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Geospatial identification of stakeholders to support dynamic ocean management in transboundary areas

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A R T I C L E I N F O

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Bluefin tuna
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A B S T R A C T

Dynamic ocean management (DOM), a new frontier in the field of operational ecology for marine resource management, is a means of protecting the dynamic features and species in the ocean by allowing management measures to move and adapt in space and time. Most DOM applications have been implemented within the jurisdictional waters of single nations, avoiding the potential issues and challenges arising from coordination in transboundary regions, which can be challenging due to the overlap of multiple and diverse jurisdictions and governance systems. This study focuses on the implementation of DOM in transboundary regions. A novel approach is presented using a geospatial information system to automatically identify relevant stakeholders from two sectors (i.e., marine traffic and marine fisheries) across multiple maritime boundaries. The objective of this study was to test the geospatial information system and examine the variability of stakeholder networks when DOM was applied in a transboundary marine region. We tested our approach in a complex geopolitical region, the Western Mediterranean Sea, building on simulated management strategies for two highly mobile species, the bluefin tuna (*Thunnus thynnus*) and the fin whale (*Balaenoptera physalus*). Substantial differences in stakeholder networks were identified depending on the focal species, highlighting the widespread responsibility among marine users for bluefin tuna compared to fin whale. Potential issues and solutions for identifying the most suitable stakeholder and governance frameworks are discussed, allowing recommendations to support the implementation of DOM in complex geopolitical contexts.

1. Introduction

Pressures from human activities on marine resources are growing globally [1], while the development of appropriate strategies for marine resource management at an international scale is considered a priority to enhance future sustainable exploitation of the oceans [2]. Natural marine processes and human maritime activities commonly occur across large marine areas that transcend the frontiers established under political agreements [3]. Thus, the adoption of a transboundary approach is fundamental to achieve effective sustainable management of marine resources [4]. In recent years, institutional bodies, managers, and researchers have tested and investigated possible strategies for effective transboundary management [5–8]. However, to date, no study has investigated the potential and challenges of implementing Dynamic Ocean Management (DOM) in transboundary scenarios. Defined as "management that changes in space and time in response to the shifting nature of the ocean and its users based on the integration of current biological, oceanographic, social, and/or economic data" [9], DOM has been posited as one of the most innovative approaches to increase the sustainable utilization and conservation of marine resources [10–15]. It enables the management of extensive marine areas by adapting the spatial boundaries of the management area to temporal changes in resource distribution [16,17].

DOM refers to the identification of focal marine areas that change in

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shape and location over time. These changes alter the socio-political framework needed for management due to differences in jurisdictional waters covered and the different stakeholders affected. While an array of guidelines and best practices for stakeholder engagement are available for static management measures (e.g. those published by RAC/SPA and IUCN-Med. [18]; Walton et al. [19]), one is lacking for DOM. To effectively coordinate stakeholders and implement DOM in transboundary areas, it is essential to address the temporal variation in the management system and how it interacts with the socio-political framework. Indeed, in transboundary scenarios, mobile management zones can include multiple nations, numerous categories of marine jurisdiction, a wide range of stakeholders (i.e., sea users), and responsible administrations. Institutional and stakeholder support is a critical aspect of an effective DOM strategy [20]); hence, the identification of key actors in the early stages of DOM design would ease subsequent coordination once implemented.

DOM strategies have already been tested in open seas with successful outcomes [11,13,17,21]. However, the applicability of DOM in semi-enclosed marine basins has not been investigated. Semi-enclosed marine basins commonly comprise transboundary ocean regions subdivided within jurisdictional waters of multiple riparian countries with adjacent or opposite coastlines. This specific setting results in a multifaceted governance framework, in which an interconnected marine space is shared and managed by different nations. The Mediterranean Sea is one of the best examples of a large semi-enclosed marine region, with a highly complex socio-political framework, where the management of marine resources and the conservation of its rich biodiversity [22] need to be pursued through an effective, transboundary approach [23,24]). The geopolitical framework of the Mediterranean Sea is highly diverse including twenty-two coastal countries. The marine jurisdictions of each country (with the exception of Monaco and Gibraltar) border with those of at least three other countries. The marine jurisdictional limits, in accordance with United Nations Convention on the Law of the Sea (UNCLOS) criteria [25], have not yet been fully transposed and recognized in the national law of several countries [26,27].

In this context, coherent spatial planning and Ecosystem-Based Management (EBM) represent a priority from both sociopolitical and environmental perspectives to ensure the sustainable use of space and resources [28,29].

In this study, a geospatial approach was developed to assess the temporal variability of the sociopolitical framework relevant to the implementation of DOM in a transboundary context. First, an information system (hereby referred as "dynamic assessment system") was created to support the identification of key stakeholders and responsible authorities by combining multiple spatial datasets. The system was tested with two different simulated cases of DOM for two large, highly mobile marine species in the Western Mediterranean Sea: the Atlantic bluefin tuna (*Thunnus thynnus*) and the fin whale (*Balaenoptera physalus*). The governance structure and stakeholders involved in two sectors (marine fisheries and marine traffic) were incorporated to illustrate our approach. Using network analysis, it was demonstrated how this approach can support the identification of stakeholders to contribute towards the implementation of DOM in transboundary regions.

2. Material and methods

2.1. Study area

The Western Mediterranean Sea was selected as the study area (Fig. 1). It is a semi-enclosed area managed by eight riparian countries, encompassing the complexity of its transboundary governance system [30]. Its boundaries correspond to those defined by the International Hydrographic Organization [31] and are officially adopted by the European Union in the Marine Strategy Framework Directive (Directive 2008/56/EC [32]), the main legislative instrument that seeks to protect the marine environment across Europe.

2.2. Dynamic assessment system

To account for potential changes in stakeholders across multiple management scenarios in transboundary areas, an automated assessment system was developed in three specific phases: (i) creation of a spatial database of stakeholders, (ii) review and integration of the governance framework at the national level for each country, and (iii) assessment of the socio-political framework and identification of key stakeholders. Further details on each phase are provided below.

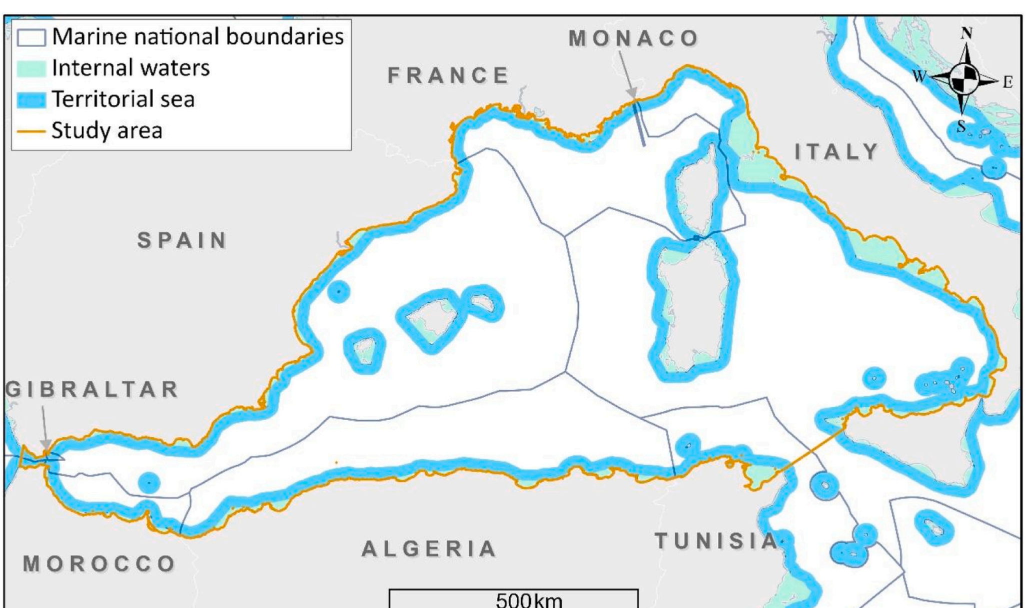

Fig. 1. Jurisdictional waters of the Western Mediterranean. Jurisdictional limits were based on UNCLOS criteria (source: Flanders Marine Institute, 2019 [33]). The boundaries of the study area are coloured in light brown.

2.2.1. Spatial database of stakeholders

A spatial georeferenced database of stakeholder organizations in the Western Mediterranean Sea (Fig. 2) was created from publicly available information (summary in Table 1 and full list in Supplementary Data). Online national repositories were consulted to search for the main stakeholder organizations. The organizations considered were those involved in the marine traffic and marine fishery sectors, as they encompass maritime activities that are highly dynamic in their spatio-temporal distribution and operate extensively in both the coastal and pelagic areas of the Mediterranean [29]. The stakeholder organizations reviewed were included in two distinct categories: a) decision makers, which correspond to public territorial organizations with an administrative role in either marine traffic or fisheries management (e.g., Transport and Fishery Ministries); and b) other organizations, corresponding to any other type of organization representing marine users in any of the two sectors (e.g., marine traffic monitoring delegations and fishing cooperatives). Each organization was further included in four subcategories: commercial fishing association, fishery administration, marine traffic monitoring delegation, and marine traffic management organization. To obtain the geographic coordinates of each organization, the official address of their venue was geocoded using the Google Maps API and “ggmap” R package [34].

2.2.2. Governance review

To identify the administrative role of decision makers in a given marine area, both maritime jurisdictions and management frameworks of all the countries involved were considered. For each country, a review was conducted on the corresponding designations of management responsibility for both the marine traffic and fishery sectors across multiple categories of jurisdictional waters (i.e., internal waters, territorial seas, and exclusive economic zones) and territorial units (see Supplementary methods, Appendix A). For example, in Spain, fishery management within internal waters is the responsibility of the regional authority (i.e., NUTS level 2), whereas the territorial sea is managed at the national level (i.e., NUTS level 0; see Supplementary Material, Appendix A, Table S1). Therefore, by linking each decision maker to its corresponding territorial unit of responsibility, it was possible to associate them to a given maritime jurisdiction. This information was incorporated into the spatial database, which also incorporated maritime jurisdictions based on criteria from UNCLOS [25] and downloaded from the Flanders Marine Institute [33].

Table 1
Number of stakeholder decision makers and other organisations included in the database. CFF (Commercial fishery federations); FAD (Fishery administrations); MTD (Marine traffic monitoring delegations); MTM (Marine traffic management organizations); “Area coverage (%)” refers to the percentage of study area covered by each national marine jurisdiction.

Country	Area coverage (%)	Other organisations		Decision makers		Total
		CFF	MTD	MTM	FAD	
Algeria	15	0	0	1	2	3
France	10	45	0	4	28	77
Gibraltar	<1	0	0	1	1	2
Italy	37	24	187	1	9	221
Monaco	<1	0	0	1	1	2
Morocco	2	0	0	1	9	10
Spain	31	102	47	1	8	158
Tunisia	4	1	0	1	9	11
Total		172	234	11	67	484

2.2.3. Spatial identification of stakeholders

To assess the sociopolitical framework and identify key stakeholders for a given protection zone (i.e., derived from a DOM application, as described in Section 2.3), two main spatial criteria were defined (Fig. 3). Decision makers were identified throughout the spatial overlap of the protection zone with the maritime jurisdictions and the governance structure incorporated into the database (Section 2.2.2). Other organizations were selected according to their proximity to the boundaries of the protection zone. In this study, we used a distance threshold (i.e., 100 km), that was large enough to ensure the selection of at least one stakeholder organization for each given protection zone.

2.3. Case studies

To illustrate the approach developed in this study, the dynamic assessment system was tested using simulated protection zones for two migratory pelagic species that are present in the Western Mediterranean, the Atlantic bluefin tuna (*Thunnus thynnus*), and the fin whale (*Balaenoptera physalus*). Our approach was tested separately for each species, and the results were compared. Habitat distribution models were used to

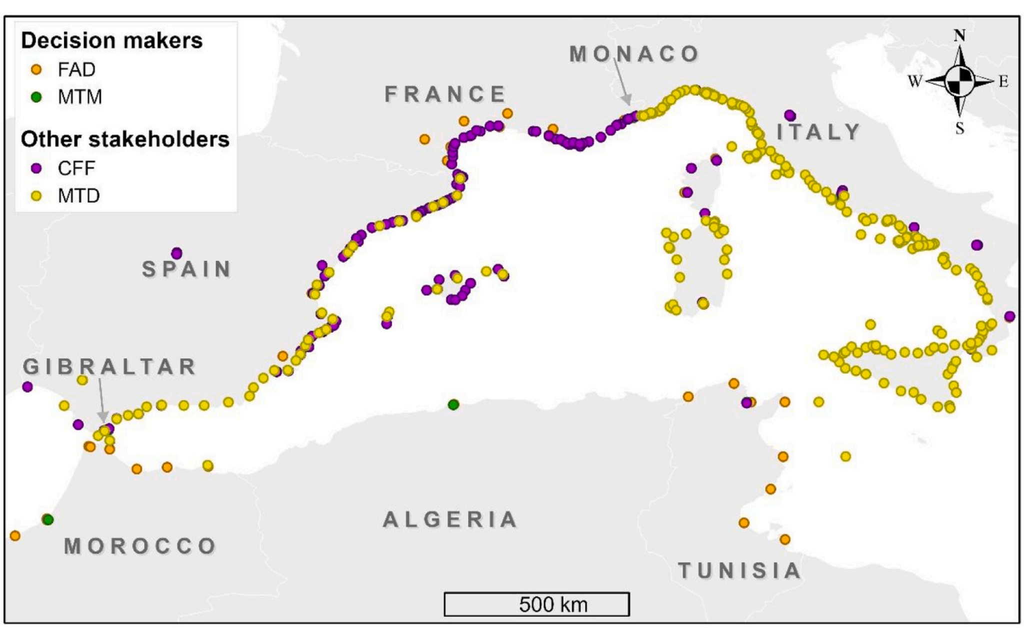

Fig. 2. Map of decision makers and other stakeholders included in the geodatabase. CFF (Commercial fishery federations, n = 172); FAD (Fishery administrations, n = 66); MTD (Marine traffic monitoring delegations, n = 234); MTM (Marine traffic management organizations, n = 12).

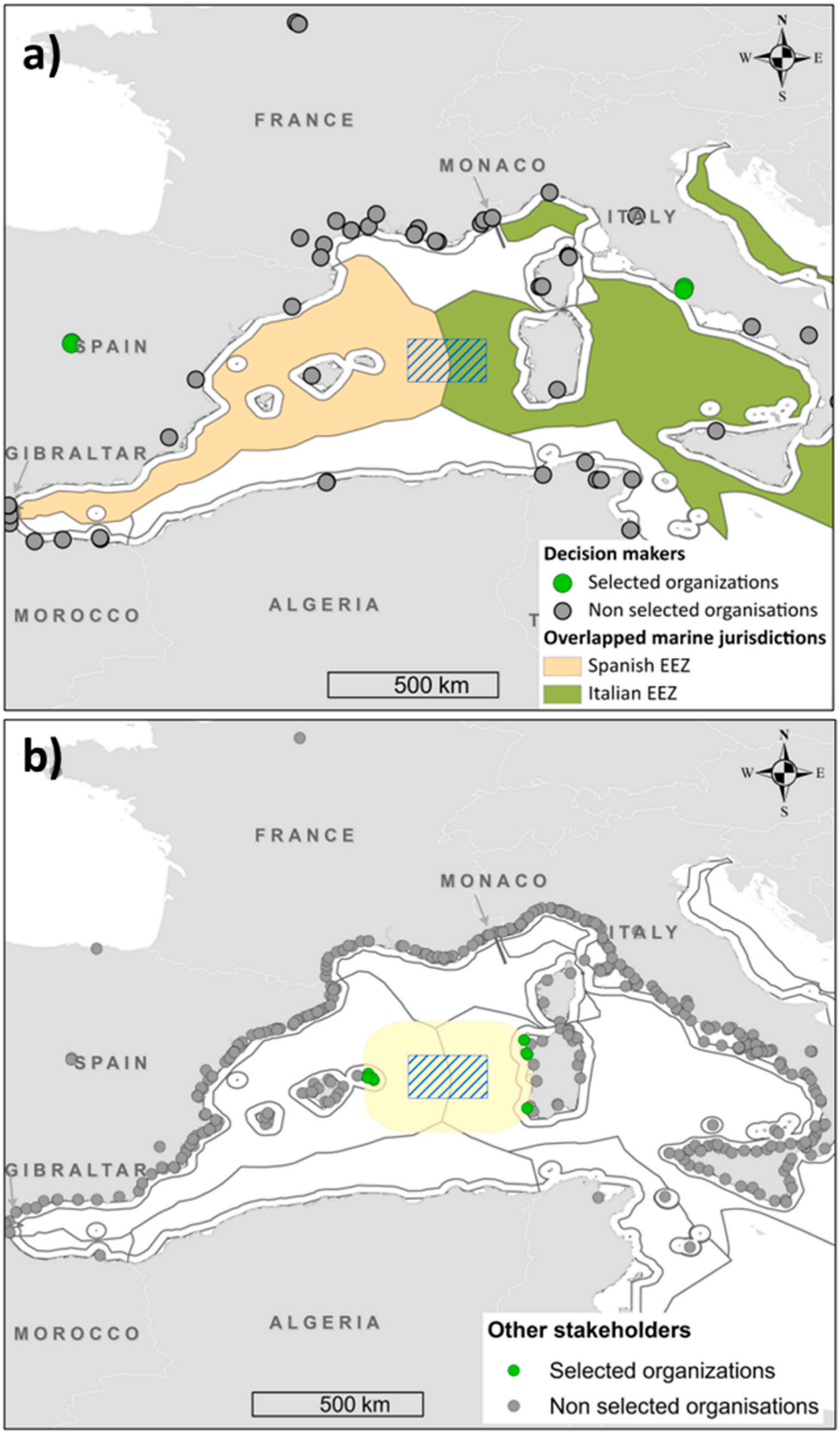

Fig. 3. Methods used to identify stakeholders. Example of selection of stakeholders for a given management area (blue rectangle): (a) selection of countries and responsible decision makers by spatial overlap of the management area with the jurisdictional waters. (b) selection of other organizations not responsible for decision making by proximity to the boundaries of the management area (i.e., 100 km threshold).

simulate hypothetical protection zones for each species on a monthly basis during the period 2003–2014.

For the Atlantic bluefin tuna, a spawning habitat model (for full details see Druon et al., 2011 [35], updated in Druon et al., 2016 [36]) was used during known months of occurrence in the Western Mediterranean (from May to July), whereas, for the fin whale, a feeding habitat model (for full details see Druon et al., 2012 [37], updated in Panigada et al., 2017 [38]) was used for all months. The spawning habitat of bluefin tuna was considered the most suitable target for a dynamic management strategy because the most impacting fishing operations (by purse seiners) target large aggregations of reproducing adults, and feeding habitats are mostly frequented by small schools of usually smaller individuals [36]. In the case of the fin whale, its year-round presence and feeding activity [37], as well as the year-round potential for negative interactions with marine traffic mandated an annual approach to management. Thus, each model provided monthly estimates of habitat suitability, ranging from 0 to 100, at a spatial resolution of approximately 4.6 km (1/24°). Habitat suitability hotspots were identified to delineate hypothetical management areas, and a bounding box around spatially coherent areas (i.e. areas larger than 10,000 km^2) was defined (see the example for bluefin tuna in Fig. 4). Habitat suitability hotspots were defined as the core area at the 90th percentile, all data pooled. Although this value can be substantially different across habitat types (e.g. feeding and spawning) and management objectives, we adopted the threshold at the 90th percentile value since it is commonly used to identify species distribution hotspots for conservation purposes [39–41].

For each management area, relevant stakeholders were identified using the dynamic assessment system presented in the previous section. We selected stakeholders related to the fishing sector for bluefin tuna, whereas organizations related to maritime traffic were screened for the fin whale. Finally, social network analysis methods were used to identify the key stakeholders in each case study [42]. The stakeholder network was created based on the co-occurrence of pairs of organizations across all simulated zones (i.e. the strength of the relationship was weighted by the number of co-occurrences). To assess the potential role of each stakeholder in the network, the betweenness centrality, a measure of centrality commonly used for stakeholder identification [43] was calculated using the "igraph" package in R [44]. Stakeholders with high betweenness centrality can enhance interaction and communication between stakeholders. In addition, a centralization score [42] was calculated for each stakeholder network at the global level based on betweenness centrality to assess the differences between case studies. The centralization score varies between 0 to 1. Its value is directly proportional to the centralization level of the network: a score of 1 corresponds to a highly centralized network, i.e., where a single stakeholder has a far greater number of connections with the others; and a score of 0 corresponds to a decentralized network, i.e., where all stakeholders are related directly to each other.

3. Results

3.1. Spatial database of stakeholders

The georeferenced database of stakeholders produced for the Western Mediterranean included 484 organizations (Fig. 2; Table 1; Supplementary Data). The number or proportion of organizations was uneven across countries. For example, in Spain, fishery organizations were extensively catalogued in publicly available sources, whereas in Italy, very few were reported and thus included in the geodatabase. The scarcity of public information related to the three African countries found in the Western Mediterranean was also revealed; 23 organizations were identified in Algeria, Morocco, and Tunisia (Table 1). In the case of Gibraltar and Monaco, only two organizations were identified for each country. The simplicity of the governance systems of the latter two countries can be ascribed to their relatively small sizes and human populations.

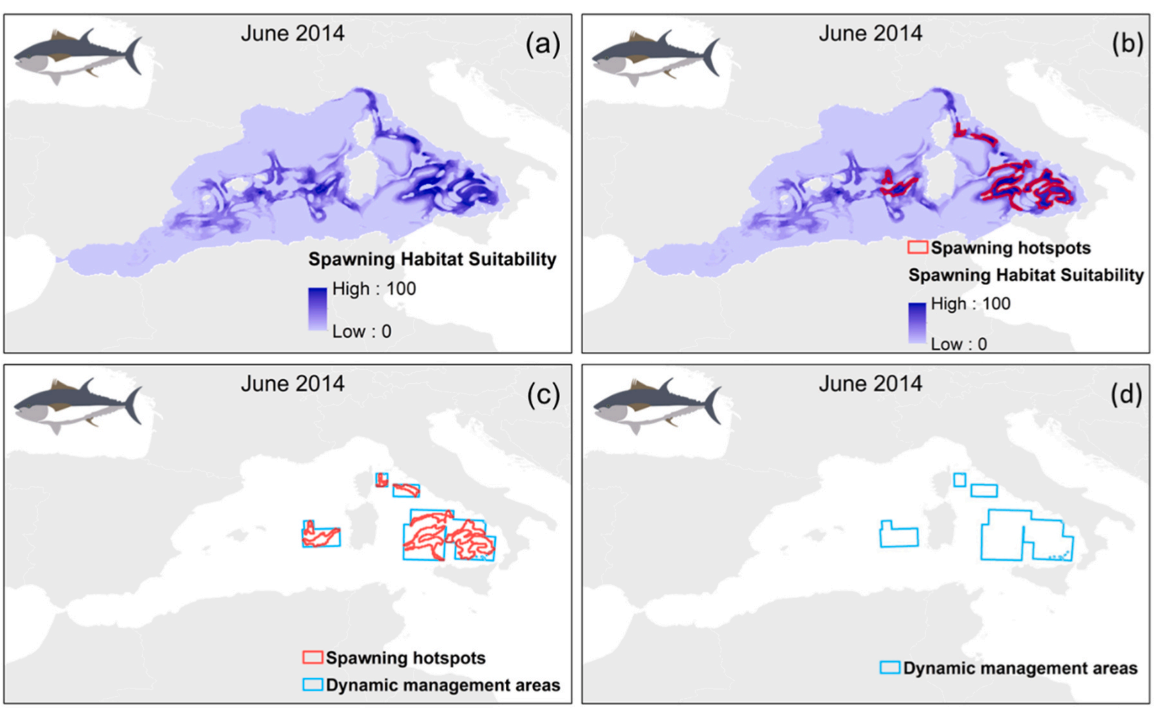

Fig. 4. Definition of dynamic management areas in a single month illustrated with the case study of bluefin tuna. Schematic representation of the main steps of the method adopted for the designation of dynamic management areas for a given month: (a) spawning habitat suitability map for bluefin tuna; (b) definition of habitat suitability hotspots (i.e. 90th percentile value in red); (c) definition of dynamic management areas as bounding boxes including habitat suitability hotspots (i.e. areas larger than 10,000 km); and (d) designed dynamic management areas.

3.2. Case studies

Hypothetically large management areas for bluefin tuna and fin whale were defined monthly, from 2003 to 2014. The management areas of the two species exhibited different spatiotemporal patterns in their annual distributions. Fin whale management areas were identified throughout all months, whereas bluefin tuna management areas were selected only during May, June, and July (i.e. the main spawning months in the western Mediterranean Sea). The extent and location of the management areas varied consistently between species. The management areas for bluefin tuna were mainly located within the Algerian Basin and Tyrrhenian Sea (Fig. 5a), whereas those for fin whale were

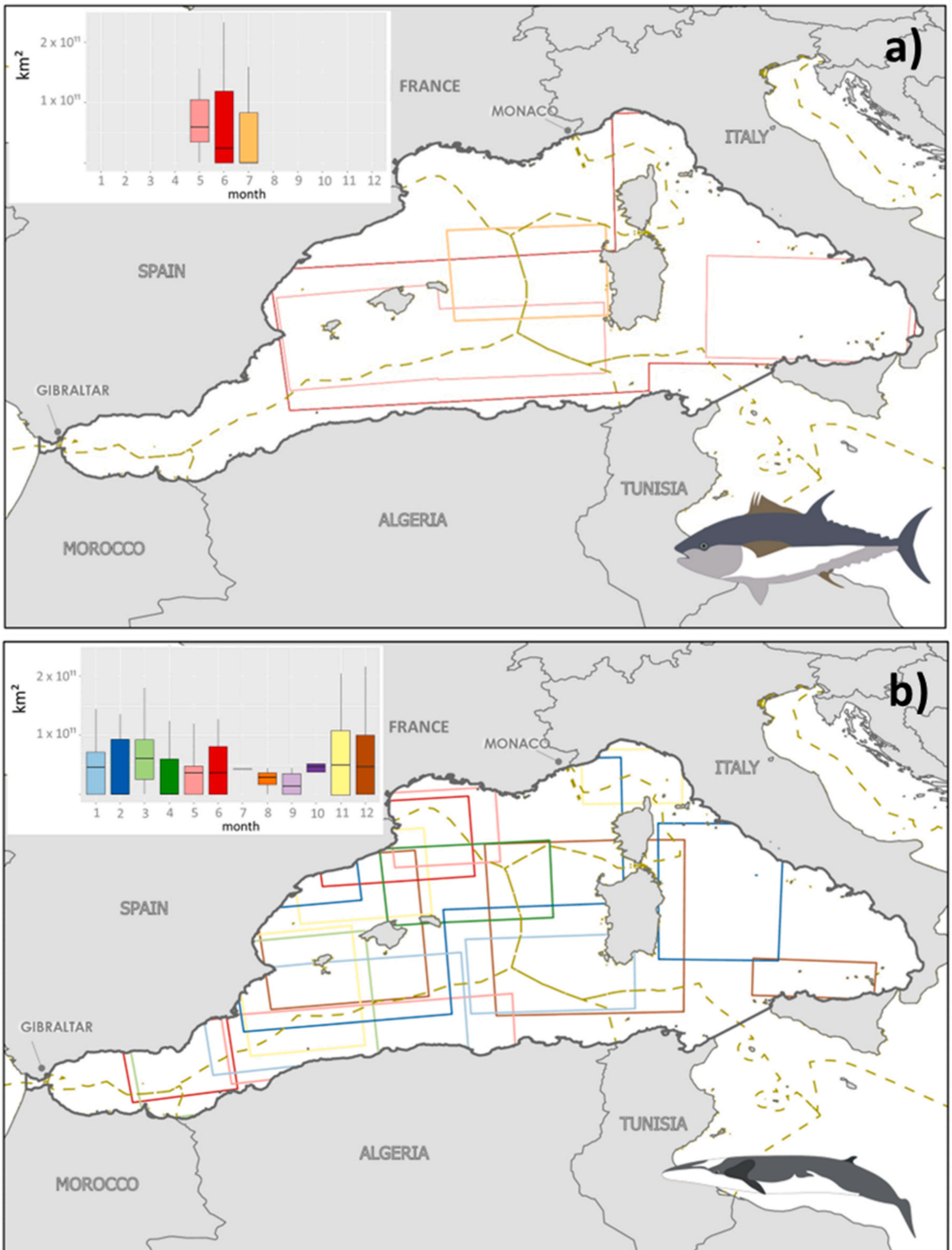

Fig. 5. Example of management areas (solid lines in different colours for each months) generated for one year (i.e. 2012) of simulations for (a) bluefin tuna, and (b) fin whale. The green dotted lines represent the EEZ for each country. The dark highlighted line corresponds to the study area used in the simulations. The inner panels with boxplots represent the monthly average extension of the management areas over the entire temporal series (2003–2014).

found in the northern region of the study area, with a higher concentration around the Pelagos Sanctuary (northeast of the western Mediterranean Sea, including Corsica, Fig. 5b).

This variability was reflected in the overlap with jurisdictional waters, with Italy and Spain showing the largest surface covered by management areas in both case studies (Fig. 6). The jurisdictional waters of some countries overlapped unevenly throughout the temporal series (e.g. France showed a high variability in bluefin tuna, Fig. 6). Inter-annual variability in the surface area covered by management areas was observed for each species. For instance, the negative anomaly of favorable spawning habitat of bluefin tuna in 2006 in the western Mediterranean (due to low sea surface temperature and height anomaly in spring) and the main remaining favorable ground north of Sicily led to only have Italy as management country with the lowest surface area of the time-series.

Finally, consistent differences were observed in the structure of stakeholder networks between decision makers and other organisations in the two case studies (Fig. 7). The network defined for bluefin tuna decision makers showed higher degree of centralization (0.38), suggesting that certain stakeholders could emerge as key actors. The other of the networks (decision makers for fin whale and other organisations for both species) presented a more decentralized structure, with low centralization values (range 0.01–0.03). In all cases, certain stakeholders, depicted as nodes with a central position and largest betweenness, exhibited high connectivity with others, indicating their potential key role in any management framework.

4. Discussion and conclusions

This work introduces the concept of the dynamic selection of stakeholders in maritime transboundary areas to contribute towards the stakeholder identification process in complex and changing management contexts. The adoption of an automated method for anticipating the selection of key actors among a large stakeholder network can support the implementation of dynamic ocean management, thus contributing to reducing potential conflicts among actors in complex systems [14], such as in the Mediterranean Sea.

In transboundary areas, key habitats and migratory paths of a specific species may overlap with the jurisdictional waters of several countries. The coordination and management of a large stakeholder network composed by a heterogeneous pool of marine users and administrative units from different countries might require consistent efforts from responsible authorities. The automated identification of relevant stakeholders has the potential to accelerate the process and increase its efficiency by providing easily accessible information on marine users, which should be prioritized and coordinated in the management of large marine zones. This is particularly advantageous for the implementation of a DOM strategy, where the stakeholder network could also differ dynamically, depending on spatiotemporal changes in the management zones.

This study identified consistent differences in the governance systems of coastal countries in the Western Mediterranean. Both decision makers and other organizations presented different structural systems across countries and sectors (i.e., maritime traffic and fisheries). Such heterogeneity may present an additional challenge to the coordination

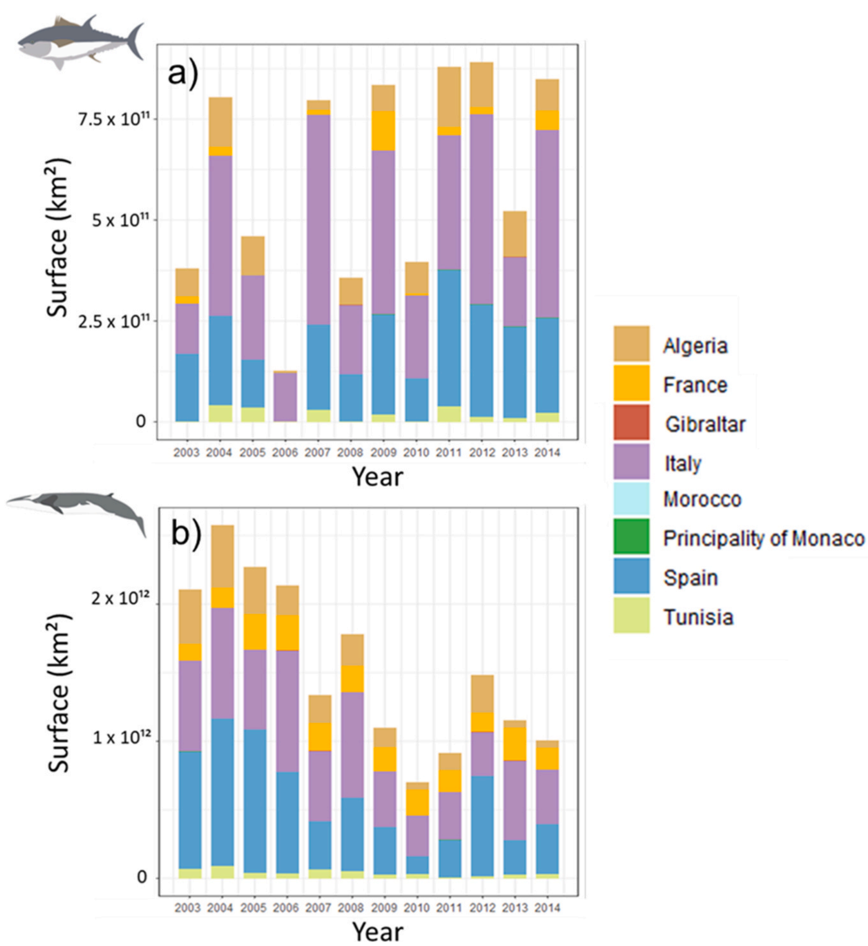

Fig. 6. Annual variation in the accumulated surface of the simulated management areas per country for fin whale (above) and Atlantic bluefin tuna (below). Note that the scale of the y-axis differs between the panels.

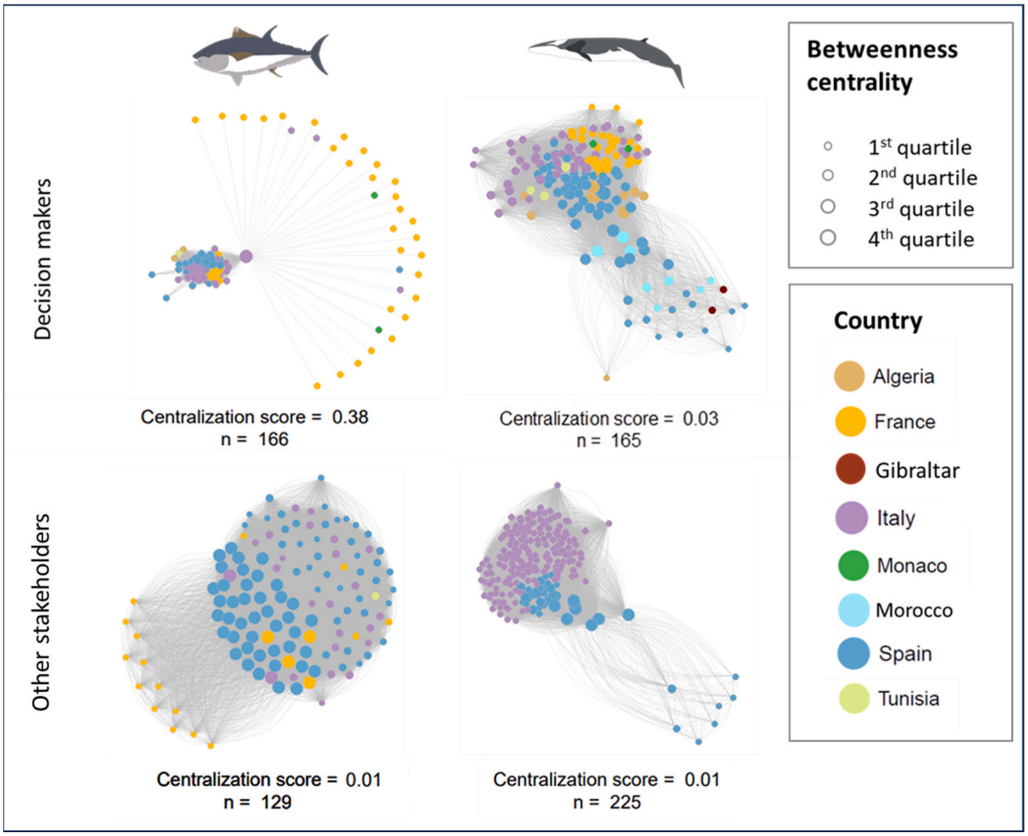

Fig. 7. Network of stakeholders identified for bluefin tuna (left) and fin whale (right) in the Western Mediterranean. Decision makers organizations were selected when their marine area of responsibility overlapped with the simulated management areas. Other organisations were selected within 100 km of the simulated management areas. Each node corresponds to a single stakeholder organization, which is colour-coded by country. The size of the nodes is proportional to the standardized betweenness centrality value of each organization within the stakeholder network. Nodes which share more connections are closer to each other. The network centralization score and number of stakeholders as the total number of nodes (n) are reported for each graph. Low stakeholder network centralization scores highlight widespread responsibility among marine users.

of stakeholders in transboundary areas. In particular, the fishing sector showed a heterogeneous and articulated governance structure that differed among countries. Additionally, the socioeconomic complexity and weakened governance system in the Mediterranean region [45] may threaten the success of DOM initiatives. To prevent this, a verification should be conducted to determine whether the organizations responsible for the management of a specific area are effectively operational, in line with their mandate. Overall, our work highlights the need to conduct an in-depth review of the governance structure of each country and sector to relate maritime jurisdictions with relevant stakeholders and assess the prevailing effectiveness of management and enforcement.

While this study summarizes the maritime traffic and fishing sector governance systems of the Western Mediterranean, the compilation of stakeholders was not exhaustive across countries and sectors. For example, maritime traffic monitoring delegations were identified only in Spain and Italy. This limitation resulted from the difficulty in obtaining comprehensive information through the review process using publicly available sources from other countries. Although further institutions might be involved at the local (e.g. marine protected area managers) and international levels (e.g., ICCAT, ACCOBAMS), we limited our analysis to a subset of national, regional, and local organizations. However, organizations operating at the local and international levels should be considered for the coordination of transboundary DOM strategies. Despite the incomplete nature of the geodatabase, this work demonstrates that automated identification of stakeholders, which was the focus of this study, is feasible. In fact, the geodatabase was designed as a flexible repository where additional stakeholders from other groups (e.g. environmental ministries, conservation agencies) and sectors (e.g. renewable energy, aquaculture) could be incorporated, depending on management goals and information availability. The present study highlights the absence of a comprehensive database of the Western Mediterranean Sea stakeholders and its potential usefulness for effective stakeholder identification for the management of transboundary areas in the region. Such a list of stakeholders should be made available for each regional sea as basic information for suitable management (e.g., European Seas for EU policies). International plans, conventions, and legal instruments are in place to support the sustainable management of the Mediterranean marine environment at the supranational level through an ecosystem-based, transboundary approach, especially the United Nations Environment Programme/Mediterranean Action Plan (UNEP/MAP) (1975) [46], the Barcelona Convention (1976) [47], the European Marine Strategy Framework Directive (2008) [32] and the Maritime Spatial Planning Directive (2014) [48].

Large transboundary areas for conservation prioritization have already been established in the Mediterranean, such as the Pelagos Sanctuary [49], and multiple Ecologically or Biologically Significant Marine Areas (EBSAs, based on the Convention on Biological Diversity). Despite the recognized importance of preserving species and ecosystems throughout these vast designated areas, there are still no static or dynamic management measures in place to achieve this. The application of DOM represents a potential strategy to increase the management effectiveness of marine resources in the Mediterranean Sea, such as highly mobile species with commercial or conservation interests (e.g., pelagic fish species, cetaceans, and sea turtles) that feed and reproduce within its waters [22].

Through a simulation exercise, the potential use of the dynamic assessment system was shown to identify stakeholders for a set of moving protection zones related to the conservation of the Atlantic bluefin tuna and the fin whale in the Western Mediterranean Sea. Consistent differences were found in the spatial and temporal variability of the simulated protection zones for the two species. This evidence suggests that DOM efforts might be calibrated depending on the species of interest. For instance, constant monitoring and coordination efforts should be maintained year-round for the fin whale. On the other hand, the management effort for protection might be temporally focused on a specific period of the year, such as spring for bluefin tuna (spawning) or summer for fin whale (population concentration in the northern area where the maritime traffic of passenger vessels and the associated collision risk intensify). Previous studies have addressed the potential of DOM to prevent bycatch in tuna fisheries [17,50], and mitigating marine traffic impacts on cetaceans, such as noise pollution and ship strikes [51]. These studies support the basis for considering DOM as a promising management strategy for highly mobile species, although recent studies have shown that, in some cases simpler static approaches demand less effort and resources from managers and may lead to more effective outcomes [52]. Overall, the aim of the simulation exercise conducted in this study was to provide hypothetical dynamic protection zones to test the applicability of the dynamic assessment system, and not to conduct a comprehensive assessment of the potential of DOM for both species (e.g., considering trade-offs between ecological and economic impacts). The selection of two highly mobile species allowed us to demonstrate the need for a transboundary approach. In particular, the results highlighted the complex geopolitical context of the Mediterranean Sea, where slight changes in moving protection zones may result in the involvement of different stakeholders. In addition, the simulations reflected the spatiotemporal variability in the presence of both species in the region. The variability in the boundaries of the protection areas was consequently reflected in the variability of the stakeholder network.

Network analysis is a valuable tool for stakeholder analysis [42]. However, different criteria should be considered when prioritizing stakeholders [53]. For example, stakeholders with high levels of power and influence, or stakeholders with an interest in bluefin tuna fisheries or fin whale conservation should be considered important, as they are more likely to support DOM. In the context of this study, we focused on network analysis because, unlike other criteria, it can be linked to the dynamic nature of DOM, thus reflecting the emerging patterns derived by moving marine zones. Overall, this study has shown that emerging stakeholder networks may depend on (1) management goals (e.g., target species), (2) maritime jurisdictions, and (3) the stakeholder and governance structure. The latter can vary between sectors (e.g., fisheries and marine traffic) and countries (e.g., administrative frameworks). The low centralization score of stakeholder networks highlighted that the prioritization of key stakeholders might be challenging, with responsibility consistently spreading over the network. Therefore, the application of inclusive approaches that consider all concerned actors may be critical for the successful management of marine spaces and resources in transboundary sea regions. Network analysis may help in resolving this prioritization challenge by allowing the classification of stakeholders based on betweenness centrality values. That is, stakeholders with higher betweenness centrality values (e.g. greater than the first percentile, as proposed by Paletto et al., 2015 [43]) can be classified as key stakeholders. Network betweenness centrality was used in this study as it constitutes a common metric for stakeholder network analysis [42] (. However, further studies might consider additional metrics (e.g. closeness centrality, eigenvector centrality) to assess stakeholder prioritization. Here, we analysed stakeholder networks by pooling a historical series of 12 years within a transboundary scenario. Further research could assess how stakeholder networks change dynamically across different temporal scales (e.g. months, years), potential governance transformations, and under future climate change scenarios.

The approach described here was illustrated by defining conservation targets based on a single species. Focusing DOM on flagship (or sentinel) species may be an effective solution for conserving multiple species and ecosystem compartments. However, the same system could be applied within the context of multiple species [54], where marine protection zones could be derived from the integration of a suite of several species (e.g. Hindell et al., 2020 [55]). A multispecies integrated management system should, however, be conducted by considering anthropogenic threats at species level (e.g., Maxwell et al., 2013 [56]). This study highlights the importance of selectively accounting for stakeholders that interact with the target species per sector (e.g., fishing organizations for bluefin tuna and maritime traffic for fin whale).

The inter-annual fluctuation in the extent covered by management areas for each species (Fig. 6) reflected the current variability of the suitability habitat models adopted in our study [36,37]. It is worth noting that the shifting habitats of the two species considered were obtained from suitability models that were found to accurately predict habitats, yet with some level of uncertainty. Thus, some potential habitats that were not realized may have been identified. This might be the case for fin whale at the entrance of the Mediterranean Sea, in the Alboran Sea, where intensive whaling occurred in the 1920 s [57], and it is only used today as a corridor despite favourable foraging conditions, and may thus correspond to habitat loss due to maritime traffic-induced chronic noise, a threat that was exposed in Notarbartolo di Sciara et al. [58].

While the simulation exercise focused on a historical long-term dataset, the dynamic assessment system could also be used in near-real time forecast systems or in future scenarios (e.g., under climate change) to rapidly detect or anticipate potential shifts in the stakeholder network. This would facilitate and accelerate managers in the process of stakeholder identification over large transboundary marine areas and accelerate the coordination process. Moreover, automated systems for stakeholder identification could be integrated within a broader scope of marine spatial planning practices to address multiple purposes and enhance their efficiency. It can support the identification of stakeholders that spatially interact with biological features, such as the approach proposed in this study, as well as with other human uses, especially those with high spatiotemporal variability.

We make four major recommendations to support DOM in transboundary contexts:

1) An in-depth review of governance structures and coordination frameworks of relevant sectors is needed to relate maritime jurisdictions to concerned stakeholders.
2) Publicly available repositories should be made available to provide comprehensive and centralized lists of stakeholder organizations to sustain regional coordination.
3) Highly suitable institutions, such as international organizations operating at the regional level, should be engaged to coordinate transboundary DOM strategies.
4) Large stakeholder communities, although within a prioritization process, may have to be involved in ensuring effective transboundary management.

The management of marine resources in large transboundary areas is challenging, and should rely on innovative approaches to favour fairness and acceptance. This is why DOM cannot be neglected in complex contexts such as the Western Mediterranean Sea. An approach such as the one proposed here is fundamental for achieving effective coordination and management in transboundary contexts.

CRediT authorship contribution statement

Federico Fabbri: Investigation, Formal analysis, Software, Writing - Original Draft. **Jean-Noël Druon**: Writing - Review & Editing. **Brendan J Godley**: Writing - Review & Editing. **David March**: Conceptualization, Methodology, Writing - Review & Editing, Supervision.

Data availability

Stakeholder database is available from Zenodo (https://zenodo.org/doi/10.5281/zenodo.10623986). R code is available from Github at https://github.com/fedefabbri/DOM_WestMed and https://doi.org/10.5281/zenodo.10624748.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.marpol.2024.106035.

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