from medium to low in the following order (from higher to lower); mesopelagic (PE_p = 0.419, PE_f = 0.418), seafloor (PE_p = 0.396, PE_f = 0.348), epipelagic (PE_p = 0.249, PE_f = 0.292), and bathypelagic bathome (PE_p = 0.221, PE_f = 0.204) (Table 1, Figure S1). The seafloor is the most diverse in terms of number of different biogeochemical regions (n = 25).

3.2. Biogeochemical regions representation in MPAs in sub-basins and countries

Across most of the sub-basin areas and the Mediterranean countries, the most protected bathomes were the seafloor and the epipelagic bathome, and the least protected one was the bathypelagic bathome (Figs. 3 and 4). The most protected sub-basins were the Algero-Provençal basin (16.72%) and the Tyrrhenian Sea (10.01%). Only these two sub-basins were above Aichi 11 target of protection (Fig. 2c). The Ionian Sea was the one with the lowest protection (0.56%), as well as one of the lowest protection equality (PE_p = 0.222, PE_f = 0.249). The most equally protected was the Algero-Provençal Basin (PE_p = 0.476, PE_f = 0.324), followed by the Adriatic Sea (PE_p = 0.383, PE_f = 0.227), and the Levantine Sea (PE_p = 0.360, PE_f = 0.184), (Table 1, Figure S2). The most diverse sub-basin was the Ionian Sea with 46 different biogeochemical regions followed by Tunisian Plateau - Gulf of Sidra (n = 33) and the Algero-Provençal basin (n = 31).

The country providing the greater protection was France (60.51%) due to the Pelagos Sanctuary, the only inshore-offshore marine protected area in the basin. A higher percentage of protection was achieved in European countries than in non-European ones. Turkey, Cyprus, and France have achieved the Aichi 11 target, across all four bathomes (Figs. 2 and 4). Regarding protection equality, there was a huge variation between countries, with France (PE_p = 0.812, PE_f = 0.353), Spain (PE_p = 0.371, PE_f = 0.379), Croatia (PE_p = 0.362, PE_f = 0.231), and Greece (PE_p = 0.354, PE_f = 0.261) being the most equally protected countries regarding the protection of their biogeochemical regions. Nevertheless, almost all countries had very low equality metrics, with Algeria (PE_p = 0.111, PE_f = 0.221), Tunisia (PE_p = 0.097, PE_f = 0.130), Libya (PE_p = 0.006, PE_f = 0.007), and Montenegro (PE_p = 0.01, PE_f = 0.091) having the lowest protection equality scores (see Table 1). The most diverse countries in terms of number of biogeochemical regions were Greece and Italy (n = 41) followed by Lybia (n = 36) and Turkey (n = 33). The lowest diversity in biogeochemical regions was found in Lebanon and Israel (n = 10), together with Montenegro and Albania (n = 12).

Table 1
Proportional (PE_p) and fixed (PE_f) Protection Equality (PE_p measures ecological representation as a determined percentage of each feature under protection, while PE_f does it as a determined amount of each feature (see further details in Chauvenet et al. (2017b)) and traditional metrics (i.e. Total, Mean Area and proportion protected) of Mediterranean Marine Protected Areas delimited in MapaMED database developed by MedPAN (MedPAN, 2017). a_i = area of each subdivision; p_i = area protected of each subdivision.

	PE_p	PE_f	Total p_i (km^2)	Total a_i (km^2)	Mean p_i (km^2)	Proportion protected (p_i/a_i)	Number of Biogeochemical regions
Mediterranean	0.339	0.334	570272	8730490	9504	6.53	60
Epipelagic	0.249	0.292	167682	2425681	13973	6.91	12
Mesopelagic	0.419	0.418	142121	2186878	12920	6.50	11
Bathypelagic	0.221	0.204	92786	1692249	7732	5.48	12
Sea floor	0.396	0.348	167682	2425681	6707	6.91	25
Sub-basins							
Algero-Provençal Basin	0.476	0.324	299544	1791147	9662	16.72	31
Adriatic Sea	0.383	0.227	9804	338364	490	2.90	20
Levantine Sea	0.360	0.184	103233	1808372	3823	5.71	27
Alboran Sea	0.346	0.323	17056	281712	852	6.05	20
Tyrrhenian Sea	0.312	0.286	97678	975398	3255	10.01	30
Aegean Sea	0.236	0.324	13493	562975	465	2.40	29
Tunisian Plateau - Gulf of Sidra	0.228	0.291	16320	1168072	494	1.40	33
Ionian Sea	0.222	0.249	10249	1823263	222	0.56	46
Countries							
France	0.812	0.353	190356	314588	8276	60.51	23
Spain	0.371	0.379	80061	951556	2760	8.41	29
Croatia	0.362	0.231	8350	137962	491	6.05	17
Greece	0.354	0.261	30874	1694560	753	1.82	41
Malta	0.317	0.323	7528	175911	376	4.28	20
Cyprus	0.313	0.199	40098	378510	1909	10.59	21
Turkey	0.287	0.168	33283	248477	1008	13.40	33
Italy	0.277	0.286	156122	1901632	3807	8.21	41
Egypt	0.254	0.290	12792	603896	492	2.12	26
Albania	0.219	0.142	291	32337	24	0.90	12
Israel	0.168	0.546	906	85043	90	1.07	10
Syria	0.159	0.221	17	36403	1	0.05	14
Lebanon	0.137	0.222	120	75154	12	0.16	10
Morocco	0.122	0.217	304	51856	20	0.59	15
Algeria	0.111	0.221	32	485957	1	0.01	26
Tunisia	0.097	0.130	428	246896	18	0.17	23
Libya	0.006	0.007	2794	1281191	77	0.22	36
Montenegro	0.001	0.091	3	19149	0.28	0.02	12

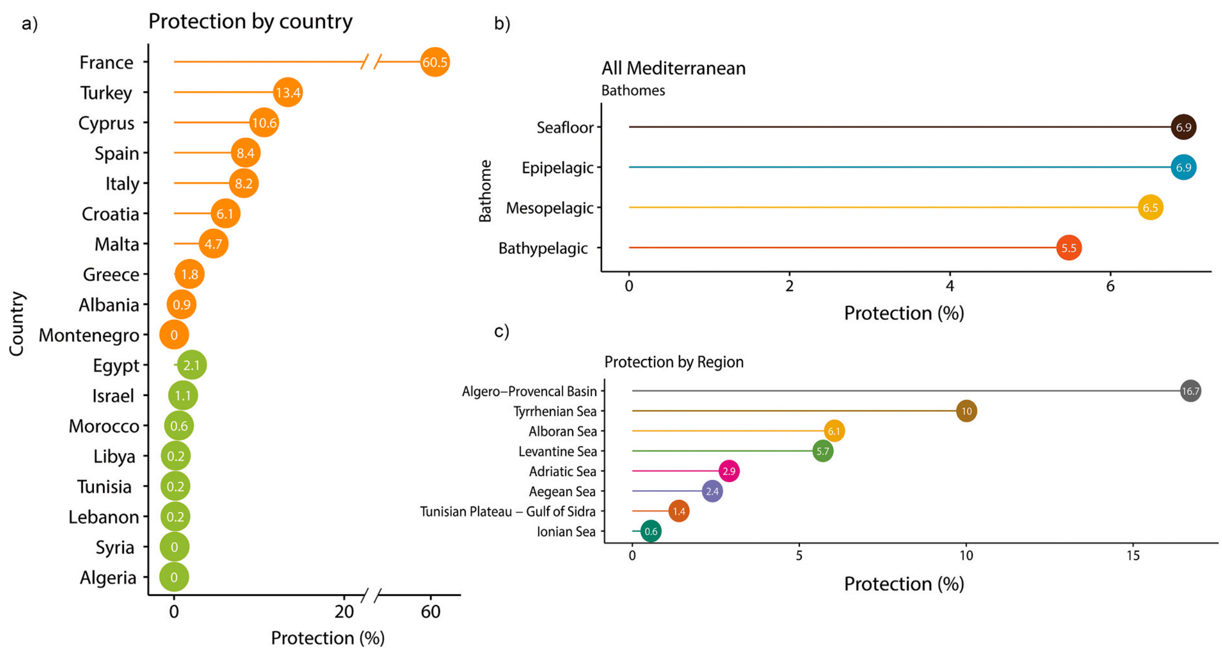

Fig. 2. Percentage of protection of the Mediterranean countries, bathomes, and sub-basins. MPAs delimited in MapaMED database developed by MedPAN (MedPAN, 2017). Orange: European countries; green; non-european countries. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

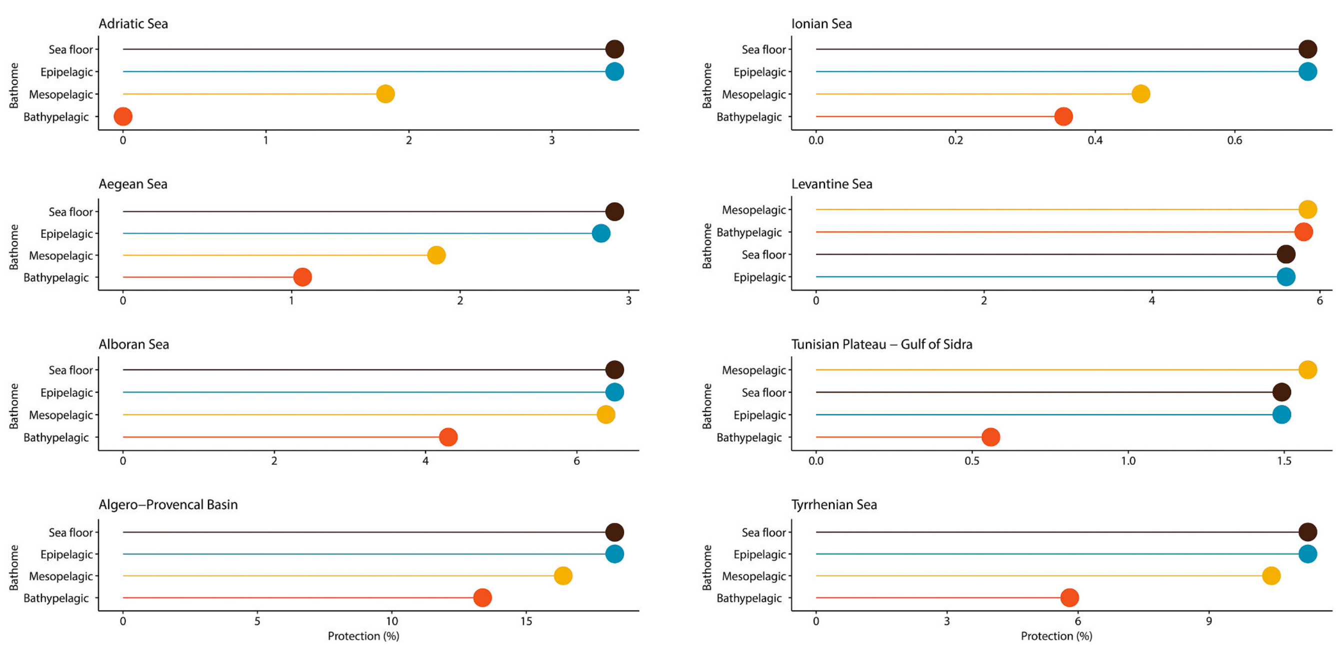

Fig. 3. Percentage of protection by MPAs of the Mediterranean biogeochemical regions split by bathomes in each sub-basin. MPAs delimited in MapaMED database developed by MedPAN (MedPAN, 2017).

3.3. Fragmentation of biogeochemical regions

We found that biogeochemical regions belonging to the seafloor were split into the greatest number of patches (Mean = 27.72 patches; Min-Max = 1–75), followed by biogeochemical regions in the mesopelagic bathome (Mean = 21.36 patches; Min-Max = 3–57) (Fig. 5a). Area wise, biogeochemical regions within the seafloor (Mean = 10057.46 km^2; Min-Max = 52.42–36585.94 km^2) and bathypelagic bathomes (Mean = 14169.63 km^2; Min-Max = 52.42–44395.83 km^2) were the smallest ones. Biogeochemical regions in the bathypelagic bathome also had the highest median value of the distance to the nearest neighbour (112.92 km), another indication of their fragmentation level (Fig. 5c).

4. Discussion

Our study reveals important gaps in the representation of multidimensional biogeochemical regions across the current protected area network of the Mediterranean Sea. Neither the conservation target (Aichi Target 11) was met nor an equitable representation in the preservation of the diverse bathomes within the basin was achieved. We found uneven protection of the different biogeochemical regions for all bathomes, leaving some regions without almost any formal protection.

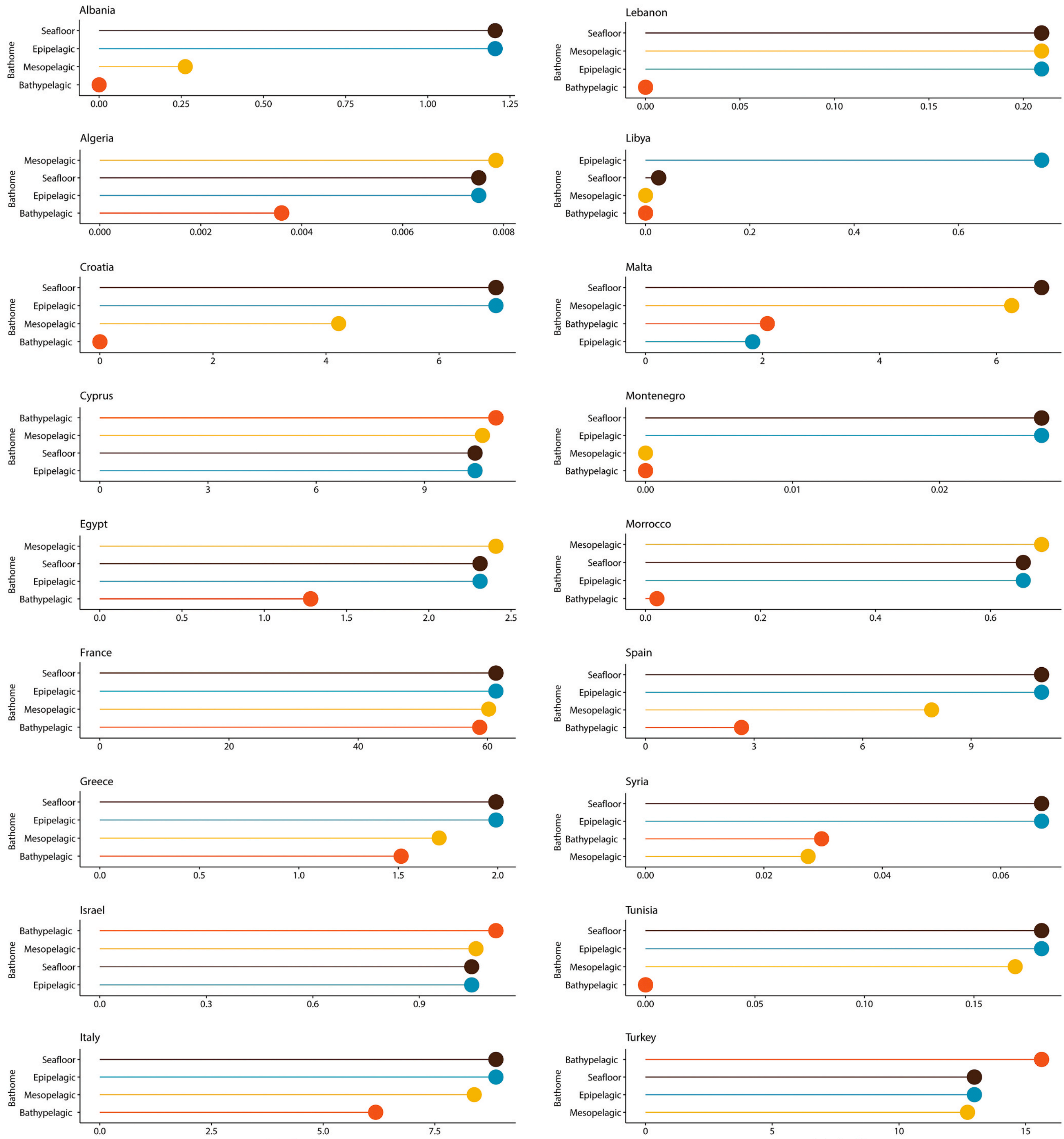

Fig. 4. Percentage of protection by MPAs of the Mediterranean biogeochemical regions split by bathomes in each country.

The Ionian Sea was identified as the most diverse sub-basin regarding biogeochemical regions but with the least protection and with low conservation equality, making this sub-basin a high priority for conservation. Amongst countries, non-European countries presented lower values for metrics of protection and conservation equality. Specifically, Algeria, Tunisia, Libya, and Montenegro were found as the less equitable countries with very low percentage of protection. In general, the bathypelagic bathome was the least protected, the most fragmented, and with low protection equality, so its protection should be enhanced throughout the entire Mediterranean Sea. This gap analysis provides a baseline for Mediterranean managers and stakeholders to improve protection equality of biogeochemical regions, and to ultimately achieve the conservation target. We recommend incorporating equality and representation metrics into the evaluation of new proposed sites for conservation to overcome the deficits in the actual marine protected network and finally capture all the biogeochemical diversity of the basin.

Conservation target (Aichi target 11) was not achieved across any of the bathomes and it was only achieved by three (France, Turkey, and Cyprus) out of 18 countries. Our results indicate that European countries are closer to achieve the 2020 targets than non-European countries. However, although some European countries are close to the 10%

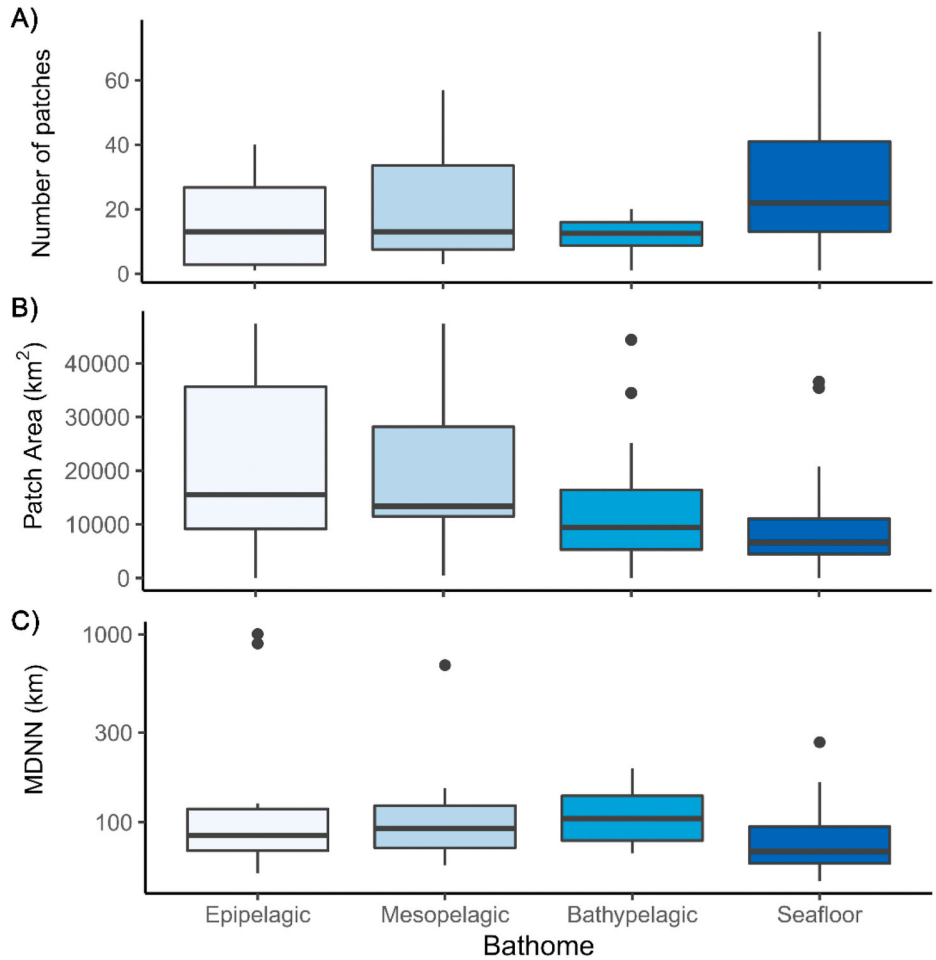

Fig. 5. Boxplots of a) number of patches, b) patch area (km^2), and c) mean distance to the nearest neighbour (MDNN) in kilometers for each bathome.

protection target, not all protected areas have the same enforcement, so their real protection might be negligible or absent in some areas (Agardy et al., 2011; Claudet et al., 2020). Nevertheless, the conservation target has increased as part of the Post-2020 Global Biodiversity Framework, with governments encouraged to increase their previous 10% target to 30% by 2030 and to 50% by 2050 (O'Leary et al., 2016; Baillie and Zhang, 2018). Such targets will become increasingly challenging for Mediterranean countries, especially for southern countries, and the focus on quantitative targets for such a vulnerable region, may mean that the qualitative components (*i.e.* the focus on equal representation) of conservation protection may be even further compromised or overlooked (De Santo, 2013; Amengual and Alvarez-Berastegui, 2018).

The use of either PE fixed or PE proportional resulted in very similar results. Although representing potentially different policies (*i.e.* protecting a set percentage of each habitat versus protecting a set amount of each habitat, Chauvenet et al. (2017b)), only slight differences were found. Equality in protection was generally low in all bathomes and all countries (Table 1, Figure S3). One exception was France due to the Pelagos Sanctuary that protects inshore and offshore areas. However this sanctuary has been considered as a "paper park", so its general protection is dubious (Notarbartolo di Sciaria, 2009). The bathypelagic bathome is the least protected due to the general trend to establish marine protected areas close to shore (Watson et al., 2014; Mazaris et al., 2018). We found that the bathypelagic bathome was the most fragmented bathome, given that its patches were quite small in area (only the seafloor bathome had smaller patches), and given that the mean distance to the nearest neighboring patch within the bathypelagic bathome was the largest. When planning networks of protected areas, it is often aimed to reduce edge effects by creating more compact protected areas ((Ball et al., 2009). Thus, where patches are smaller, a greater percentage should be protected to reduce edge effects. The high fragmentation of deep-sea ecosystems highlights their fragility (Danovaro et al., 2020) and sensitivity to anthropogenic impacts, and thus the need for enhancing their conservation. A high number of cumulative impacts have been identified in the deep Mediterranean Sea. For example, anthropogenic litter tends to move downwards and accumulate in the deeper areas of the sea (Ramirez-Llodra et al., 2013), but those impacts are probably underestimated due to the paucity of knowledge in deep-sea ecosystems (Glover et al., 2018; Manea et al., 2020), so its conservation is urgent. Deep-sea habitats may be thus seen as the equivalents of mountain peaks on land (Dobrowski, 2011), and may serve as climate refugia (albeit disconnected) for unique habitats and species, in the face of a warming world, and especially of warming oceans. Recent studies have highlighted that climate velocities are faster in the deep ocean than in the surface (Brito-Morales et al., 2020), so the protection of this deep-sea habitats and communities is of particular relevance to conserve, as well as biota that are predicted to migrate to those areas with rising sea temperatures.

While there is a ban in the Mediterranean Sea for trawlers and towed dredges at depths below 1000 m (Micheli et al., 2013), offshore MPAs are needed in order to increase the protection of deep areas of the basin due to other important impacts such as hydrocarbon exploration, deep-sea mining, and pipelines present in these waters (Micheli et al., 2013). Other studies that explored ecoregions, confer the lack of ecological coherence and representation of the basin, with a bias towards protection of coastal areas of northern parts of the basin (Abdulla et al., 2009; Montbrison et al., 2012; Giakoumi et al., 2013; Mazaris et al., 2018). Reasons behind such poor equality could be due to opportunistic MPAs (Baldi et al., 2017), the need to quickly reach quantitative targets (Amengual and Alvarez-Berastegui, 2018), or that former legislation was not aligned to the principle of an ecosystem-based management approach, such as the EU's Habitats Directive which only specifies 9 of more than 1000 marine habitats (EEA, 2015).

Marine systems are multidimensional so proper 3D information on biodiversity and threats is needed to adequately conserve it. Innovative tools to conduct 3D conservation planning are developing and need to be applied urgently (Levin et al., 2018; Venegas-Li et al., 2018). Nevertheless, as 3D species distribution models for all Mediterranean species are far from becoming available, we encourage including biogeochemical regions within systematic marine spatial planning exercises to increase the protection of all bathomes and to achieve better equality of protection between the different regions. Despite the huge amount of biodiversity data for the Mediterranean Sea, for some areas data is lacking, such as southern and deep waters of the basin (Levin et al., 2014; Glover et al., 2018; Mannocci et al., 2018; Manea et al., 2020). Special effort should be placed in these areas to improve species distribution models. Despite this gap of data, an appropriate protection of biogeochemical regions could provide an accurate representation of ecological complexity, as biogeochemical and hydrodynamic conditions may support different biodiversity assemblages (Reygondeau et al., 2017). Each biogeochemical region can be seen as a different environmental biotope represented as 3D jigsaw puzzle (Reygondeau et al., 2017) where different species assemblages can develop and maintain their populations (Odum, 1971), so its protection equality is crucial if trophic links and biodiversity wants to be preserved.

5. Conclusion

Our study highlights the importance of incorporating multidimensional (depth-related) gap analyses to better understand protection in the marine realm. The representativeness of the Mediterranean's MPA network was recently evaluated, but only in a 2-dimensional context (Claudet et al., 2020). Furthermore, our results shows that the application of PE metrics to evaluate protection provides critical information, as not always the most protected bathome, country, or sub-basin is the most equitably protected. This is the case for the mesopelagic bathome, that although not the most protected in terms of total area, is the most equitably protected. On the other hand, the sub-basin of the Adriatic Sea achieved high equality of protection but its general protection is relatively low compared to other sub-basins. Thus, the application of the PE metric is highly recommend for evaluation purposes to achieve a balanced and comprehensive representation of conservation features in marine protected areas (Chauvenet et al., 2017b) together with classical metrics of protection. This study provides a baseline context for Mediterranean countries to expand their marine protected networks in a representative and equitable fashion towards achieving current protection targets and the recently set 2030 targets (i.e. 30% of the ocean). To advance marine conservation in the European and contiguous Seas (Katsanevakis et al., 2015), we recommend incorporating conservation equality when establishing an ecological coherent marine protected areas area network. Decision makers should move away from only pursuing protection targets but aim to achieve equitable protection between all ecological components. Future marine conservation targets must convey qualitative importance, representativeness, and equitability, not just quantity.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

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