Identification and prioritization of areas with high environmental risk in Mediterranean coastal areas: A flexible approach
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HIGHLIGHTS
- Respond to the need of an interdisciplinary management of coastal ecosystems
- Biosphere, lithosphere and anthro- morphosphere data were considered, combined in a prioritization procedure
- A set of criteria for prioritizing sites mainly based on plant diversity in response to oil spill, fragmentation and HNS
- Different areas were prioritized for each hazard, the response of habitat and habitat species were highly correlated
- This approach can provide public administrations and local communities an easy to use instrument towards ICZM

DATEPLOT
- Study Pilot Areas
- Risk Management Framework
- Prioritization of High-Risk Areas

ABSTRACT
Interdisciplinarity and transdisciplinarity are the cornerstone for the future management of coastal ecosystems with many vulnerability and hazard indexes developed for this purpose, especially in the engineering literature, but with limited studies that considered ecological implications within a risk assessment. Similarly, the concept of prioritization of sites has been widely examined in biodiversity conservation studies, but only recently as an instrument for territory management. Considering coastal plant diversity at the species and community levels, and their vulnerability to three main potential hazards threatening coastal areas (oil spills, Hazardous and Noxious Substances pollution, fragmentation of natural habitats), the objective of this paper is to define an easy to
1. Introduction

The Mediterranean Basin constitutes one of 200 ecological regions with the highest level of biodiversity in the world (Olson and Dinerstein, 1998). Although covering only 0.8% of the world’s sea surface and 0.3% of its seawater volume, the Mediterranean Sea is home to 10,000 to 17,000 marine species, 20% of which are endemic (Bazairi et al., 2010; Coll et al., 2010). The terrestrial plant diversity of the Basin is similarly rich, with about 25,000 species native to the region (60% of them are Mediterranean endemics, half of which correspond to narrow endemics; Thompson, 2005), and around 10% of the world’s higher plants concentrated in an area covering <2% of the land mass (Medail and Quezel, 1999). Therefore, the Mediterranean Basin is also recognized as one of 34 Global Biodiversity Hotspots (Mittermeier et al., 2014) with limited studies focusing on the assessment of the concept of risk and hazard considering the ecological implications (see for a review De Lange et al., 2010). More recently, the definition of an easy to use approach to locate and prioritize the areas more susceptible to those stressors, in order to have a practical instrument for risk management in the ordinary and extraordinary management of the coastline. The procedure has been applied at pilot areas in four Mediterranean countries (Italy, France, Lebanon and Tunisia). This approach can provide policy planners, decision makers and local communities an easy to use instrument able to facilitate the implementation of the ICZM (Integrated Coastal Zone Management) process in their territory.

2. Material and methods

2.1. Pilot areas

The project implemented its activities in four pilot areas in the Mediterranean basin, which are characterized by high levels of biodiversity and economic development. Each pilot area comprises at least 60 km of coastline that is meant to cover the broad scale extension of the assessment in which 11 sites were selected to address the local scale (small extension, Fig. 1). The selection process encompassed the main types of land use/cover, environmental characteristics, and main types of human pressures present in the whole Mediterranean basin. In particular, we focused on the presence of oil refineries, commercial port, Hazardous and Noxious Substances (HNS), and urban pressure.

**Pilot Area 1** The Provence Alpes Côte d’Azur (PACA) region is at the southeastern coast of France. This region includes two National Parks, Calanques and Port Cros with terrestrial and marine protected areas and is limited to the west by the Camargue Regional Park. Tourism activities play a central role in the regional economy, with the PACA Region being the second most important tourist region in France. The
area is home to four oil refineries and the port of Marseille, which is the largest in France and the fifth in Europe. In this pilot area, four study sites were selected along the coastal of the PACA region, which include several Habitat Directive sites (92/43/EEC).

**Pilot Area 2** The Gulf of Cagliari in southern Sardinia includes habitats of priority and community interest under the Habitats Directive (92/43/EEC) and two sites under the Ramsar Convention (UN Treaty Series No. 14583). The outstanding environmental and touristic value of the Gulf exists a short distance away from the city of Cagliari (>150,000 people) and its major port, as well as with one of the largest refineries in Europe (Sarroch). Along the Gulf of Cagliari two study sites were selected: Capo Sant’Elia Poetto Molentargius and the coastline stretching between the towns of Chia and Pula.

**Pilot Area 3** The Gulf of Gabès in southern Tunisia is one of the coastal areas where tourism, increased urbanization and chemical industry (phosphate) carry the heaviest impact. The Gulf holds two major ports and is characterized by important salt marshes. Three study sites with different levels of human impact and development were selected: the island of Djerba and the surroundings of both Sfax and Gabès cities.

**Pilot Area 4** In Lebanon, the high demand for coastal lands coupled with poor enforcement of legislation led to uncontrolled urban development along the coastline. The coast is also littered with illegal occupation (recreational projects, breakwaters and marinas) that prevents public access to the seashore. These changes are major causes of coastal hydrodynamic modifications, degradation, soil erosion and biodiversity loss. Byblos and Beirut coastal regions were selected as the two study sites in Lebanon. The first zone is eligible to be part of the upcoming network of Marine Reserves in Lebanon, and the second one is characterized by being highly urbanized.

2.2. Vulnerability, hazard, risk and prioritization: four linked concepts

Vulnerability is defined as “the degree to which a system is susceptible to, and unable to cope with, injury, damage or harm” (De Lange et al., 2010). It is a function of exposure, effect (potential impact, sensitivity) and recovery (resilience or adaptive capacity). Several elements are normally considered in its assessment including: ecological or ecosystem, socio ecological and the use of expert judgment (De Lange et al., 2010). Wamsley et al. (2015) adopts the definition proposed by Füssel (2007), where vulnerability is defined according to the system being assessed, the attribute of concern, and the hazard (or the “threat”, “stressors” or anything recognized as “a threatening event, or the probability of occurrence of a potentially damaging phenomenon within a given time period and area”).

In the environmental studies, to assess the risk, defined as the probability of a harmful effect due to a given hazard and resulting consequences (De Lange et al., 2010), considerations are given to ecological characteristics of the biological system potentially exposed. The results of an environmental risk assessment can be used to prioritize the coastal area according to the chances that one of multiple risks can happen. In fact, hazard and vulnerability are closely linked to the topic of scheduling of management as well as conservation action and the consecutive selection and prioritization of sites. When prioritizing, a temporal dimension is added to the ordinary management of the territory: it means to fix a time for and plan in advance where the interventions will go first in case of an emergency and where to direct our attention later. In the same way, we can prioritize to schedule the possible actions on a territory in order to propose where conservation action will produce the best long term protection and conservation outcomes, considering that species, habitats and ecosystems can be compromised at rates that vary depending on the habitat type, location and management (Kukkala and Molilanen, 2013).

In this study, we used plant diversity (including plant species and plant assemblages, hereafter referred to as habitats) as an indicator for ecosystem vulnerability: we assumed that the greater the plant diversity, the greater the vulnerability of the location (De Lange et al., 2010). This is because coastal areas that are naturally heterogeneous are likely to be relatively rare along the highly urbanized Mediterranean coasts and representative of environmental conditions that are under threat.
Moreover, in this context, the potential loss of plant species or habitats of concern is of high significance since largely irreplaceable (very low recovery and/or resilience, De Lange et al., 2010).

The variety and availability of biological data is a common limit for many studies that conduct biodiversity assessments (Marignani et al., 2014); during the vulnerability assessment, the greatest impediment for a consistent evaluation is the lack of biological data (De Lange et al., 2010). Diverse situations are encountered in the four countries encompassing the pilot areas. While in Italy, Lebanon and Tunisia primary data collected during the project implementation were used, in France existing databases were relied upon. To face the problem of the availability and the use of heterogeneous biological data we tested a two scale approach in terms of spatial extension and data types.

At the pilot area level (broad extension: PACA region, France; Gulf of Cagliari, Italy; coastal areas between Byblos and Beirut, Lebanon; Gulf of Gabès, Tunisia, see Fig. 1) we considered habitat data, which are generally more easily available; at the site level (small extension, see Fig. 1) we used both species and habitat data (for more details on the plant diversity assessment see the Supplementary material).

We adopted a multi scale approach for two main reasons: data constraints and theoretical issues. Undeniably finer resolution data and richer set of variables permit the conduction of more precise risk assessments and more accurate management planning (Norton et al., 2016; De Lange et al., 2010). Nevertheless, as stated by Levin (1992), modeling at finer scales demands more detailed data in order to predict outcomes effectively, while at larger scales statistical patterns become more regular and the use of coarser proxies more rational. Biodiversity knowledge is scale dependent and when moving from coarser to finer spatial resolution, our knowledge shortfalls expand (Hortal et al., 2015).

For the hazard assessment we selected three main threat/pressure indicators: i) habitat loss and fragmentation due to urbanization ii) exposure to Hazardous and Noxious Substances (HNS) and iii) exposure to oil spills (see Fig. 2). For the assessment of oil spills risk, we also used the morphology of shoreline to evaluate the sensitivity to pollution (for more details see Al Shami et al., 2017 and Supplementary material).

All spatial analyses were performed at pilot area (habitat only, broad extension) and at site level (habitat and species, small extension), using the GIS software Qgis and ArcGIS® 10.X ESRI.

2.2.1. Assessing vulnerability: plant diversity and coastal morphology

To quantify vulnerability, we used two synthetic spatial indices. The biological one refers to plant species and habitat types and is based on a common set of simple indicators: species richness, presence of species of conservation concern, diversity of natural habitats and cover of habitat of conservation value. Species of conservation concern refer to species of national or regional interest according to global, national and regional Red Lists (IUCN), international Conventions and Directives (Habitats Directive, Bern Convention, CITES), or judgment of local plant experts (for instance, for narrow endemics or species with reduced population size). For habitats we referred to international and national policies when available (e.g. Habitats Directive for Europe, 92/43/EEC), or to local expert judgment (for more information on the concept of concern for species and habitats, see Blasi et al., 2011; Rossi et al., 2013). Note that all plant and habitat indicators refer to a standard spatial grid of 1 × 1 km (100 ha). We adopted this size considering data availability in the pilot areas, time and money constraints; compared to other widely adopted spatial grids, e.g. 4 km² for the IUCN red listing assessment (IUCN, 2016), a 1 km² grain for biological data appeared as a good compromise, suggested also by the standard adopted in Europe for e.g. Habitats Directive (INSPIRE, Infrastructure for Spatial Information in Europe).

Besides existing data sources, for Italy, Lebanon and Tunisia data on plant species were collected through field surveys, with a sampling strategy designed to ensure at least one sample plot per habitat type within each grid cell. In France, plant species data were derived from the SILENE (System of Information and Localisation of native and invasive species) georeferenced database compiled by the National Mediterranean Botanical Conservatory (CBNMed). It contains ~4.5 million plant species and habitats vulnerability

Biodiversity Vulnerability Index (BVI)

Coastal vulnerability to oil pollution

Environmental Sensitivity Index (ESI)

BVI x ESI

Habitat Fragmentation Hazard Index (HFI)

HNS/Anthropogenic Hazard Index (HNSI)

Shoreline exposure index to oil (SEI)

Habitat Fragmentation Risk Index – HFRI (BVI × HFI)

HNS/Anthropogenic Risk Index – HNSRI (BVI × HNSI)

Oil Spill Risk Index - OSRI [(BVI x ESI) x SEI]

Fig. 2. Flowchart of the methodological approach.
records on plant species occurrences in the French Mediterranean region (approx. 300 km coastline), which derived from different sources (herbaria specimen, field data, etc…).

Habitat data were derived from land cover maps at the regional or local scale available for each country, except for Tunisia, where original data were produced. For habitats of conservation value, France and Italy used also the habitat maps, available from the Natura 2000 network (Habitats Directive, Council Directive 92/43/EEC).

The complete use of indicators (habitat plus floristic data) covered the study sites because existing georeferenced data on plant occurrences are discontinuous over the whole pilot areas with resource constraints preventing the extension of field surveys over long coastal stretches. This restriction does not affect the flexibility of the approach and allows future data addition and refinements.

For each cell, the scores of each descriptor are ranked in three classes, from one (lowest value) to three (highest value). The classified values of all indicators are then summed up to obtain an overall score, which we called Biodiversity Vulnerability Index (BVI), with values ranging from four (when all individual values are one), to a maximum value of 12 (when all indicator values are three, see Supplementary material for details). We used a classification that permits us to distinguish among low, medium and high risk and vulnerability levels, which is a common approach in risk assessments (see for instance Halpern et al., 2008; Arkema et al., 2013). Also Gauthier et al. (2010) recommended to use an impair number (3 or 5 classes) for the classification of species according to the conservation priority. We chose an additive score method because it is relatively easy to create and teach, despite its cons (Hubbard and Evans, 2010).

The morphological index, or the Environmental Sensitivity Index (ESI), quantifies the sensitivity of the coastline to oil pollution. Shoreline lines are first classified in typologies according to a modified version of the NOAA coastline classification system (NOAA, 2002); classes are then ranked on the basis of their susceptibility to damage by oil spills, with lower rankings indicating lower vulnerability (0 lowest vulnerability, 10 highest vulnerability). Shoreline classification criteria refer to a set of factors including relative exposure to wave and tidal energy, shoreline slope and substrate type (Al Shami et al., 2017 and Supplementary material).

2.2.2. Hazard analysis: urbanization and pollution

The aim of the hazard analysis is to quantify potential and actual impacts that can threaten the terrestrial plant diversity and the shoreline. In this context, fragmentation and habitat loss due to urbanization as well as oil and HNS pollution are recognized as main threats to coastal biodiversity in the Mediterranean (Cuttelod et al., 2008; Frondoni et al., 2011; Astiaco Garcia et al., 2013c; Lhotte et al., 2014; Malavasi et al., 2014) and as such were used to quantify the hazard through the development of synthetic spatial hazard indices. To ensure harmonization of indicators across the four pilot areas, fragmentation was calculated based on the Global Land Cover for the year 2010 (Global Land Cover of China, 2014). It was measured by a set of five landscape metrics that provide information on different aspects: the relative urban cover, the roads length, the mean and maximum patch size of natural and semi natural habitats and their total length of borders (McGarigal et al., 2002). All landscape metrics refer to a standard spatial grid of 1 x 1 km, calculated using a 3 x 3 km moving window, to better reflect the isolation effect (e.g. in the case of a cell where land cover is mainly natural, but it is surrounded by cells where urban areas dominate). In the context of the quantification of urban pressure, we also used a floristic indicator “richness in exotic species”, since they represent a major threat to biodiversity worldwide and their occurrence is considered a good indicator for human pressures (Mack et al., 2000; Hejda et al., 2009). Due to differences in ecological requirements, habitat preferences and invasion dynamics between ancient and recent introductions, we opted to consider only neophytes (Pysek et al., 2004, 2005; Celesti Grapow et al., 2009; Seebens et al., 2017). In fact, the response of archaeophytes to environmental factors is often similar to that of native species (Celesti Grapow et al., 2010). Data on the occurrence of exotic plant species in each cell derived from field surveys and the literature.

The individual values of each indicator were ranked into three classes scored from one to three, with three representing the highest hazard. All individual values were reclassified and then summed up to calculate an overall score, which represents the Habitat Fragmentation Index (HFI) ranging from 6 (low impact) to 18 (high impact)1 (see Supplementary material for details).

As for the impacts of pollution on terrestrial plant diversity, we considered the effects of anthropogenic pollution sources, hazardous and noxious substances (HNS) and hydrocarbons (Al Shami et al., 2017). In dices were calculated only for grid cells that are located along the coast line (Astiaco Garcia et al., 2013c). All other cells were assigned a value of zero. Shoreline hazards associated with non oil pollution threats were assessed for all four study areas (Al Shami et al., 2017); these hazards included both land and marine based pollution sources (e.g. industries, agricultural activities, ports and marinas). We also collected data on oil volumes and types stored at airports, ports, industries, storage sites, oil rigs, maritime traffic, as well as potential exposure of shorelines to a hypothetical worst case oil spill. The latter was assessed through a set of oil spill simulations along the pilot areas’ coastlines using the MedSLIK II model (see Al Shami et al., 2017). The simulated oil spill accounted for variations in sea temperature, current velocity and direction, wind speed and direction along the Mediterranean coastline (El Fadel et al., 2012; Astiaco et al., 2013b). Oil spill simulation results were used to generate a Shoreline Exposure Index (SEI) that defined both the areas that might be hit most frequently as well as the areas that are exposed to the highest concentrations. HNSI and Shoreline Exposure Index (SEI) range from 0 to 10.2

For more information on vulnerability and hazard assessment please refer to the Supplementary material.

2.2.3. Prioritization of the coastline for specific risks

The vulnerability assessment outcomes were combined with the hazard analyses for the creation of three integrated evaluations that allow to prioritize the coastline for specific risks. To combine vulnerability and hazard indexes without downweighting or upweighting any index, all original indices (BVI, HFI, HNS, SEI and ESI) were rescaled to a common 1 to 5 scale. This procedure can be changed in case the operator wishes to give more importance to one of the variables: for example, the operator wishes to give more importance to the stressor “urban fragmentation” HFI can be used with its original ranges (6 18) without rescaling, this giving to this factor more weight on the final prioritization score. Prior loadings were performed according to the two different BVI evaluation and spatial extension: using habitats only (area level, broad extension) and habitat and species (site level, small extension).

2.2.3.1. Prioritization for the risk of fragmentation of natural ecosystems

The HFRI was developed combining the Biodiversity Vulnerability Index (BVI) and the Hazard Fragmentation Index (HFI). Both indices are cell based, hence we simply calculated the final prioritization ranking for the fragmentation of natural ecosystems combining the indices according to the risk matrix (see Table 1.a and Fig. 2).

HFRI = BVI × HFI

where HFRI is the Habitat Fragmentation Risk Index, BVI is the Biodiversity Vulnerability Index and HFI is the Habitat Fragmentation Index at cell level. Note that the Spearman rank correlation was used to quantify the coherency of the results obtained at site vs pilot area level.

1 http://www.envipcbmed.eu/projects/library-of-deliverables and reports
2 http://www.greatmed.eu/joomla/component/content/article/reports-96
2.2.3.2. Prioritization for the risk of anthropogenic, hazardous and noxious substances (HNS). The HNS/Anthropogenic Risk Index (HNSRI) was developed combining the Biodiversity Vulnerability Index (BVI) and the HNS/Anthropogenic Hazard Index (HNSI). Using a geo-processing instrument, we extracted the overlapping areas of BVI cells and HNSI polygons. HNSRI was calculated by combining the indices according to the risk matrix (see Fig. 2).

HNSRI = BVI × HNSI

2.2.3.3. Prioritization for the risk of an oil spill event. The Shoreline Exposure Index to Oil (SEI) was integrated with the Biodiversity Vulnerability Index (BVI) and with the Environmental Sensitivity Index (ESI) to develop an overall Oil Spill Risk Index (OSRI), according to the following formula: OSRI = (BVI × ESI) × SEI.

Overlaying the three data layers, we extracted the overlapping areas and calculated the final OSRI prioritization value (see Table 1.b).

3. Results

We produced the prioritization of the coastline for the three hazards analyzed, at site and area level, for the four countries (Fig. 3). At the pilot area level we analyzed in Italy about 90 km of coastline, in France >150 km, about 80 km in Lebanon and >254 km in Tunisia; at the site level, we sampled and analyzed a total of approximately 82 km of coastline (26 in Italy, 23 in Lebanon, 23 in France and 10 in Tunisia).

Ranking the territory according the risk assessed for each hazard, we obtained different prioritization areas: for example in France the area to be monitored for oil spill hazard does not coincide with the one identified as more prone to suffer from future urbanization of the coastline. Combining BVI with HNSI we identify the level of susceptibility of the areas to a future hazard caused by hazardous and noxious substances (HNS). For oil spill prioritization we adopted a slightly different approach.

The countries exhibited a different distribution of the pilot areas at the different levels of prioritization (see Table 2). For example, with regards to the percentage of cells to be prioritized for plant diversity conservation vs the fragmentation hazard, all countries show values ranging from medium to low, except Lebanon, which was characterized by >50% of the cells as “high medium” level (in comparison to other countries accounting for <30%). For HNS, Lebanon and Tunisia showed the highest alert with a significant portion of areas ranked as very high priority (Tunisia 42%, Lebanon 25%) and <50% included in the low/very low priority ranking. The prioritization for oil spill considered only a strict portion of the coastline but it gave, nevertheless, indication for the management of the coastline. In France the priority was lower, but we identified a portion of high priority in the area of Martigues (see Fig. 3a). In Tunisia the results described the pilot area as more in need of attention for oil spill risk (41% for high to medium risk, which was considerably higher than the one estimated for the other countries, i.e. 16% for Italy, 3% or less for France and Lebanon).

4. Discussion

We presented a methodological framework to identify the locations where plant diversity is more likely to be damaged by the most common human activities along Mediterranean coastal areas (Cuttelod et al., 2008). For this purpose, several topics were considered. To start with, defining the most appropriate scale is critical because ecological boundaries often do not coincide with the administrative ones, rendering the management of the coastline more difficult. Moreover, sampling biological features is expensive and time consuming (Hortal et al., 2015; Marignani et al., 2014); hence the extent of the study area can also be delimited by the sampling effort that can be covered. In this study, we adopted a double spatial scale (extent) and different levels of ecological information (habitats only, and habitats and plant species).

The two scale approach (area vs site scale) permitted us to show that the detailed information on species richness indicators was important especially for areas of specific conservation interest that other landscape indicators may not efficiently reflect. However, we acknowledge that the use of such indicators can be considerably time and money consuming for data collection (Hortal et al., 2015). Our approach shows that in the absence of such detailed indicators the biodiversity vulnerability indicator can still identify reasonably good the vulnerable areas even though the local variability may be disregarded.

For the fragmentation hazard, the results showed a good agreement among site vs pilot area level in most cases, suggesting that in this kind of assessment the greatest part of diversity can be summarized using...
data on habitats. When congruence was not respected, in most cases the prioritization based on more data (habitat and species, site level) compared to the area based (habitats only) identified a greater number of high medium priority cells. Nevertheless, the Tunisian case suggests that when dealing with a reduced dataset, the correlation among habitats vs habitats and plants is weak and, consequently, the results of the prioritization can lead to a poor instrument for decision making. It is preferable to present prioritization results in the right context, whereby a first survey

a) France

Fig. 3. Investigated coastline was ranked according to three hazards, producing maps showing the area more prone to suffer from the selected hazards. a) France b) Italy c) Lebanon d) Tunisia.
b) Italy
is suggested first on a larger area (e.g. pilot area level) to determine the most important sites at broad scale and then perform a more detailed investigation on biological elements in identified critical areas.

Selecting the location where to intervene first represents one of several actions that must be taken to preserve the ecological integrity of the Mediterranean coastline. But to prioritize areas according to their environmental risk, we must first assess and then combine ecological and hazard indicators into a repeatable risk assessment procedure. Our approach highlighted the chance to follow a methodology that can be flexible and weigh the different elements composing the procedure according to local needs. The matrices adopted to prioritize the coastline for specific risks can be modified and different weight can be assigned.
d) Tunisia
As for any other methodology, the real efficiency (and relative limitations) of the method will be tested if it will be applied in other sites, keeping the general approach and modifying, e.g. the weights of the singular indexes or the stressors assessed, to adapt it to the specific local needs and verify its potentiality of flexibility and adaptability. For example, we could have investigated more deeply the influence of agricultural activities (fertilizers and/or agrochemicals), but in the involved countries agricultural activities have different forms and different influence on biodiversity. In Tunisia for example, the presence of agricultural areas have a great impact on the coastal aquifer and salt habitats considered in the study (El Ayni et al. 2012), in France the majority of agricultural areas in the gulf of Marseille consists in traditional agricultural landscapes, which have an important role for the conservation of the plant species; in Italy the situation is in between (Tieskens et al. 2017). Moreover, except for Lebanon, we could not gather any information on the quantity and quality of the fertilizers and agrochemicals used in the agricultural areas. Nevertheless, we chose to include agricultural pollution in the Anthropogenic hazard to maintain the possibility to include this type of stressor in the proposed approach.

We believe that the analyzed case studies represent a good range of the different situation we can find in the Mediterranean basin but, at the same time, we acknowledge that the application of the method in other Mediterranean countries could highlight the limitations and the possible future improvements of the method. These improvements could come not only from the application in other geographically distinct situations, but more interestingly in the implementation of the method in prioritizing the landscape for other stressors such as invasive alien species or increasing sea level rise.

5. Conclusions

Coastal management in the Mediterranean is an important issue for the conservation of biodiversity and cultural heritage, and represents a chance for the sustainable use of resources. We proposed an integrated transdisciplinary method that incorporates technical and scientific disciplines combining an engineering approach to the problem of risk indices development (based on maritime traffic, morphological and hydrodynamic factors) with an ecological approach that considers the value of plant diversity at species and habitat level in a highly biodiverse, but in a increasingly stressed, system such as the Mediterranean basin. Nevertheless, transdisciplinarity does not directly ensure management success, which depends also on the complexity of the problem and the difficulties in finding compromises between protection and conservation goals on one hand, and socio economic development on the other.

The proposed approach can help in providing solutions to face common threats and pressures across the Mediterranean Basin in a more comprehensive way. Its generality and transferability, provides a common sampling strategy for biodiversity assessment, a set of criteria for prioritizing sites based on biodiversity, and protocols and equations to generate maps of environmental vulnerability and evaluate hazards and priorities. As such, the approach has the potential to become a standard framework for monitoring and assessment of projects in coastal regions for the entire Mediterranean Basin.

It can provide public administrations and local communities an easy to use instrument towards ICZM and preventing and managing unforeseen spills of hydrocarbons or other stressor menacing biodiversity, cultural heritage or other valuable elements to be protected. We believe that building a cross border network where all partners meet to share needs, objectives, expertise and results is crucial to converge towards a single strategy that has the potential to be extended to other coastal Mediterranean areas.

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Appendix A. Supplementary data
Supplementary data to this article can be found online at http://dx.doi.org/10.1016/j.jsctoret.2017.02.221.

References
Abdulla, A., Linden, O. (Eds.), 2008. Maritime traffic effects on biodiversity in the Mediterranean Sea: review of impacts, priority areas and mitigation measures. IUCN Centre for Mediterranean Cooperation, Malaga, Spain.