



Short communication

The threat of biological invasions is under-represented in the marine protected areas of the European Natura 2000 network

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ABSTRACT

To effectively tackle the challenge of biological invasions through targeted strategies and mitigation measures, managers and policy makers require adequate reporting and flow of information. For this reason, the European 'Natura 2000' network of protected areas, which is the main conservation tool of the European Union, is supported by a standardized database. All threats to biodiversity are supposed to be reported in sufficient detail through that database. We compared the reported threats by 'invasive non-native species' in the Natura 2000 database with the actual cumulative impacts of invasive alien species on marine habitats in the Mediterranean using the CIMPAL index (Cumulative IMPacts of invasive ALien species). CIMPAL estimates cumulative impact scores on the basis of the distributions of invasive species and ecosystems, and both the documented magnitude of negative ecological impacts and the strength of such evidence. We showed that the threat of invasive alien species is substantially under-reported in the official documentation. Specifically, among the 1455 marine sites of the network, no threat was officially reported in one third of the sites. The threat of biological invasions was only reported in 154 sites, despite negative impacts by invasive alien species being predicted for 98% of all sites when using CIMPAL. In fact, in the subgroup of sites where no threats have been officially reported, the impacts predicted by CIMPAL were the highest. Such, inadequate and insufficient reporting of threats in the Mediterranean marine Natura 2000 sites presents a significant obstacle to the flow of accurate information needed to support conservation policies and marine management.

1. Introduction

Over the last decades, cumulative impacts on marine ecosystems (Halpern et al., 2008; Stelzenmüller et al., 2018) have resulted in local and global extinctions, the degradation of habitats and the redistribution of marine biodiversity (Lotze et al., 2006; Worm et al., 2006). Reflecting the needs to conserve biodiversity, marine protected areas (MPAs) became a key management tool (Agardy, 1994).

The Natura 2000 network reflects the ambitious goal of the European Union (EU) to conserve biological diversity through a network of protected areas extending across Member States (Evans, 2012; Orlikowska et al., 2016). Today, the network contains > 27,000 sites, of which 15% have a marine component (Mazaris et al., 2017). Common monitoring programs operate at the national level, and conservation targets for species and habitats were established under a common legislative basis. Nevertheless, as any MPA network, the Natura 2000 network, is exposed to many large-scale stressors, such as climate change, chemical and biological pollution (Bruno et al., 2018;

Simberloff, 2000). Standardized protocols exist to record, within and around each site of the Natura 2000 network, all human activities and processes that potentially have a negative impact on species and habitats. Such data do actually reflect the management and conservation priorities of each site, and mirror the quality of scientific and management information gathered (Tsiapoulis et al., 2013).

Invasive alien species are one of the most severe threats to marine biodiversity (Molnar et al., 2008). They can cause population declines and local extinctions, alter the structure of biotic communities, affect food webs, ecosystem processes, functionality and services (Katsanevakis et al., 2014a; Molnar et al., 2008). The accelerating global trends of trade and transportation, the intensification of aquaculture and aquarium trade, and the enlargement of navigational canals, have been driving an increasing rate of biological invasions (Essl et al., 2015). Still, regardless of the scientific and political consensus on the urgent need for targeted management actions, the ability to mitigate the impacts of biological invasions and prevent new introductions is a challenging task.

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The Mediterranean Sea represents a hotspot of marine biological invasions, and is among the most affected marine regions globally (Edelist et al., 2013; Katsanevakis et al., 2014b). Biological invasions in the Mediterranean have caused large-scale biogeographic changes (Bianchi et al., 2012; Katsanevakis et al., 2014b), population declines or local extinctions and range shifts of marine life (Edelist et al., 2013; Galil, 2007). The boundaries of MPAs have offered no protection from many high-impact invasive species, such as the green alga *Caulerpa cylindracea*, which overgrows other native macroalgal or invertebrate species, or the fishes *Siganus luridus* and *Siganus rivulatus*, which have caused the severe degradation of shallow rocky reefs, by transforming them from ones dominated by lush and diverse brown algal forests to ones dominated by bare rock (Katsanevakis et al., 2014a; Otero et al., 2013).

This study sought to evaluate whether the threat of invasive alien species to biodiversity has been adequately assessed in the Natura 2000 network by marine managers, as a first step to properly prioritize mitigation measures. We have focused in the Mediterranean Sea, and compared the reported threats by ‘invasive non-native species’ in the Natura 2000 database with the actual cumulative impacts of invasive alien species on marine habitats as assessed by a regional spatial model. The latter accounted for the distribution of invasive alien species and of impacted marine habitats, as well as the vulnerability of its habitat by each invasive species. By highlighting deficiencies in the Natura 2000 monitoring and reporting system, this study aimed to stress the need of improving monitoring and reporting practices, and thus management efficiency in the European network of protected areas.

2. Methods

Spatial data on the distribution and extent of the Natura 2000 sites found in the Mediterranean region were retrieved from the European Environment Agency (EEA; <http://www.eea.europa.eu/data-and-maps>; accessed 15/5/2017). Eight EU Member States border the Mediterranean Sea, and contain a total of 7891 Natura 2000 sites. The sites of the network are not defined as terrestrial or marine, with many sites expanding to both realms. Thus, for our analyses, we used all sites that fully or part of them encompass the sea. To identify these sites, we removed terrestrial areas adjacent to coastlines by clipping out surfaces occurring within the terrestrial terrain of Europe, also derived from the EEA.

The digital layer of European coastlines was derived by EEA (<https://www.eea.europa.eu/data-and-maps/data/eea-coastline-for-analysis-1>; accessed 15/5/2017). This layer was generated for high resolution analyses (1:100,000), and was derived from the EU-Hydro (i.e. a high resolution high- hydrography datasets; Copernicus Services, EEA (2018) and GSHHG [i.e. a high resolution spatial dataset on global coastlines (Wessel and Smith, 1996)]).

To support and direct conservation and management initiatives, the Natura 2000 database compiles related data collected by each EU Member State. This database includes site-specific information on the conservation status of species and habitats of EU interest. These publicly available data are gathered according to Standard Data Forms (EU, 2011). A critical piece of information archived in the Natura 2000 database refers to the actual threats to species and habitats. These records are listed under a section of the Natura 2000 database which is called “activities, threats and pressures”; any natural or human-related process or activity with a potential impact on biodiversity that is detected at each site is classified according to a list of 397 different types. Here, we extracted all available records on “activities, threats and pressures” reported for each Mediterranean Natura 2000 site with a marine component. To explore the extent to which biological invasions are identified as potentially impacting biodiversity in a negative way, we investigated for which of these sites “invasive non-native species” were reported within the Standard Data Forms.

We used the index on the Cumulative IMPacts of invasive ALien

species (CIMPAL) applied in the Mediterranean Sea (Katsanevakis et al., 2016) to examine whether the records on biological invasions for the marine Natura 2000 sites were consistent with the cumulative impact scores due to biological invasions for each of these sites. CIMPAL was estimated at 10×10 km cells as $I_c = \sum_{i=1}^n \sum_{j=1}^m A_i H_j w_{ij}$, where: A_i is an index of the state of the population of invasive alien species i in a specific cell, and was transformed and normalized to range between 0 and 1; H_j is an index of the extent of habitat j in the cell, standardized to range between 0 and 1; and w_{ij} is the impact weight for the combination of species i and habitat j estimated on the basis of both the reported magnitude of ecological impacts in the scientific literature and the strength of such evidence (detailed information is provided in Katsanevakis et al., 2016).

The spatial distribution of the CIMPAL index, retrieved from Katsanevakis et al. (2016), was laid over the distribution map of the Natura 2000 sites to derive CIMPAL values for each protected site. As CIMPAL was reported at a resolution of 10×10 km, when a protected site overlapped with more than one 10-km^2 cell, the mean value of the index in the covered cells was calculated and assigned to this site. If the CIMPAL index was > 0 (i.e. there was a non-zero impact) in a Natura 2000 site, and if biological invasions were not reported as a threat for this site in the Natura 2000 database, this was translated as inadequate reporting and assessment of the threat of biological invasions in the particular site.

For some sites, no record on any type of threat, activity or impact was provided, while for others the reported threats did not include biological invasions. We grouped sites into three categories, i.e. (a) sites with no record of any activity, threat, and pressure; (b) sites reporting some activities, threats, and pressures, but not including biological invasions; and (c) sites reporting biological invasions as a threat for biodiversity. To investigate whether these categories differed to the CIMPAL values, we applied a non-parametric Kruskal-Wallis test. Dunn's Method was further applied for pairwise comparisons. A Mann Whitney test was applied to explore for significant differences in the mean number of reported “activities, threats and pressures” between sites for which the threat of biological invasions was reported, in comparison to the rest of the sites. Non-parametric tests were applied, since the Kolmogorov-Smirnov normality test failed.

3. Results

In total, we identified 1455 distinct sites of the Natura 2000 network in the Mediterranean Sea that have a marine component. Threats were reported for 66% of these sites ($n = 963$), with only 154 (11%) reporting the threat of biological invasions. For predominantly marine protected areas, (i.e. for sites with a marine component of $> 50\%$ of their area; $n = 650$), 69 (11%) reported biological invasions as a threat (Fig. 1). We found that for sites where the threat of biological invasions was reported, the mean number of reported “activities, threats and pressures” was significantly higher than for the other sites (Mann Whitney U = 182,617, $P < 0.01$). Thus, some sites have generally low monitoring effort, in which no threat at all or very few threats are recorded. In comparison, other sites have more intense monitoring effort, and many threats, including biological invasions, have been reported. At a Member State level, we found that, the percentage of protected areas for which at least one threat was reported was above 40%, with the exception of Italy (35%) and Slovenia (8%). Still, biological invasions were reported as a threat in $> 15\%$ of sites only in Spain (15%) and Malta (56%).

Within marine Natura 2000 sites, CIMPAL values ranged between 0 and 149 (mean = 37 ± 23). The index had a non-zero value for 98% of sites (Fig. 2). For all sites reporting biological invasions as a threat in the Natura 2000 data form, the CIMPAL index had a non-zero value. Significantly higher CIMPAL values were observed at sites with no relevant information on any type of “activities, threats and pressures” ($P < 0.05$). We found no statistically significant difference between

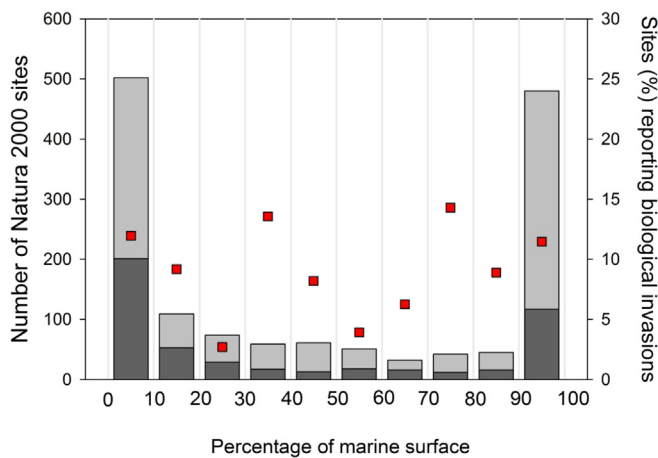


Fig. 1. Total number of Natura 2000 sites, in which the sea covers specific percentages of their total area (left axis-bars); the dark gray part of the bars indicate the number of the sites for which records on “activities, threats and pressures” are available in the official EU database. The percentage of these sites reporting biological invasions is illustrated by the red boxes (reference to right axis). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

sites reporting biological invasions as a threat for biodiversity and sites reporting some other threats, but not biological invasions ($P > 0.05$).

Given the potential lack of consistency between the spatial distribution of Natura 2000 sites and the spatial interpretation of the coastline used to define the sites with a marine component, we repeated the analyses by considering only the sites for which the marine component exceeds 10% of the site's area. The patterns remained the same: for only 9.8% of these sites ($n = 953$) biological invasions have been reported as a threat; there was a significantly higher number of total records on ‘activities, threats, and pressures’ at these sites when compared with the rest of the sites (Mann Whitney $U = 12,577$, $P < 0.01$). The mean CIMPAL was estimated as 34.8 ± 22 , with statistically higher values at sites with no relevant information on any type of “activities, threats and pressures” ($P < 0.01$).

4. Discussion

Our study clearly demonstrates that the actual threat of invasive species in the marine sites of the Natura 2000 network in the Mediterranean Sea is significantly underestimated, especially in the eastern and central areas (Fig. 2). Contrary to the official reporting, our findings reaffirm concerns raised over the last decade on the increased threat of biological invasions, especially their impact on conservation efforts (Otero et al., 2013). Recently, a series of studies stressed the need to improve the functional and structural properties of the Natura 2000 network, further recognizing several gaps in protection coverage and habitat representativity (Giakoumi et al., 2012; Mazaris et al., 2017; Rodríguez-Rodríguez et al., 2016). Similarly, suggestions have been made to expand the current network through the enlargement of existing sites or the addition of new ones (Bastari et al., 2016; Giakoumi et al., 2012). While all such inputs contribute towards enhancing the capacity of conservation planning, the results of our analyses question whether basic and critical information is adequately used to inform marine managers and policy makers.

Most Mediterranean Natura 2000 marine sites are exposed to biological invasions, but this is not sufficiently acknowledged within the Natura 2000 database. This finding has serious management implications, as each Member State has the obligation to monitor, report and share all available information accurately, so that it could be used to improve conservation capacity. European policies and strategies depend on such information, which they utilize to prioritize management

actions (Lisón et al., 2017; Popescu et al., 2014). At the same time, the actual cost for the operation of the Natura 2000 sites is rather high; funds allocated annually, only for management purposes, have been estimated at around 6.1 billion euros (EU, 2004). The fact that the cumulative impacts of invasive alien species is the highest in sites where no threats are reported indicates the lack of thorough and proper consideration of actual threats.

Undoubtedly, proper reporting of the threat of invasive alien species requires not only a yes/no indication, but also an adequate risk assessment. Such an assessment should quantify the number and abundance of invasive species and evaluate their current and potential negative impacts. A better knowledge of their role in ecosystem processes, functioning and services is critical for conservation planning (Mačić et al., 2018). Still, considering that the dataset used in the present study was based on official EU information, the failure to simply report if invasive species were considered as a threat in a given site, due to limited effort or mistaken interpretation, represents a potential bottleneck for conservation efforts. Despite the wealth of information emerging from scientific papers, research projects and strategic documents, it seems that a gap in practical implementation remains.

We were not able to detect any clear pattern explaining the lack of information on the negative impacts of biological invasions in many of the Mediterranean Natura 2000 sites. Records were low regardless of the relative marine area of the protected site (Fig. 1). Furthermore, the highest CIMPAL values did not correspond to the sites with reported threats from biological invasions in the Natura 2000 database. In a recent study, the information included in the standard Data Forms of the Spanish terrestrial Natura 2000 sites, was found to under-represent known occurrences of biodiversity (Lisón et al., 2017). Here, we expand this concern by suggesting that the underrepresentation is also evident for the reporting of threats.

Revisiting current standards and processes for monitoring and reporting should be considered as a first step towards ensuring the assimilation of key information. Moreover, the synchronization and coordination of the research (Orlikowska et al., 2016) and the updating of monitoring schemes (Hochkirch et al., 2013) are urgently needed to achieve the standardization of the information supporting the Natura 2000 network. The limited political willingness to fulfill reporting obligations (Lisón et al., 2017) seem to remain basic obstacles for European conservation.

In assessments of the environmental status in their seas, 14 Member States of the European Union, (including the EU countries bordering the Mediterranean Sea) ranked invasive alien species as among the three most important threats on marine ecosystems (Palialexis et al., 2014). Attempts have been made to offer guidelines for the reporting and monitoring of marine invasive species within MPAs in the region, as a way of engaging managers to help mitigate threats (Otero et al., 2013). Yet, we conclude that efforts to improve the quality of accompanying information need to be substantially strengthened.

The establishment of protected sites per se cannot guarantee biodiversity protection. Effective conservation depends on the assimilation of sound ecological data and proper evaluation of risks at different spatial and temporal scales (Edgar et al., 2016). As a means towards improving data quality, spatial cover and temporal resolution of information on the abundance, diversity and distribution of invasive species, citizen science could have a critical role (Crall et al., 2011; Delaney et al., 2008). Manipulative experiments could improve our understanding on the biology of invaders, the expansion patterns and the changes they may cause at community or ecosystem level (Johnson et al., 2009; Sorte et al., 2010). Expanding on the key suggestions by Edgar et al. (2016) on how to advance marine conservation, flexible and reliable indicators which would account for the interactions between invasive species, ecosystems status and multiple other threats, could allow to communicate the potential risks to the public and policy makers and, to determine the magnitude and directionality of the dependencies among the expected impacts (Mačić et al., 2018). Deficient,

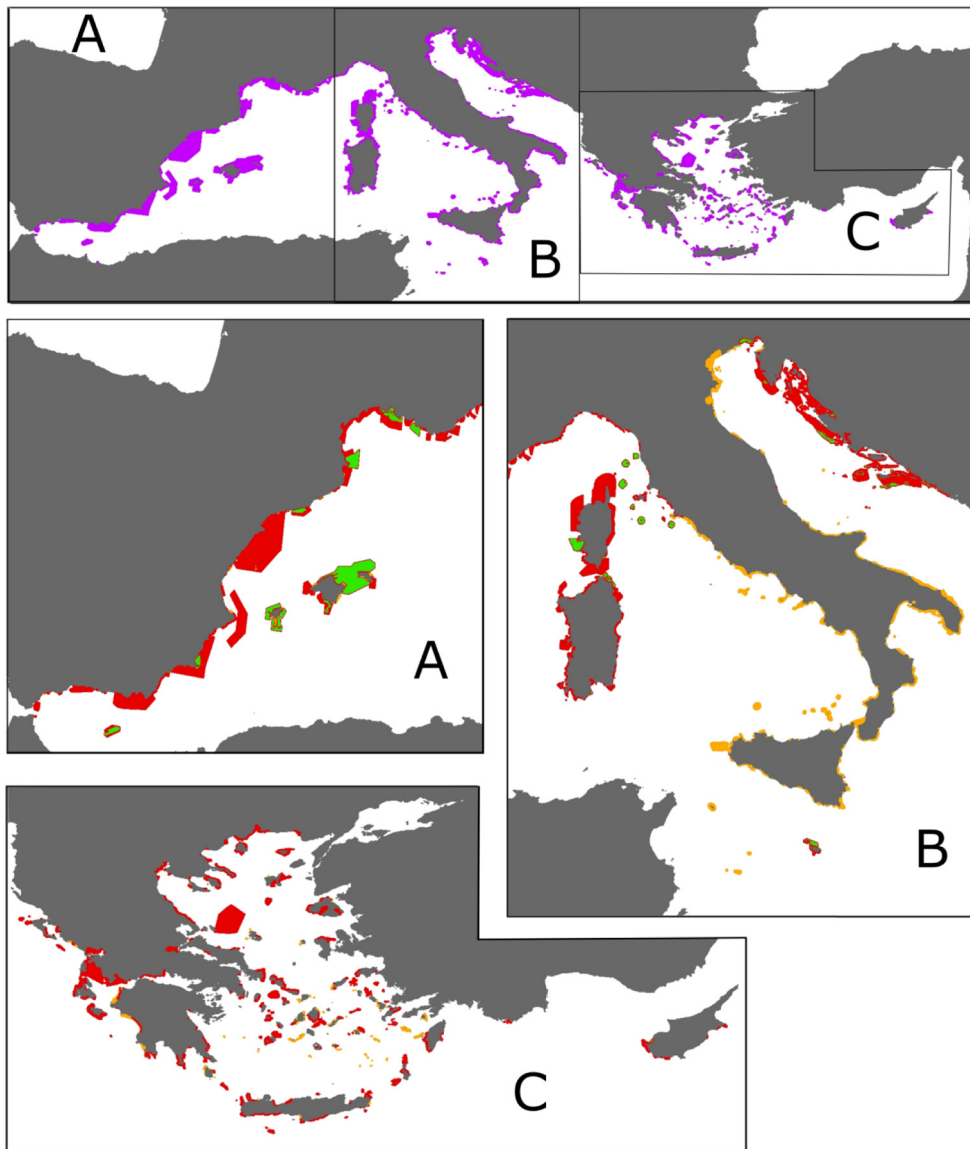


Fig. 2. The Mediterranean Natura 2000 sites (purple polygons — upper panel) for which the threat of biological invasions is reported within the EU Natura 2000 database are presented by green polygons. The sites for which any other type of “activities, threats and pressures”, but not biological invasions, is reported but the index on Cumulative IMPacts of invasive ALien species (CIMPAL) had positive values are presented as red polygons. The sites for which there is no reporting of any type of “activities, threats and pressures”, but a positive CIMPAL value was obtained are presented as orange polygons. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

unfiltered information might mask actual problems and restrict how actions are prioritized. We, therefore, suggest that certain measures (such as data monitoring, data quality control and reporting) should receive high priority to help to improve the active participation of managers (Cook et al., 2010). Ultimately, the development and maintenance of integral standards of responsible monitoring and management would help protect investments (scientific, political, economic) made in the marine protected areas of the Natura 2000 network.

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