Addressing transboundary conservation challenges through marine spatial prioritization

Abstract

The Adriatic and Ionian Region (AIR) is an important area for both strategic maritime development and biodiversity conservation in the European Union (EU). However, given that both EU and non-EU countries border the sea, multiple legal and regulatory frameworks operate at different scales which can hinder the coordinated long-term sustainable development of the region. Transboundary marine (or maritime) spatial planning can help overcome these challenges by building consensus on planning objectives and making the trade-offs between biodiversity conservation and its influence on economically important sectors more explicit. We approach this challenge by developing and testing four spatial prioritization strategies, using the decision-support tool Marxan, which meets targets for biodiversity conservation whilst minimizing impacts to users. We evaluate these strategies in terms of how priority areas shift under different scales of target-setting (e.g. regional versus country-level). We also examine the trade-off between cost-efficiency and how equally solutions represent countries and maritime industries (N=14) operating in the region using the Protection Equality metric. We show that there are negligible differences in where priority conservation areas are located when we set targets for biodiversity at the regional versus country scale. Conversely, the prospective impacts on industries, when considered as costs to be minimized, are highly divergent across scenarios and bias the placement of protection towards industries located in isolation or with few other industries. We conclude by making several recommendations to underpin future MSP efforts in the region, including the identification of: 1) areas of national significance, 2) transboundary areas requiring cooperation between countries, and 3) areas where impacts on maritime industries require careful consideration of the trade-off between biodiversity conservation and socio-economic objectives.

Introduction

Marine or maritime spatial planning (MSP) has been widely accepted as a powerful tool for ecosystem based management of coastal and ocean resources (Ehler 2008; Mcleod et al. 2005; UNEP 2011). The European experience with MSP has evolved from the development of a thematic strategy on the conservation of the marine environment adopted by the European Commission (EC) in 2005, to the European Framework Directive on Maritime Spatial Planning (2014/89/EC) in 2014 (EC 2014a). Several European countries have now developed marine spatial plans, notably Belgium and the Netherlands, however these plans often lack coordination beyond borders (Douvere & Ehler, 2009).

The Adriatic-Ionian Region (AIR) is an important maritime region for Europe and provides a challenging case study for the identification of a basin-wide MSP strategy, specifically due to the differences in capacities between the east and west (Brussels, COM(2012) 713 final, EC 2012)). The current EU Integrated Maritime Policy specifically recognises the importance of cooperation at the sea-basin level, and suggests that the best results will be achieved through developing MSP at national and cross-border levels. The role of MSP as a framework for coordinating sectors and countries across EU policies has carried over into existing AIR initiatives, such as the Maritime Strategy for the Adriatic and Ionian Sea (EC 2012). The European Union Strategy for the Adriatic Ionian Region (EUSAIR, EC 2014b) has four main pillars: blue growth, connecting the region, environmental quality, and sustainable tourism (EC 2014b). Targets for sustainable development of maritime sectors include the expansion of aquaculture, fisheries, maritime transport, coastal tourism, energy and other maritime activities (EC 2014c). Additionally, given the AIR is is a Mediterranean biodiversity hotspot (Coll et al. 2010; Fraschetti et al. 2011), the region is also subject to several independent biodiversity conservation initiatives (such as EBSAs, Micheli et al. 2013), complicating the multi-level governance of the region.

Despite the significant EU investment in MSP-related projects in regions, including SHAPE (http://www.shape-ipaproject.eu/), AdriPLAN (http://adriplan.eu/), Adriatic Plus (http://www.adriaticplusplatform.eu) and SUPREME (http://www.msp-supreme.eu/) to name a few, strategies for MSP remain largely uncoordinated (Barbanti et al. 2015; Piante & Ody 2015) with competition between sector-oriented governments. While EU member states have been called to integrate their maritime spatial plans into a transboundary approach by year 2020 (EC, 2014d) there is no clear direction on how to put this into practice. The aim of this work is to demonstrate how to simplify the highly dynamic, multi-actor, multi-scalar, multi-national challenge of developing a strategic transboundary MSP framework for the AIR using a marine spatial conservation prioritization approach.

The identification of spatial conservation priorities provides a starting platform to engage with stakeholders, industries and policy-makers about balancing natural resource management and sectorial development through a transparent and well established method (e.g. Fernandes et al. 2005; Jumin et al. 2017). Spatial conservation prioritization is the process of analyzing quantitative data to identify locations for conservation investments (Wilson et al. 2009). Maps of priority areas can be used to broker negotiations about conservation actions and their associated costs for countries (Mazor et al. 2013; Beger et al. 2015) and/or industries (Carwardine et al. 2008; Klein et al. 2008; Giakoumi et al. 2013). Prioritization activities assist with building consensus on planning objectives and examining trade-offs that are essential to understand the costs of alternative plans in relation to different conservation outcomes (Beger et al. 2015; Brown et al. 2015; Di Fonzo et al. 2017). Conservation prioritisation, embedded into broader MSP, has been shown to lead to more durable outcomes than site-specific planning of marine protected areas or other biodiversity conservation measures (Agardy et al. 2011; Mazor et al. 2013, Beger et al. 2015).

Here, we consider spatial conservation prioritisation as a ‘purposeful problem-solving tool’ (sensu Starfield, 1997) to facilitate discussion, collaboration and catalyse the development of a regional approach to MSP in the AIR. We use the spatial decision-support tool Marxan, which aims to meet targets for conservation features (e.g. habitats, species, ecoregions, etc) whilst minimizing the socio-economic costs of the intended conservation action (e.g. establishing marine protected areas (MPAs)). Given no prioritization framework exists in the region, we seek to answer to two specific questions: 1) How does setting targets for biodiversity across the AIR or within individual countries influence planning outcomes? and 2) How does including data on the distribution of maritime industries and activities - as a cost to be minimized, influence the selection of priority conservation areas? We evaluate solutions based on the trade-offs between their cost-efficiency as well as how they impact countries and industries as defined by the Protection Equality metric (Chauvenet et al. 2017). We identify priority conservation areas to promote future discussions with key stakeholders and conclude by encouraging the adoption of systematic approaches and decision support tools to inform MSP processes in the region.

Methods

We used the systematic decision support tool Marxan to identify priority conservation areas in the AIR (Ball & Possingham 2000; Possingham et al. 2000). Marxan meets predefined conservation targets and minimizes costs to resource users (Possingham et al. 2001; Wilson et al. 2007; Ban et al. 2009). We constructed a 10 x 10 km planning grid of 3,366 units covering the entire maritime area of the AIR (Pfeifer 2011; INSPIRE CRFGGS 2010). Our conservation features were sourced from the ADRIPLAN data portal (source: data.adriplan.eu, Barbanti et al. 2015) and included: 31 seabed habitats (EUNIS classification, EEA 2012); 14 spawning sites and 16 recruitment habitats for important fish species; and the distributions of seven mapped species groups, namely sea turtles, dolphins, whales, monk seals, giant devil rays, seabirds and white corals (Table S1, Supporting Information).

We treated cost in two different ways, using common proxies: 1) we used the area of each planning unit as the baseline cost, meaning targets are met with the smallest possible spatial footprint, and 2) we used the number of maritime industries occurring within each planning unit as a proxy for the transaction costs of negotiating biodiversity protection in each unit (e.g. the more industries, the higher cost to conserve) (Figure S1, Supporting Information). For the later treatment, we included the distributions of 14 industrial sectors and activities, hereafter “industries” as mapped by ADRIPLAN: aquaculture, coastal and maritime tourism, coastal defence works, dumping area for dredging, liquefied natural gas offshore terminals, maritime transport, military areas, naval based activities, off-shore sand deposit, oil and gas extraction, oil and gas research, renewable energy facilities, small scale fisheries, commercial fishery (Table S2 and Table S3, Supporting Information). We assumed that all maritime industries have equal standing in the negotiation process. We ran Marxan 100 times per scenario and did not aggregate planning units.

Scenarios

We constructed four planning scenarios by varying the geographical scope at which conservation targets were set in combination with the two treatments of cost described above (Table 1). We applied conservation targets at two scales: 1) for the distributions of features across the entire AIR; and 2) for each feature’s distribution found inside the jurisdiction of AIR countries (Albania (AL), Croatia (HR), Greece (GR), Italy (IT), Montenegro (MT), Slovenia (SL))(Table S4, Figure S2, Supporting Information). The disputed marine waters between Croatia and Slovenia (Disputed Area, DA) were considered as an independent geographical area.

Two different targets were set according to the characteristics, extent and resolution of the conservation features. For features categorised as “endangered” according to the IUCN red list of threatened species (IUCN 2016), or identified as high priorities for conservation by the European Directive 92/43/EEC on the conservation of natural habitats and of wild fauna and flora (Annex II, EC 1992), we set targets of 30% of the distribution of the conservation feature. This value is in line with the 2030 targets recently launched by the IUCN World Conservation Congress in Hawaii (2016). For conservation features with large distributions throughout the AIR (> 5000 km^2), we used the 10% target outlined by Aichi Target 11 (CBD, source: https://www.cbd.int/sp/targets/).

[Table 1]

Marxan generates two different outputs which we used to evaluate our scenarios: solutions – which are the spatial configurations of selected planning units from each run; and the selection frequency - the amount of times a planning unit is selected across all runs (maximum = 100). The higher the selection frequency of a planning unit, the higher priority it is for achieving a scenario's objectives. We used the selection frequency to analyze how priority areas for conservation shift between the four scenarios (Carwardine et al. 2007; Giakoumi et al. 2013). We also analyzed scenarios using the proportional Protection Equality (PE_P) metric (Chauvenet et al. 2017). PE_P evaluates how equally represented features are in a conservation plan (Kuempel et al. 2016). PE_P ranges between 0 (highly unequal) to 1 (perfect equality). We calculated PE_P based on the proportion of AIR countries' jurisdiction (Mosetti and Lipizer, 2014) and the distribution of each maritime industry captured in solutions for each scenario using the R package "ProtectEqual" (Chauvenet et al. 2017). We then examined the trade-off between mean PE_P and mean cost of the top 10% of solutions for each scenario (Beger et al. 2015). Lastly, we evaluated how considering industries as costs influenced conservation priorities (defined by selection frequency) by analyzing their patterns of co-occurrence within planning units and the cost of those units.

Results

Priority areas for conservation

We discovered that the distribution of priority areas for conservation (i.e., the planning units with highest selection frequency) varied significantly across our four scenarios (Fig. 1). When cost was assigned as the area of the planning units, regardless of the target-setting strategy, solutions were very flexible, with almost 98% of the AIR included at some point (Fig. 1a,1c). When we accounted for industries operating in the AIR by including them as a cost (Scenario 1b, 2b), the resulting solutions became more spatially decisive and 25% of the AIR was never selected (Fig. 1b,1d). When we accounted for industry costs, the results identified priority areas around the presence of spatially constrained biodiversity features. These areas include: the central areas of the Northern Adriatic that are spawning areas of *Mullus barbatus* (Red mullet); the central Adriatic between Italy and Croatia as the preferential presence of *Eledone cirrhosa* (Horned octopus) and the spawning ground of *Nephrops norvegicus* (Norway lobster); the coastal areas of Albania host *Aristaeomorpha foliacea* (Giant red shrimp) spawning and recruits and *Galeus melastomus* (Blackmouth catshark) recruits; and, the coastal areas of Greece with the exclusive presence of monk seals and whales as well sea turtles nesting sites and *Raja clavata* (Thornback ray) spawners.

[Figure 1]

When we examined the selection frequency by country across our scenarios, we saw similar patterns of flexibility for scenarios when costs were considered as area. When variable industry costs were considered, the number of planning units with higher importance for conservation (i.e., higher selection frequency) increased. The percentage of the AIR with a selection frequency in the highest quartile increased from 0.45% (scenario 1a) to 5.47% (scenario 1b), and from 0.86% (scenario 2a) to 5.7% (scenario 2b) (Figure S3, Supporting Information).

The influence of regional vs national target setting

When conservation targets are assigned by country, the number of features in the analysis grows from 70 to 263 (Table 1; Table S4, Supporting Information). This had little influence on the area of the conservation footprint required to meet these additional targets in the best solutions (with an average of 16.8% of the area in the AIR for scenario 1a, 17.1% for scenario 2a, 18.3% for scenario 1b, and 19.1% for scenario 2b, Table S5, Supporting Information). The greatest impact of setting targets at the national level occurred when industry costs were also included (Scenario 2b). This increased the total cost of the network by 20% with a marginal increase in total area compared to setting targets across the AIR (Scenario 1b).

Protection equality across countries and industries

Country-level protection equality values ranged between 0.83-0.85 across scenarios. Industry-level protection equality varied between 0.63 and 0.69. Planning at the national level and using area as the cost of a planning unit (Scenario 2a) was the worst performing scenario in terms of cost-efficiency (determined by highest mean costs) (Fig. 2a,b). Planning at the regional scale and accounting for industry costs (Scenario 1b) was the worst performing in terms of PE_P for both countries and industries, despite delivering the most cost-efficient plans. Interestingly, considering area as a cost performed the best for PE_P across industries of any scenario tested (Scenario 1a and 2a, Fig. 2b).

[Figure 2]

Spatial patterns of maritime sectors

We examined the spatial relationships between the 14 industries by analyzing the frequency of occurrence of each industry in the planning units and the subsequent cost of those planning units

(Fig. 3). This allows us to understand which industries are frequently co-located with others, and therefore incur a higher cost to protect. Those industries commonly co-occuring with others are: maritime transport, oil and gas extraction, oil and gas research, and commercial fishing. In the AIR, aquaculture, coastal defense works, coastal and maritime tourism, naval-based activities and small scale fisheries typically occupy cells with few other activities and therefore reflect lower costs (Figure S3, Supporting Information).

[Figure 3]

Identifying priorities for transboundary MSP

For further discussion, we emphasize the results of Scenario 1b, which considered planning at the regional scale because it is the most cost-efficient scenario in achieving conservation targets and, importantly, includes industry costs. We constructed Fig. 4 to identify those places emerging as conservation priorities which are transboundary and under national jurisdiction.

[Figure 4]

Discussion

Under the objectives of the EUSAIR, MSP processes are underway to balance maritime development with biodiversity objectives (EC 2014b), yet coordination across jurisdictions remains a major challenge. We demonstrate how decision –support tools can help harmonize the needs of both nature conservation and maritime industries within the complex AIR seascape through spatial conservation prioritization.

Costs are more critical than the target setting strategy

We expected that setting targets for biodiversity at the country-level would significantly increase the total area required to meet conservation objectives due to the increasing number of features (Table 1), but instead discovered this had a negligible effect on the spatial footprint of the solutions. However, the inclusion of an industry-driven cost significantly influenced where priority areas were best located across the AIR. The areas selected as highest priority for biodiversity trended towards the lower cost areas (e.g. coastal areas in the North-Eastern AIR where the number of industries is fewer). In some places, such as in the central Adriatic, priorities also occurred in areas of high cost for important fisheries features such as *Illex coindetii* (Broadtail shortfin squid) and *Nephrops norvegicus* (Norway lobster) recruits and spawning areas, *Merluccius merluccius* (European hake) recruits, and *Eledone cirrhosa* (Horned octopus) spawning areas.

The inclusion of costs is essential to deliver conservation plans that are efficient and feasible. Ignoring other users of the sea is unlikely to deliver politically acceptable plans, nor lead to holistic ecosystem-based management (Ban et al. 2009, 2013; Carwardine et al. 2008, 2010; Cheok et al. 2016; UNEP 2011). However, spatially-explicit data on costs at regional scales rarely exist, hence proxies are often used. In this study, we considered the number of industries operating in a planning unit as a proxy for the transaction cost of protecting a site. While our proxy for cost was rather coarse, we demonstrate that the way costs are considered in conservation planning scenarios will impact maritime industries operating in the AIR in different ways. These findings could thus be used to promote awareness across sectors and engage industries in the planning process (Flannery & Cinnéide 2008; Pomeroy & Douvere 2008; Olsen et al. 2014).

Trade-offs across maritime sectors need to be explicit

Understanding trade-offs is an essential component of spatial conservation prioritization and can greatly influence planning success (Berkes 2004; Solar & Irwin 2007; Halpern et al. 2013; Klein et al. 2015). Through the protection equality metric we found that countries maintained a high level of equality regardless of the scenario (Fig. 2a), but protection equality across industries was significantly lower (Fig. 2b) and more variable across scenarios. This can be partially explained by our construction of the industry cost proxy and its use in the Marxan objective function. Marxan aims to minimize the overall cost of spatial plans, which consists of the sum of costs of the selected planning units. We considered the number of industries operating in a cell to reflect a higher cost to conserve that cell. Due to this, industries that are less often co-located with other industries will be disadvantaged, as these industries have more of their areas selected for conservation when they overlap with biodiversity features because the total cost of those cells is lower. This in turn reduces the protection equality performance across industries. The method of including costs has significant implications for evaluating trade-offs that are critical to decision-making and their treatment should be carefully considered.

Limitations

Spatial conservation prioritization requires several key decisions about data, scale, and costs that affect the planning outputs and which should be made explicit. In this study, we used conservation features based on the best available data for the AIR provided by Adriplan. This dataset suffers from some uncertainties and limited coverage, especially regarding marine mammals and giant devil rays in the Ionian Sea, and the deep sea (Gissi et al. 2017).

The size of the planning unit also influences outcomes. We used a planning unit size of 10x10 km, having selected this resolution because it represents a reasonable scale for regional decision-making. However, we acknowledge that this scale affects our analysis for countries with small marine jurisdictions, such as Slovenia (174 km^2 represented by 4 planning units), and the disputed area between Croatia and Slovenia (646 km^2 represented by 6 planning units). For example, when we set explicit targets for these areas (scenarios 2a and 2b), the entire jurisdiction emerges as a conservation priority due to how the planning unit scale interacts with the targets set (Cheok et al. 2016). We note we did not consider the contribution of these areas in the protection equality analysis as it would bias the results.

Finally, there are the important considerations regarding how to incorporate costs. Ban et al. (2009) recommend testing several approaches, which could include different types of costs (e.g. opportunity costs, enforcement capacity, etc. (Carwardine et al. 2008; Arafeh-Dalmau et al. 2017)). We did by using both the area of the planning units and the number of industries in a planning unit as a proxy for the transaction cost of conserving a site. While this is an estimate based on available data, we note that important cost considerations for future planning should pursue estimates of profitability, intensity of uses, or impacts on conservation features (Gissi et al. 2017), rather than just the distributions of industries across the AIR. Weighting industries by their relative importance is also an option, but this introduces a level subjectivity that must be carefully examined (Game et al. 2013).

Recommendations for the future

Our analysis illustrates how strategic spatial conservation prioritization can cost-effectively identify: areas of national significance and transboundary areas requiring cooperation between countries for biodiversity conservation; and explicitly account for the impacts to different maritime industries (Figure 4). Importantly, we demonstrate how conservation objectives for the AIR can be achieved from the joint contribution of both areas of national significance and strategic transboundary areas.

Regarding areas of national significance, there are several conservation features that predominately fall under the jurisdiction of individual countries. These include maerl beds in Italy, Slovenia and Croatia, and Cymodocea beds in Italy; nursery areas for *Merluccius merluccius* (European hake) spawners in Croatia, *Raja clavata* (Thornback ray) spawners in Greece, *Scomber scombrus* (Atlantic mackerel) and *Solea solea* (Common sole) recruits in Italy, whales and monk seal habitats in Greece. However, many conservation priorities are located in transboundary areas and will require collaboration across governments. In particular these include: areas in the Northern Adriatic between Italy, Slovenia and Croatia for the common bottlenose dolphin (*Tursiops* *truncatus*) and the loggerhead sea turtle (*Caretta caretta*); the Central Adriatic for nursery habitats of *Eledone cirrhosa* (horned octopus) spawners, and *Nephrops norvegicus* (Norway lobster) spawners and recruits among others; and the areas between the Southern Adriatic and Northern Ionian Seas for *Aristaeomorpha foliacea* (Giant red shrimp) spawners and recruits, and *Galeus melastomus* (Blackmouth catshark) recruits (Table S7, Supporting Information).

Transboundary conservation requires cooperation between countries while managing the impacts on industries requires strategic discussions with these key stakeholders. For example, commercial fishing and maritime transport sectors co-occur in many priority areas for conservation (Fig. 4). Given the influence of these industries in the AIR, a critical future priority for addressing transboundary MSP in the region is to acquire better spatial data across maritime industries so that more accurate evaluations of trade-offs can be made. Another useful application of these data could be for incorporating more sophisticated zoning in the AIR, potentially with Marxan with Zones analysis (Watts et al. 2009). This can build on the work we present, but with additional socio-economic objectives for maritime industries alongside biodiversity conservation. For example, this could ensure that no industry loses more than certain percentage of their annual income when zoning for protected areas (Jumin et al. 2017, Klein et al. 2008).

Our study operates in an area where individual countries do not yet have MSP processes implemented, or even approved, but where there is an expectation of collaboration and expediency according to the EU directive on MSP 2014/89/EC (EC, 2014a). It is our recommendation that MSP be considered as the cross-cutting framework that could be used to integrate the priorities of the four pillars of the EUSAIR. However, the choice of method used to develop MSP in this this region has significant implications for both the countries and the maritime sectors. Indeed, we showed that achieving targets for biodiversity conservation in the AIR by simply adding the conservation efforts of individual countries, without coordination, will not be cost-efficient nor equitable for maritime industries or biodiversity (see also Mackelworth 2012). As such investment should be made to ensure that the MSP process is open and transparent not only to the countries involved but the industries operating in the region. We strongly emphasize that the governance process should adopt systematic approaches, such as spatial conservation prioritization and the use of decision support tools, as demonstrated here, to achieve transboundary MSP objectives in the future.

Supporting Information

Information on conservation features considered in the study for the AIR (Table S1); Costs surface representing the sum of the area of industries per each planning unit (Figure S1); Maritime industries included as a proxy of transaction costs for conservation (Table S2); Data availability of maritime industries (Table S3); Stratification of conservation features per country used in scenarios 2a and 2b (Table S4); Maritime jurisdictions in the Adriatic and Ionian Region (Figure S2); Selection frequency per country under the 4 scenarios (Figure S3); Area of the conservation footprint for the 10 best solutions under the 4 scenarios (Table S5); Distribution of Planning Units (PUs) per combination of uses (Figure S4); Description of key conservation features and maritime industries per priority areas under scenario 1b, where targets are set at regional scale and transaction costs are incorporated (Table S6) are available online. The authors are solely responsible for the content and functionality of these materials. Queries (other than absence of the material) should be directed to the corresponding author.

Literature cited

Agardy T, G. Notarbartolo di Sciara and P. Christie. 2011. Mind the gap: Addressing the shortcomings of marine protected areas through large scale marine spatial planning. Marine Policy **35 (2):** 226-232

Arafeh-Dalmau N, Torres-Moye G, Seingier G, Montaño-Moctezuma G, Micheli F. 2017. Marine Spatial Planning in a Transboundary Context: Linking Baja California with California's Network of Marine Protected Areas. Frontiers in Marine Science 4:150. doi: 10.3389/fmars.2017.00150.

Auerbach NA, Tulloch AIT, Possingham HP. 2014. Informed actions: where to cost effectively manage multiple threats to species to maximize return on investment. Ecological Applications, **24:**1357-1373. DOI:10.1890/13-0711.1.

Ball IR, Possingham H. Marxan (V1.8.2): marine reserve design using spatially explicit annealing, a manual. 2000.

Ban NC, Hansen GJA, Jones M, Vincent ACJ. 2009. Systematic marine conservation planning in data-poor regions: socioeconomic data is essential. Marine Policy, **33:**794–800.

Ban NC et al. 2013. A social–ecological approach to conservation planning: embedding social considerations. Frontiers in Ecology and the Environment, **11(4):**194-202.

Barbanti A, Campostrini P, Musco F, Sarretta A, Gissi E editors. 2015. Developing a Maritime Spatial Plan for the Adriatic-Ionian Region. CNR-ISMAR, Venice, Italy.

Barr LM, Pressey RL, Fuller RA, Segan DB, McDonald-Madden E, Possingham HP. 2011. A New Way to Measure the World's Protected Area Coverage. PLoS ONE. 6(9):e24707. pmid:21957458

Beger M, McGowan J, Treml EA, Green AL, White AT, Wolff NH, Klein CJ, Mumby PJ, Possingham HP. 2015. Integrating regional conservation priorities for multiple objectives into national policy. Nature communications **6** DOI:10.1038/ncomms9208.

Berkes F. 2004. Rethinking community-based conservation. Conservation biology **18(3):**621-630.

Brown C, Bode M, Venter O, Barnes MD, McGowan J, Runge C, Watson JEM, Possingham HP. 2015. Effective conservation requires clear objectives and prioritising actions, not places or species. Proceedings of the National Academy of Sciences of the United States of America **112(32)**:E4342.

Carwardine J et al. 2007. Conservation planning with irreplaceability: does the method matter?. Biodiversity and Conservation **16:**245–58.

Carwardine J, Wilson KA, Watts M, Etter A, Klein CJ, Possingham HP. 2008. Avoiding costly conservation mistakes: the importance of defining actions and costs in spatial priority setting. PLoS One (e2586) DOI: 10.1371/journal.pone.0002586.

Carwardine J, Wilson KA, Hajkowicz SA, Smith RJ, Klein CJ, Watts M, Possingham HP. 2010. Conservation planning when costs are uncertain. Conservation Biology **24(6)**:1529-1537.

Chauvenet AL, Kuempel CD, McGowan J, Beger M, Possingham HP. 2017. Methods for calculating Protection Equality for conservation planning. PloS One (e0171591) DOI: 10.1371/journal.pone.0171591

Cheok J, Pressey RL, Weeks R, Andréfouët S, Moloney J. 2016. Sympathy for the Devil: Detailing the Effects of Planning-Unit Size, Thematic Resolution of Reef Classes, and Socioeconomic Costs on Spatial Priorities for Marine Conservation. PloS One (e0164869) DOI: 10.1371/journal.pone.0164869.

Coll M, Piroddi C, Steenbeek J, Kaschner K, Lasram FBR, Aguzzi J. 2010. The biodiversity of the Mediterranean Sea: estimates, patterns, and threats, PloS One 5(8) (e11842) DOI: 10.1371/journal.pone.0011842.

Di Fonzo MM, Nicol S, Possingham HP, Flakus S, West JG, Failing L, Long G, Walshe, T. 2017. Cost-effective resource allocator: a decision support tool for threatened species management. Parks, DOI: 10.2305/IUCN.CH.2017.PARKS-23-1MMIDF.en.

Douvere F, Ehler CN, 2009. New perspectives on sea use management: initial findings from European experience with marine spatial planning. Journal of environmental management **90(1)**:77-88.

Ehler C. 2008. Conclusions: benefits, lessons learned, and future challenges of marine spatial planning. Marine Policy **32(5)**:840-843.

European Commission. 2012. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions, a Maritime Strategy for the Adriatic and Ionian Seas. Brussels, 30.11.2012 COM(2012) 713 final.

European Commission. 2014a. Directive 2014/89/EC of the European Parliament of the Council of 23 July 2014 establishing a framework for maritime spatial planning. Official Journal of the European Union L257: 135±145.

European Commission. 2014b. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee of the Regions concerning the European Union Strategy for the Adriatic and Ionian Region. COM (2014) 357 final.

European Commission. 2014c. Commission Staff Working Document, Action Plan Accompanying the document Communication from the Commission to the European parliament, the Council, the European economic and social Committee and the Committee of the Regions concerning the European Union Strategy for the Adriatic and Ionian Region {COM(2014) 357 final}, SWD(2014) 191 final. 17.6.2014.

European Commission. 2014d, Report from the Commission to the European Parliament, the Council, the European Economic and Social Committee of the Regions concerning the governance of macro-regional strategies, COM/2014/0284 final.

European Council Directive 92/43/EEC on the conservation of natural habitats and of wild fauna and flora (OJ L 206, 22.7.1992, p.7)

European Environmental Agency, 2012, EUNIS Marine Habitat classification 2007 (revised description 2012), available at http://www.eea.europa.eu/themes/biodiversity/eunis/eunis-habitat-classification/.

European Commission. 2008. Directive 2008/56/EC of the European Parliament of the Council of 17 June 2008 establishing a framework for community action in the field of marine environmental policy (Marine Strategy Framework Directive). Official Journal of the European Union L164: 19±40.

Fernandes L, Day J O N, Lewis A, Slegers S, Kerrigan B, Breen D A N, et al. 2005. Establishing representative no-take areas in the Great Barrier Reef: large-scale implementation of theory on marine protected areas. Conservation Biology **19(6):**1733-1744.

Flannery W, Cinnéide MÓ. 2008. Marine spatial planning from the perspective of a small seaside community in Ireland. Marine Policy **32(6):**980-987.

Fraschetti S, Guarnieri G, Bevilacqua S, Terlizzi A, Claudet J, Russo GF, Boero F. 2011. Conservation of Mediterranean habitats and biodiversity countdowns: what information do we really need?, Aquatic Conservation **21(3):**299-306.

Game ET, Kareiva P, Possingham HP 2013. Six common mistakes in conservation priority setting. Conservation Biology **27(3)**:480-485.

Giakoumi S et al. 2013. Ecoregion-Based Conservation Planning in the Mediterranean: Dealing with Large-Scale Heterogeneity. PLoS One (e76449) DOI:10.1371/journal.pone.0076449.

Gissi E, Menegon S, Sarretta A, Appiotti F, Maragno D, Vianello A, Depellegrin D, Venier C, Barbanti A. 2017. Addressing uncertainty in modelling cumulative impacts within maritime spatial planning in the Adriatic and Ionian region. PLoS One (e0180501) DOI: 10.1371/journal.pone.0180501.

Halpern BS et al. 2013. Achieving the triple bottom line in the face of inherent trade-offs among social equity, economic return, and conservation. Proceedings of the National Academy of Sciences **110(15):**6229-6234.

INSPIRE Thematic Working Group Coordinate reference systems and Geographical grid systems, 2010. D2.8.I.2 INSPIRE Specification on Geographical Grid Systems Guidelines, INSPIRE Infrastructure for Spatial Information in Europe, 2010/04/26 http://inspire.ec.europa.eu/documents/Data_Specifications/INSPIRE_Specification_GGS_v3.0.1.pdf.

IUCN 2016. The IUCN Red List of Threatened Species. Version 2016-3. <http://www.iucnredlist.org>. Downloaded on 07 December 2016.

Jumin R, Binson A, McGowan J, Magupin S, Beger M, Brown C, Possingham H, Klein C. 2017. From Marxan to Management: Ocean Zoning with stakeholders for the proposed Tun Mustapha Park in Sabah, Malaysia. Oryx 1-12 DOI: 10.1017/S0030605316001514.

Klein CJ, Chan A, Kircher L, Cundiff AJ, Gardner N, Hrovat Y, Scholz A, Kendall BE, Airame S. 2008. Striking a balance between biodiversity conservation and socioeconomic viability in the design of marine protected areas. Conservation Biology **22(3):**691-700.

Klein C, McKinnon MC, Wright BT, Possingham HP, Halpern BS. 2015. Social equity and the probability of success of biodiversity conservation. Global Environmental Change **35:**299-306.

Kuempel CD, Chauvenet AL, Possingham HP 2016. Equitable representation of ecoregions is slowly improving despite strategic planning shortfalls. Conservation Letters **9(6):** 422-428.

Mackelworth P. 2012. Peace parks and transboundary initiatives: implications for marine conservation and spatial planning. Conservation Letters **5(2):**90-98.

Mazor T, Possingham HP, Kark S. 2013. Collaboration among countries in marine conservation can achieve substantial efficiencies. Diversity and Distributions **19(11):**1380-1393.

McLeod K, Lubchenco J, Palumbi R, Rosenberg A. 2005. Scientific consensus statement on marine ecosystem-based management. Communication Partnership for Science and the Sea.

Micheli F et al. 2013. Setting priorities for regional conservation planning in the Mediterranean Sea. PLoS One (e59038) DOI: 10.1371/journal.pone.0059038.

Mosetti R, Lipizer M. (eds) 2014. ADRIPLAN Initial assessment, WP 1: Set up of MSP AIP-1.2-1.1–Initial Assessment. Doi:10.6092/a0c08436-868b-4cc2-9cb8-532dd32f2621.

Olsen E, Fluharty D, Hoel AH, Hostens K, Maes F, Pecceu E. 2014. Integration at the round table: marine spatial planning in multi-stakeholder settings. PloS One (e109964) DOI: 10.1371/journal.pone.0109964.

Peifer H. About the EEA reference grid, European Environmental Agency, September 2011, http://www.eea.europa.eu/data-and-maps/data/eea-reference-grids-1/about-the-eea-reference-grid/eea_reference_grid_v1.pdf/at_download/file.

Piante C, Ody D. 2015. Blue Growth in the Mediterranean Sea: the Challenge of Good Environmental Status. MedTrends Project. WWF-France.

Pomeroy R, Douvere F. 2008. The engagement of stakeholders in the marine spatial planning process. Marine Policy **32(5):**816-822.

Possingham HP, Andelman SJ, et al. 2001. Making smart conservation decisions. Pages 225– 244 in Orians G, Soul M, editors. Research Priorities for Conservation Biology. Island Press, Washington, DC.

Possingham HP, Ball IR, Andelman S. 2000. Mathematical methods for identifying representative reserve networks. Pages 291–305 in: Ferson S, Burgman M, editors. Quantitative methods for conservation biology. Springer, New York.

Qiu W, Jones PJ. 2013. The emerging policy landscape for marine spatial planning in Europe. Marine Policy **39:**182-190.

Schaefer N, Barale V. 2011. Maritime spatial planning: opportunities & challenges in the framework of the EU integrated maritime policy. Journal of Coastal Conservation **15(2):**237-245.

Solar O, Irwin A. 2007. A conceptual framework for action on the social determinants of health. Social Determinants of Health Discussion Paper 2 (Policy and Practice), Starfield AM. 1997. A pragmatic approach to modeling for wildlife management. The Journal of wildlife management **61(2):**261-270.

Tulloch et al. 2015. Why do we map threats? Linking threat mapping with actions to make better conservation decisions. Frontiers in Ecology and the Environment. **13:**91–99 DOI:10.1890/140022.

UNEP (2011): Taking Steps toward Marine and Coastal Ecosystem- Based Management. - An Introductory Guide. Tundi Agardy, John Davis, Kristin Sherwood, and Ole Vestergaard. UNEP, Nairobi

Watts ME, Ball IR, Stewart RS, Klein CJ, Wilson K, Steinback C, Lourival R, Kircher L, Possingham HP. 2009. Marxan with Zones: software for optimal conservation based land- and sea-use zoning. Environmental Modelling & Software **24(12):**1513-1521.

Wilson KA et al. 2007. Conserving biodiversity efficiently: what to do, where and when. PLoS Biology (e223) DOI: 10.1371/journal.pbio.0050223.

Table 1: Scenarios for conservation prioritization.

Scenarios	Target treatment	Cost treatment	Targets for conservation features		No. of features
			L	E	
Scenario 1a	1. Conservation targets assigned at AIR level	Area	30%	10%	70
Scenario 1b		No. of Industries	30%	10%	70
Scenario 2a	2. Conservation targets assigned at country level*	Area	30%	10%	263
Scenario 2b		No. of Industries	30%	10%	263

L=limited areas, for conservation features with areas <5000 km^2; E= extensive areas, for conservation features with areas >5000 km^2.

*on Albania, Croatia, Disputed Areas, Greece, Italy, Montenegro, Slovenia

Figure-legend page

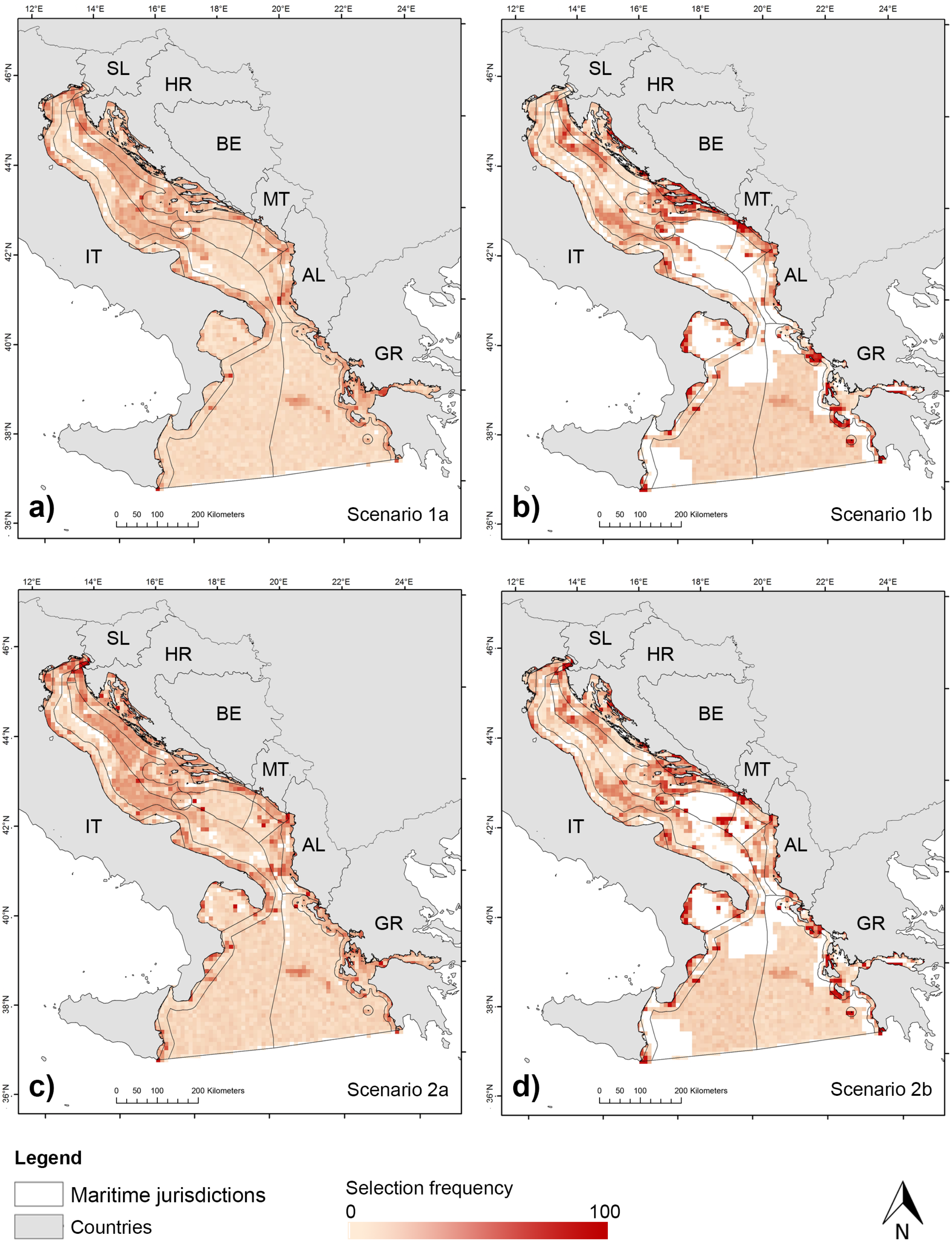
Figure 1. Selection frequency for the four scenarios; Scenario 1a results from planning at the regional scale using the area of the planning unit as the equal costs planning units; Scenario 1b results from planning at the regional scale using the sum of industries affected as the cost of a planning unit; Scenario 2a results from planning at the country scale using the area of the planning unit as the equal costs planning units; Scenario 2b results from planning at the country scale using the sum of industries affected as the cost of a planning unit; AL= Albania, BE=Bosnia-Herzegovina, GR=Greece, IT=Italy, MT=Montenegro, SL=Slovenia.

Figure 2 Trade-offs between the mean total cost and mean Protection Equality (PE$_{P}$) by countries (panel a), and by industries (panel b) of the top 10% of solutions for each of the four scenarios.

Figure 3 RDI plots (Raw data, Descriptive and Inference statistics) show the distribution of industries in planning units, according to the total cost of each PU, which is represented by the sum of industries potentially affected; center bars indicate the mean of industries on PUs, beans outline the smoothed density, whiskers mark the 10% and 90% quartiles of the data, and inference bands show the Bayesian 95% High Density Interval inferential statistics for each group. LNGs stands for Liquefied Natural Gas offshore terminal.

Figure 4 Transboundary and National Priority areas for conservation under scenario 1b. Icons represent important biodiversity features and industries occurring in priority areas. The complete description of conservation features and maritime sectors is reported in Table S6, Supporting Information.

Figures with legend



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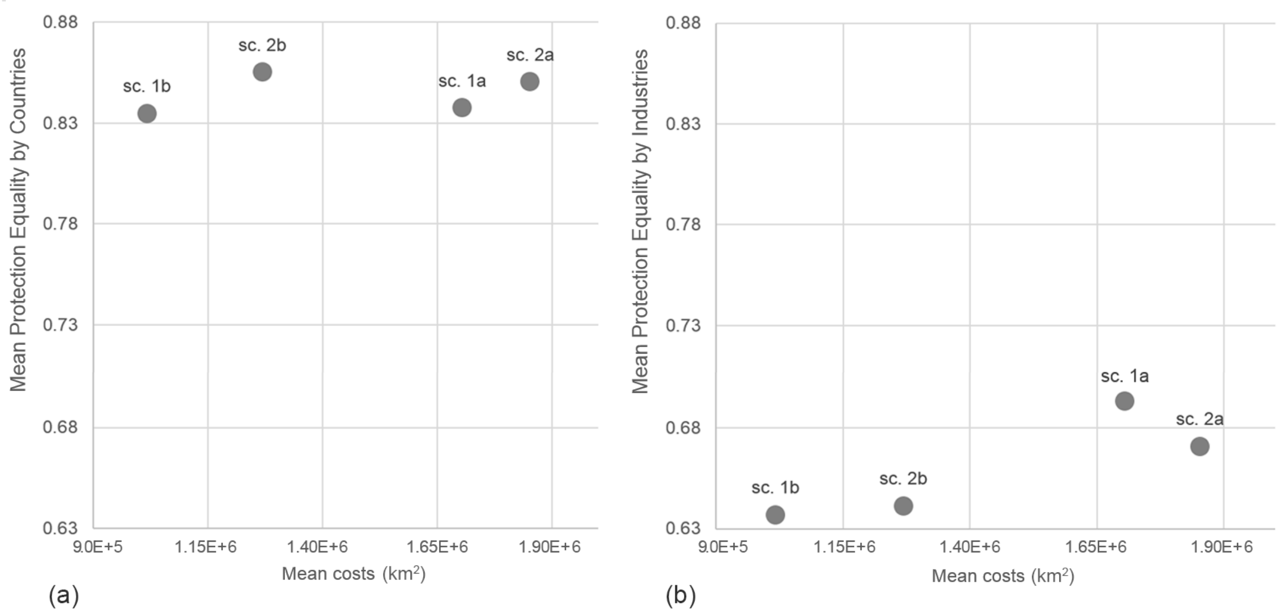

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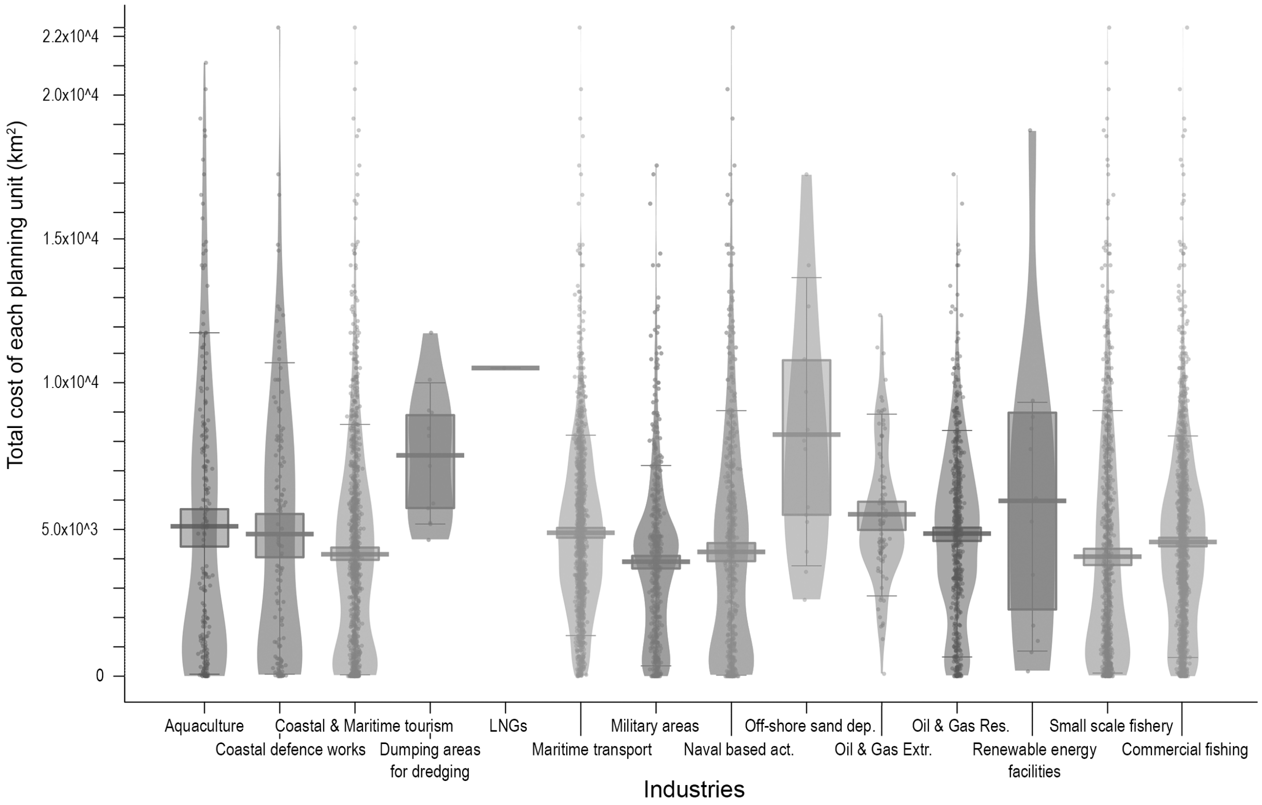

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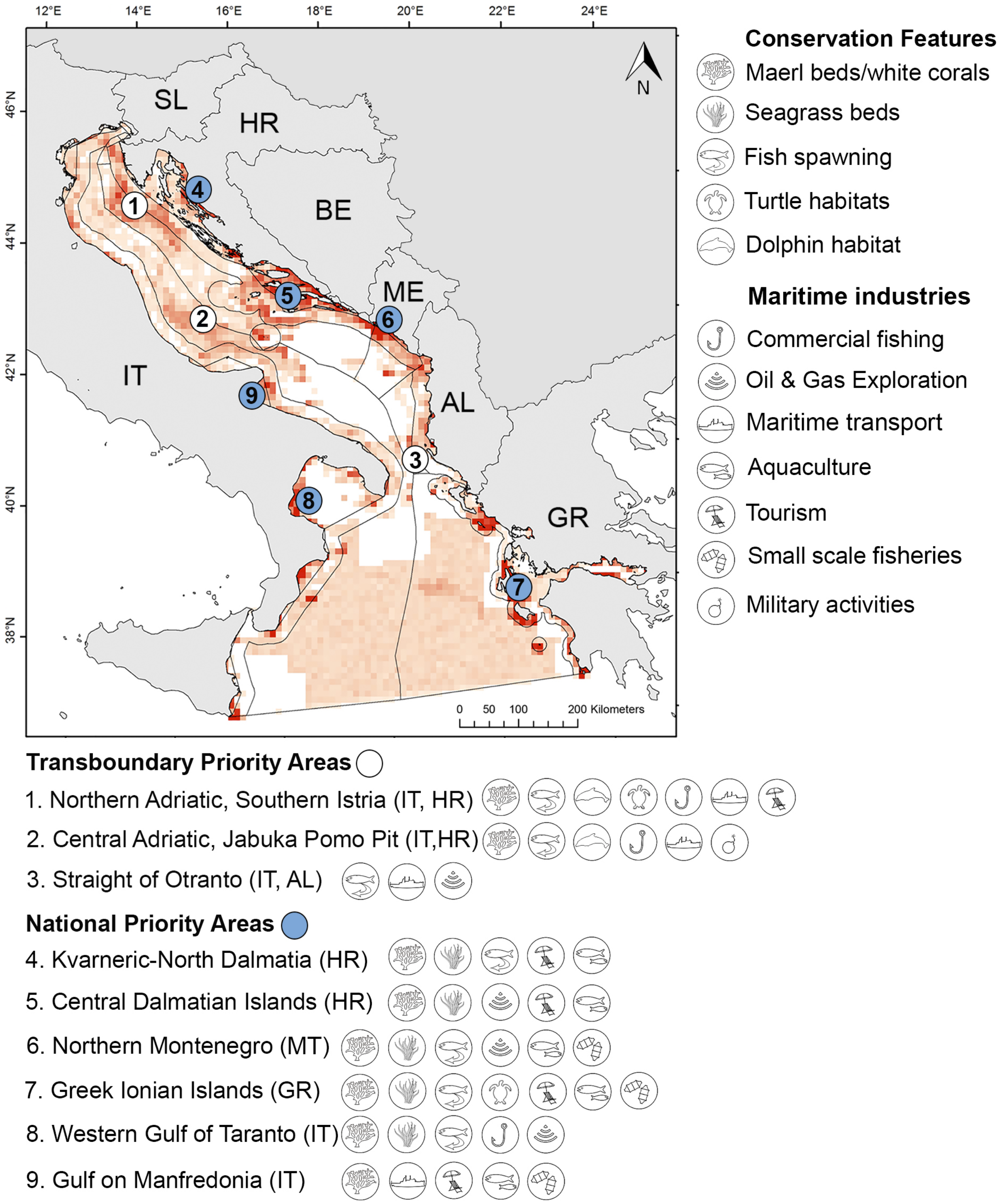

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