Threats to marine biodiversity in European protected areas

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Title: Threats to marine biodiversity in the protected European Seas

Threats to marine biodiversity in the European Seas protected system

Threats to marine biodiversity in the European Seas marine protected areas

Short Title: Threats to marine biodiversity

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Abstract:

Marine protected areas (MPAs) represent the main tool towards halting the loss of marine biodiversity. However, there is increasing evidence on their limited capacity to eliminate or even reduce some threats even within their boundaries. Here, we analyzed a European wide database comprising 31579 threats recorded in 2230 MPAs . Focusing explicitly on threats related to marine species and habitats, we found that fishing and outdoor activities were the most widespread within MPA boundaries, although some spatial heterogeneity in the threats distribution was evidenced. Our results clearly demonstrate the need to reconsider current management plans, and measures within and beyond MPAs, while any such planning should avoid a centralized decision processes, and thus properly account for the heterogeneity that is inherent in conservation networks.

INTRODUCTION

Marine protected areas (MPAs) represent a core strategy for conservation of marine biodiversity, and, when properly planned and well managed, they reduce habitat loss and are effective in maintaining species populations (Claudet et al. 2008; Fenberg et al. 2012). Nevertheless, global studies highlight that many existing MPAs lack efficiency, failing to both achieve their conservation objectives (**Leverington et al. 2010; Edgar et al. 2014; Gill et al. 2017**). and secure the flow of ecosystem services (**Allison et al., 1998; Agardy et al., 2011).** Systematic spatial prioritization of conservation needs together with effective management and mitigation actions both within and beyond MPAs is required to overcome shortcomings and maximize conservation efficiency (**Margules and Pressey, 2000**).This however requires a sound database on spatial-temporal patterns of biodiversity measures and risks in relation to current and future threats (**Halpern et al. 2008; Levin et al. 2014**). Still, scarcity of information about the presence, extent and magnitude of the threats that biodiversity faces may lead to biased and ineffective management decisions (**Coll et al., 2012; Schulze et al., 2018**).

Acknowledging the need to develop comprehensive risk assessments for the marine environment, a common practice is to assemble various layers of information on the most acknowledged threats (**Micheli et al. 2013**). Such data are often accumulated through remote sensing, satellite imaging or extensive field surveys (**Depellegrin et al., 2017; Ouellette and Getinet, 2016**). These approaches are often guided by the application of future conservation priorities at broad spatial areas, which bears the risk of failing to track threats either operating at finer scales (e.g. recreational fishing) or being difficult to extrapolate to broad spatial maps (e.g. contamination). As an alternative of improving our understating on the actual threats that are present in the marine realm, questionnaire surveys and expert contributions have also been placed in the front line of research (**Halpern et al., 2006; Donlan et al. 2010**). Such methods could offer critical insights on the identification of basic threats and their ranking based on the vulnerability of marine biodiversity, and thus could be used for directing conservation investments (**Ban and Klein, 2009;Klein et al. 2017**) and for recognizing the scales at which management actions should be taken (**Stelzenmüller et al., 2013**). Still, biases due to background (i.e. education, scientific, professional, regional) and actual interest of responders (e.g. expertise and interest in a given ecosystem type or species) could affect the generated outputs (**Spruijt et al., 2014; Rudd, 2015; Gissi et al. 2017**).

Site-specific data on threats might exist for some MPAs, often used towards directing management actions and understanding conservation conflicts and local threats for biodiversity (**Zupan et al. 2018a**). At the same time, key management directives, are often centralized, with decisions being taken at higher administrative levels largely ignoring local knowledge, conditions and needs (**Helvey, 2004; Christie and White, 2007**). Under this context, the identification of main threats and the assessment of patterns in their spatial distribution could inform more effective management by directing fewer, focused, and realistic measures (**Knight et al., 2013**).

Here, we focus on three key issues related to the diversity and distribution of threats within MPAs: (1) We provide an overview of threats identified in 2230 MPAs located in the European Seas, (2) investigate regional patterns among the reported threats, and (3) identify groups of threats appealing the most for immediate management actions.

METHODS

Datasets for the European conservation network

The Natura2000 conservation network of the European Union (EU) represents the largest network of protected areas in the world, which was established on the basis of two EU legislative instruments, the Habitats and Birds Directives. The network currently consists of more than 27,700 sites. These sites have been selected according to the occurrence of habitat types and species of community interest for the EU (Annexes I and II of Habitats and Annex I of Birds Directives).

For the purpose of this study, data on the spatial distribution of the sites of the Natura2000 network were derived from the database compiled and made available by the European Environment Agency (EEA; http://www.eea.europa.eu/data-and-maps). As no *a priori* distinction is made between marine, coastal or terrestrial Natura2000 sites, we selected sites that host at least one marine habitat listed in the Habitats Directive. Following this process, we selected a total of 2230 sites of the Natura2000 network.

To support and direct conservation and management initiatives, each EU Member State has the obligation to compile related data for each Natura2000 site. These data are gathered by experts following standardized protocols (**EU 2011**), and submitted within Standard Data Forms, that actually represent the official documentation for justifying the importance of each site. Once validated, this information becomes publicly available through the 'Natura2000 Database' (EEA; http://www.eea.europa.eu/data-and-maps). A key piece of information archived in this database refers to a list of processes that could directly or indirectly affect biodiversity. These records are listed under a section of the database named '*activities, threats and pressures*', which offers a classification scheme according to a predetermined list of 397 different categories (Supplementary Table 1). No distinction is made between natural or anthropogenic processes. For each record of any process, the experts have to report its perceived impact (i.e. positive or negative) on the conservation and management of the site (**EU 2011**). Here, we maintained only the records that were assigned as having negative impacts; we hereafter collectively refer to these records as *threats*.

Threats classification

In the Natura 2000 database the classification of threats follows a hierarchical structure with four levels of information, starting from a broad description of 11 types (e.g. pollution). At the second hierarchical level, each group is divided into more informative categories (e.g. pollution to surface waters). Some of these threats are further divided into an additional level providing a more detailed description of the reported activity (e.g. pollution to surface waters by industrial plants). For a few of these sub-categories, a further lower hierarchal level exists.

With a few exceptions (e.g. marine water pollution, fishing and harvesting aquatic resources), the majority of threat types found in the Natura2000 database refer to processes originating in the terrestrial environment. At a site level, no reference is made if a reported threat is having a potential effect on the marine or terrestrial part of the site. Therefore, in order to focus our analyses on those threats that are likely to cause harm to marine species or habitats, we selected only those types that impact marine biodiversity. This was achieved by analyzing information from national reports on the conservation status of protected marine habitats and species. These reports are compiled by each Member State every six years, as an obligation to the Article 17 of the Habitats directive, and include aggregated information on threats for each of the protected species and habitats at a national level (**Tsiripidis et al., 2018**). After filtering out non-marine threats, we ended up with a list of 5094 reported threats for marine biodiversity (see **Supplementary Methods**). These reported threats were classified into 71 different threats types belonging to the second hierarchical level of the threat classification. To exclude threat types that explicitly reflected only extreme and rare conditions (e.g. restructuring agricultural land holding was reported in only one case), we removed rare threats that accounted for less than 1% of the records. This resulted in a selection of 25 threat types of the second hierarchical level (**Fig. 1**).

At a next step, we analyzed the site-specific Standard Data Forms of the 2230 Natura2000 protected areas that included a marine component, extracting all records of the 25 identified threats. A total of 31579 site-specific records at the finest hierarchical level were identified. Here, we performed our analyses on threats at the second hierarchical level, since experts recorded more than 50% of the records at this level. By aggregating records of lowest levels to the second hierarchical level, we ended up to 8861 distinct site-specific records of threats.

For a number of Natura2000 sites with a marine component, no record on marine related threats, or even of any type of threat, were available. In an effort to investigate for the potential factors that might have driven this gap on recording, we employed a Kruskal Wallis test. We examined whether any difference among sites occurred in respect to a) their surface, b) the relative percentage of marine surface covered. To estimate the percentage of marine surface covered, we overlaid the spatial data on the Natura2000 sites against the digital terrestrial terrain of Europe; both spatial datasets were derived by EEA (https://www.eea.europa.eu/data-and-maps/).

Spatial patterns of threats

To explore the spatial patterns of the diversity of threats across European waters we assigned each site to one of four marine regions (i.e. the Baltic Sea, the north-eastern Atlantic Ocean, the Mediterranean Sea and the Black Sea) and used the Spearman rank coefficient to detect any pairwise difference in the rank of the 25 marine related threats.

Analysis of similarities (ANOSIM; **Clarke 1993**) was used to compare threat composition within and among regions. The level of similarity regarding reported threats was calculated by using the Bray-Curtis similarity index. The degree of discrimination was determined based on a test statistic (i.e. global R) which varies between -1 and 1, and is higher when records within groups of sites (i.e. marine regions) are more similar than those from different groups. In cases with many records, R could be significantly different from zero but attaining very small values (**Clarke and Warwick, 2001**); the level of significance was determined after 999 permutations. To further delineate the contribution of individual threats to overall dissimilarity of the four marine regions, we applied SIMPER analyses (**Clarke 1993**). Analyses were conducted using the *vegan* package in R (**Oksanen et al., 2011**).

RESULTS

Threats in MPAs of the European Union

For about one fourth (24%, n =538) of the 2230 European Natura2000 sites that host marine habitats, no record on threats related to marine biodiversity was reported (**Fig. 2**). Actually, for 17% (n = 383) of the total sites, no record of any type of threat was reported, while for 7% of these sites (n = 155) there were records only for threats to terrestrial biodiversity. The total surface and the relative marine surface covered did not statistically differ between the sites for which records on threats were or were not available (in both cases $p>0.05$).

The most frequently recorded threat was 'outdoor sports and leisure activities, recreational activities', reported at 57% of the sites (n = 970) for which marine threats were reported. The second and third most frequent threats were 'fishing and harvesting aquatic resources' and 'human induced changes in hydraulic conditions' reported in 55% (n = 924) and 40% (n = 679) respectively of the sites for which marine threats were reported.

Spatial patterns of threats

Correlation analyses demonstrated significant positive associations between the ranking of the different threats in the four marine regions (r_s ranged from 0.752 to 0.875, in all cases $P<0.01$). Some threats (e.g. fishing, outdoor activities, urbanization) were highly ranked in all regions but their relative importance varied (**Fig. 1, 2**). Threats listed under the category of 'fishing and harvesting of aquatic resources' were most frequently reported in the marine Natura2000 sites located in Atlantic and the Black Sea, while this group was ranked second in Mediterranean sites and third in Baltic Sea sites. Similarly, 'outdoor sports and leisure activities, recreational activities' was the most frequent threat in the Mediterranean and the Baltic Sea, but ranked second in Atlantic sites and third in Black Sea sites. The group enclosing threats related to 'discharges' was the second and fourth more frequently reported in the Black Sea and Mediterranean MPAs respectively, but it was ranked 14th and 15th in the Atlantic and Baltic Sea respectively.

Pollution-related threats, i.e. threats listed as 'pollution to surface waters' and 'marine water pollution' were recorded relatively often (ranked 4th and 5th respectively) in the Baltic Sea but none of them was listed within the 7 more frequently reported groups of threats in the other regions. The threat of 'biological invasions' was frequently reported in the Atlantic (41% of sites with records on marine threats) but in only 28%, 26% and 21% of the sites in the Mediterranean, Black, and Baltic Sea, respectively. Threats that are related to climate change, and have been reported to have a potential impact upon biotic conditions, were only listed within the last 4 reported threats at all regions. Similarly, 'climate change driven alteration of abiotic conditions' was the least reported threat in the Baltic Sea, while also ranked very low in the other regions. These examples are indicative of the significant differences detected among the four marine regions (ANOSIM R=0.08; p<0.001), despite that the overall pattern in the frequency of threats was similar among regions for most of the threats (**Figs 1 & 2**).

'Discharges' was recognized as the main driver of differences between the Black Sea and the other three marine regions (contributing from 8.0% to 10.5%). The distribution of 'outdoor recreational activities' contributed the most to group similarity between Mediterranean and the Atlantic or the Baltic Sea (8.0% and 9.3% respectively), while 'fishing and harvesting of aquatic resources' was the threat that mainly reflected differences between the Atlantic and Baltic Sea. Other threats that were recognized to contribute the most to regional differences were 'urbanization, human intrusions and disturbances', 'pollution to surface waters', and 'marine infrastructure (i.e. shipping lanes, ports)'.

DISCUSSION

The network of Natura2000 marine sites in European seas is subjected to a suit of diverse threats. Importantly, the most common threats can be directly controlled through targeted management actions at the scale of the protected areas, i.e. in their management plans, because they mainly concern human activities of local impact (e.g. fishing, recreational activities, intrusions and disturbances) (but see Zupan et al. 2018a).

Although the assessment, reporting and prioritization of threats are key steps for the establishment of efficient conservation measures, we show that many sites of the European conservation network lack records on any marine related threats. Recently, concerns on irregular and insufficient reporting were raised for the Mediterranean sites of the Natura2000 network, regarding the threat of biological invasions (**Mazaris and Katsanevakis, 2018**). Such information gaps accompany the limited number of Natura2000 sites with an implemented management plan (**Mazaris et al., 2017**), but also the lack of systematic procedures for the network site selection (**Giakoumi et al., 2012**). Even though there is now a scientific consensus that fully protected areas could maximize conservation outputs (**Fraschetti et al., 2018**), Natura2000 sites are not meant to be exclusively fully protected areas but rather areas where human activities are regulated and biological resources are used sustainably, using the range partially protected area classes (Horta e Costa et al. 2016). However, care should be given when assigning protection levels in the system of Natura2000 sites as not all classes of partially protected areas can confer ecological benefits and some moderately protected areas, where some fishing activities are still allowed can be effective only when adjacent to a fully protected area (Zupan et al. 2018b)

Targeted management actions for threat mitigation should be prioritized regionally (**Pascual et al., 2016; Gissi et al. 2018**). For example, while fishing remains the largest threat and a huge conservation challenge, the fishing types threatening marine biodiversity vary between regions and the respective socio-cultural context. When looking at the more detailed classification of threats in the Natura2000 dataset, professional active fishing (i.e. benthic, demersal or pelagic trawling, demersal and purse seining, benthic dredging) is identified as the most common fishing-related threat in the Atlantic MPAs, while leisure fishing (e.g. bait digging, pole and spear fishing) dominates in MPAs in the other three regions. Although it is well recognized that the design and establishment of conservation networks should consider a coarser scale to ensure representativity, connectivity and replication of ecological conditions (**Rees et al. 2018**), the importance of a given threat, its perceived and actual impact and the potential solutions vary across spatial and administrative scales (**Stelzenmüller et al. 2010**).

Through multiple ecosystem services delivery, MPAs can attract tourism and recreation (e.g. **Rodriguez et al. 2017**), but if not appropriately managed conceal a risk of impairing conservation efficiency (Zupan et al. 2018b). Outdoor activities inside MPAs are often proposed to raise awareness of citizens to conservation issues. Still, in partially protected areas such activities may lead to unexpected impacts (**Refs**). If we further consider that MPAs often attract masses of tourists (**Dimitriadis et al., 2018; Ref**), the pressures from such activities is often higher in such partially protected areas compared to unprotected areas (**Zupan et al. 2018a**). At the same time, given that outdoor and leisure activities often lead to high economic benefits, restrictions upon such activities could raise obstacles in the expansion, management, and acceptance of MPAs (**Ruiz-Frau et al. 2013, Refs**). Our results showed for the first time that outdoor activities are among the most extensive threats in European Natura2000 MPAs offering priorities for setting key management directions for this highly heterogeneous European conservation network. However, the large range of potential impacts of these threats is often difficult to assess (**Refs**), and therefore their consideration in systematic spatial planning and risk assessment remains challenging.. Acknowledging that outdoor and recreation activities could also embed many benefits for conservation, with regional agreements setting a pillar for sustainable development (e.g. the European Stategy for the Adriatic and Ionian region), the tradeoffs between benefits and threats should be made clear along the management process.

Climate change is often cited as a major threat for marine protected areas (**Bruno et al., 2018**) but seems rather underestimated in the European conservation network. Plausible explanations could be a gap between scientific evidence on climate change and the perception at local scale, a gap already detected in MPAs outside EU (e.g. **Cvitanovic et al., 2014**; **Hopkins et al. 2016**). For example, there is ample evidence that the Mediterranean Sea is very sensitive to climate change, with mounting evidence on adverse effects reported throughout the region (e.g., **Sara et al. 2014; Rilov 2016; Almpanidou et al., 2018**). However, most scientific advice spans over less than a decade, thus a short time lag for reporting on the Natura2000 threats. Also a possible explanation may refer to the lack of available information on physical and biochemical data at temporal and spatial scales relevant to organisms' biology and behavior, which could serve as a main obstacle in our understanding on how ocean variability could affect biodiversity (**Bates et al., 2018**). Even in the context of global changes such as increase in sea water temperature or ocean acidification, management of local threats is a key for effective conservation. Global threats interact with local threats and conditions, thus leading to cumulative effects on marine ecosystem components (**Stelzenmüller et al., 2018; Coll et al. 2008**). Mitigating local threats is often the only feasible course of action to reduce negative synergies with global threats. Still, further efforts are needed to comprehensively monitor threats on marine biodiversity and manage human impacts (**Mazaris and Katsanevakis, 2018; Refs**). With the need to attain good environmental status in all marine areas, monitoring threats that would need other regulatory measures beyond MPAs is also important. Still, the network of Natura2000 sites could be used as a network to monitor both Essential Ocean Variables (Miloslavich et al. 2018) and marine human uses in wider regions (**Addison et al. 2018, Weatherdon et al. 2017**).

Threats to marine biodiversity are not only related to activities in the ocean but may originate from land-based activities (**Tallis et al., 2008; Depellegrin et al. 2017**). For example, pollution as the result of coastal or terrestrial inputs is widely recognized in European MPAs, (**Refs**). Assessment frameworks should thus account for land based uses and land use changes acknowledging land-sea interactions s. Still, in highly heterogeneous conservation networks such as the Natura2000 where political, societal and economic factors are largely driving criteria for prioritizing the site support (**Tsianou et al., 2013**) but also the type, intensity and magnitude of threats (**Tsiafouli et al., 2014**), the centralization of prioritization actions might be misleading.

Despite a remarkable expansion in the number of MPAs in European seas, it is clear that long standing and well recognized threats such as fishing, recreational activities or pollution are still persistent inside most MPAs. Of additional concern is the relatively high number of sites (of the largest conservation network globally) that fail to provide information on the actual threats present. Thus, our results put a spotlight on the need of standardized monitoring and assessment approaches ensuring spatial coverage, consistency, and clarity. The banning of highly impacting activities should gain more attention at the political level, in order to make trade-offs explicit in conservation planning.

Figure 1. Ranking of 25 marine related types of threats reported at the sites of the European Natura2000 conservation network that host marine habitats of community interest, located within the four marine regions of the European seas. The ranking follows a grey gradient, with darker types of threats been more frequently identified.

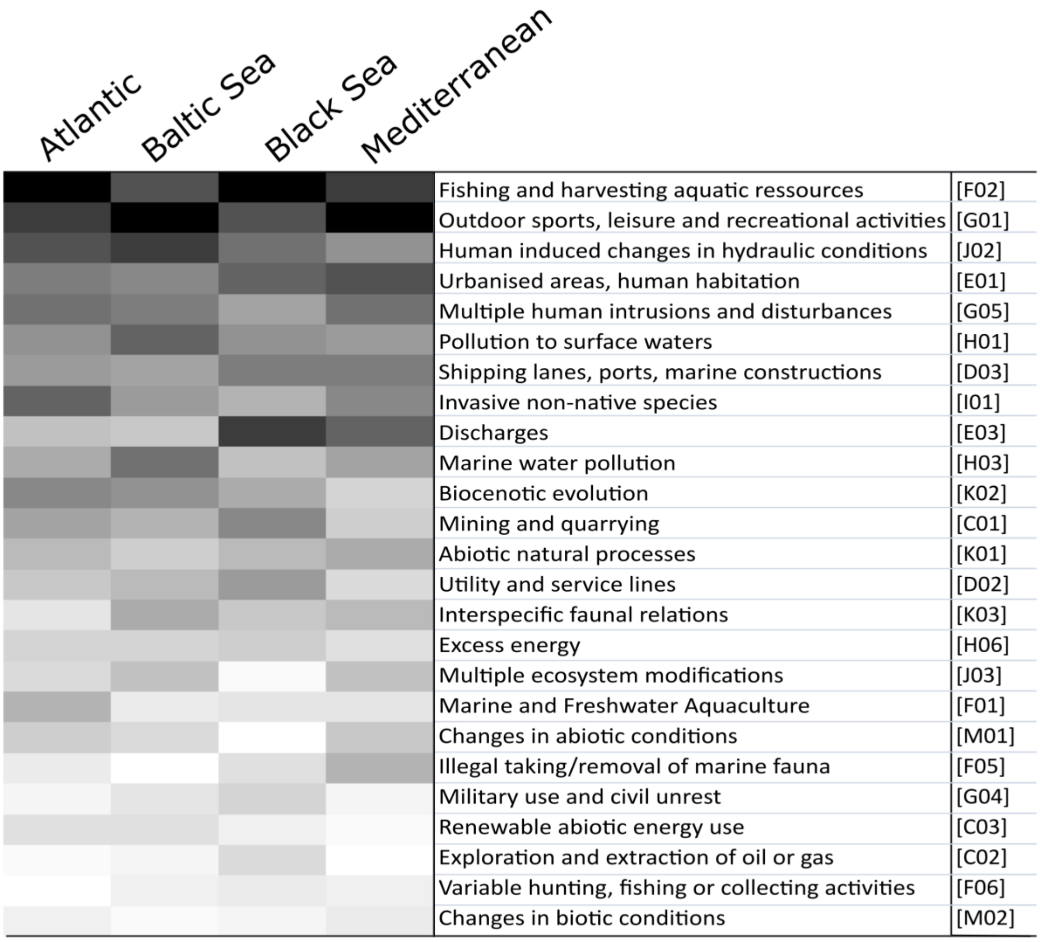
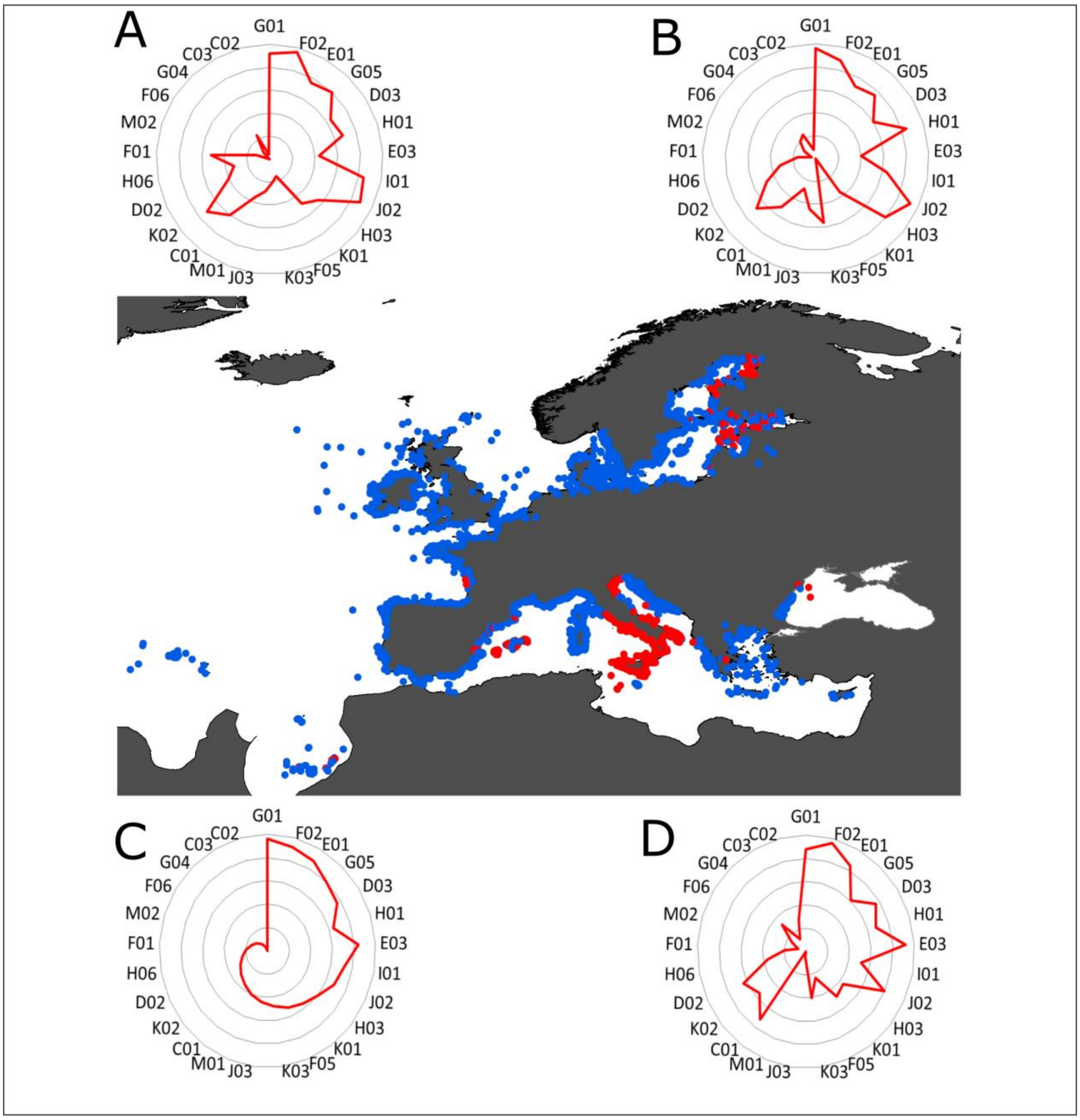


Figure 2. The distribution of the Natura2000 marine sites. The centroid of each site is presented; sites for which no record on threats was reported are colored in red. In panels A to D, the relative ranking of the various threats in the Atlantic, the Baltic Sea, the Black sea and the Mediterranean, respectively, is depicted. The coding of threats if presented in Figure 1 and is in accordance to the classification provided by the European Environmental Agency.


A
G01 F02 E01 G05 D03 H01 E03 I01 J02 H03 K01 F05 K03 J03 M01 C01 K02 D02 H06 F01 M02 F06 G04 C03 C02
B
G01 F02 E01 G05 D03 H01 E03 I01 J02 H03 K01 F05 K03 J03 M01 C01 K02 D02 H06 F01 M02 F06 G04 C03 C02
C
G01 F02 E01 G05 D03 H01 E03 I01 J02 H03 K01 F05 K03 J03 M01 C01 K02 D02 H06 F01 M02 F06 G04 C03 C02
D
G01 F02 E01 G05 D03 H01 E03 I01 J02 H03 K01 F05 K03 J03 M01 C01 K02 D02 H06 F01 M02 F06 G04 C03 C02