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Identification and prioritization of areas with high environmental risk in Mediterranean coastal areas: A flexible approach

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-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 extra-ordinary 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.

Running head: *Methodological Framework for Risk Analysis*

Keywords hazard analysis; plant diversity; risk assessment; habitat fragmentation; GREAT Med Project.

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 corresponds to narrow endemics; Thompson 2005), and around 10% of the world’s higher plants concentrated in an area covering less than 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 2005; Myers et al. 2000).

According to the IUCN (IUCN 2015), the major causes of threat to Mediterranean species include, by order of importance, habitat loss and degradation, pollution and over exploitation of natural resources (Cuttelod et al. 2008). Moreover, urbanization, tourism and industrial development are the main drivers of land cover change (Benoit and Comeau 2005; European Environment Agency 2013). It is estimated that the number of people living permanently in the Mediterranean coastal regions will increase by 1.4% per annum along the Southern and Eastern shorelines, reaching 108 million by 2025; while the Northern shorelines are expected to stabilize at about 68 million (Coudert and Larid 2006). These increases are predicted to cause the loss of 200 km per year of coastline to urban areas between the present and 2025. The Mediterranean Basin is also one of the world’s busiest areas for maritime traffic with 200,000 commercial ships crossing annually the sea and approximately 30% of international sea-borne volume originating from its ports or directed towards them (Abdulla and Linden 2008). Tourism and freight transport, offshore platforms and waste discharges from boats or affluent rivers are an additional important pollution source for the semi-enclosed sea

(Lejeusne et al. 2010; Cózar et al. 2015). The request for an easy and efficient application of ICZM to the Mediterranean Basin remains very relevant (Buono et al. 2015; Prem 2010). This is especially true when considering also that the overall response capability of many Mediterranean countries (Italy, Greece, Malta, Spain) to deal with Hazardous and Noxious Substances (HNS) incidents was still rather limited few years ago (EMSA 2013)..

Historically, engineers were the main party in charge of the management of coasts, because management was essentially focused on coastal projects that consisted of infrastructure design and construction to enhance the exploitation, or the physical protection of the coastal area (Kamphuis 2011). As such, several instruments for the assessment of vulnerability and hazard have been developed, especially in the engineering literature (Appelquist and Balstrøm, 2015; Komendantova 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 definitions of coastal management and engineering have been extended with interdisciplinarity and transdisciplinarity evolving to become the cornerstone for the future management of coastal ecosystems (Kamphuis 2011; Stock and Burton 2011). In fact, decision makers have started to feel that “simple solutions to complex problems” is not the key towards the successful management of a territory (Jackson 2006; Reyers et al. 2010). As a consequence, both the scientific communities and funding agencies are refocusing their efforts towards integrating the research outcomes from multidisciplinary research, trying to break down barriers that often prevent our shared understandings of complex issues (Jackson 2006; Stock and Burton 2011). Similarly, the concept of prioritization of sites has been widely examined for biodiversity conservation (e.g. Pressey et al. 1993; Wilson et al 2006), for public health implications in case of pollution (Harold et al 2014) but only recently as an instrument for the routine management of the territory (e.g. for harbors in Valdor et al. 2016).

Within this context, the GREAT Med project (Generating a Risk and Ecological Analysis Toolkit for the Mediterranean), funded by the ENPI CBC Med program of the European Union, aims to contribute to the development of an interdisciplinary strategy for assessing plant diversity and the main human pressures in critical areas of the Mediterranean coasts, with a view towards conservation and monitoring of natural heritage. The specific objectives of the project include the development of an accessible and understandable procedure for assessing coastal plant diversity and its vulnerability to potential stressors (such as oil spills, fragmentation of natural habitats), and the definition of an easy-to-use approach to locate and prioritize the more susceptible areas . This would provide a practical instrument for risk management in the ordinary and extra-ordinary management of the coastline. The project involves several pilot areas in four Mediterranean countries from different sides of the Mediterranean Basin (Italy, France, Lebanon and Tunisia), an engagement deemed crucial for setting up effective and standardized descriptors, criteria and indicators that take into account different ecological and socio-economic contexts. The objective of our planning was to create a methodological framework that can be used and adapted to diverse situations, i.e. different knowledge of the biodiversity of the local area, different types of threats/pressure, different socio-economic situation, different objectives of prioritization (for instance for biodiversity conservation, tourism development, oil spill emergencies).

We present a flexible and adaptable methodological approach to i) assess environmental risk in coastal areas and, accordingly, ii) prioritize the areas more prone to suffer from one (or more) selected risks.

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, Figure 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.

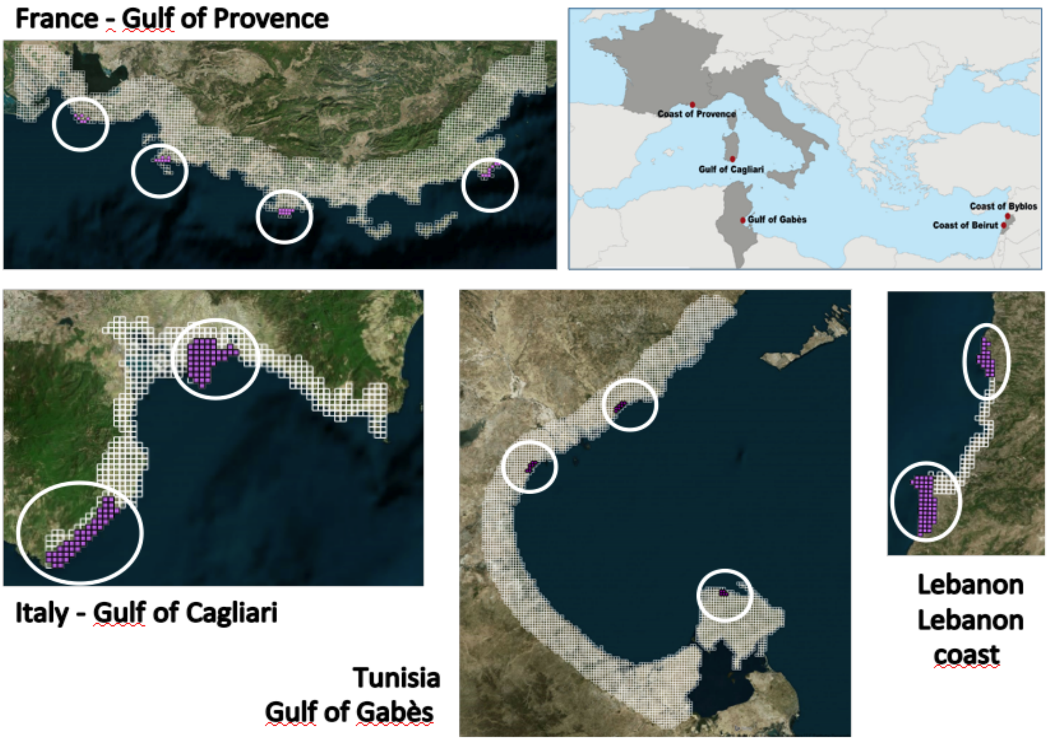
Pilot Area 1 - The Provence-Alpes-Côte d'Azur (PACA) region is at the southeastern coast of France. This region includes two National Parks, *Calanques* and *Port Cros* with terrestrial and marine protected areas and is limited to the west by the Camargue Regional Park. Tourism activities play a central role in the regional economy, with the PACA Region being the second most important touristic 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 (1971). 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 Gabés 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 Gabés cities.

Figure 1.



Location of the pilot areas in the four partner countries. Each pilot area is delimited by the white squared grid and it includes the study sites (white circles, purple grid).

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 seafront. 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 Moilanen 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 (Bazairi et al. 2010; European Environment Agency 2013). 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 figure 1) we considered habitat data, which are generally more easily available; at the site level (small extension, see figure 1) we used both species and habitat data (for more details on the plant diversity assessment see the supplementary material).

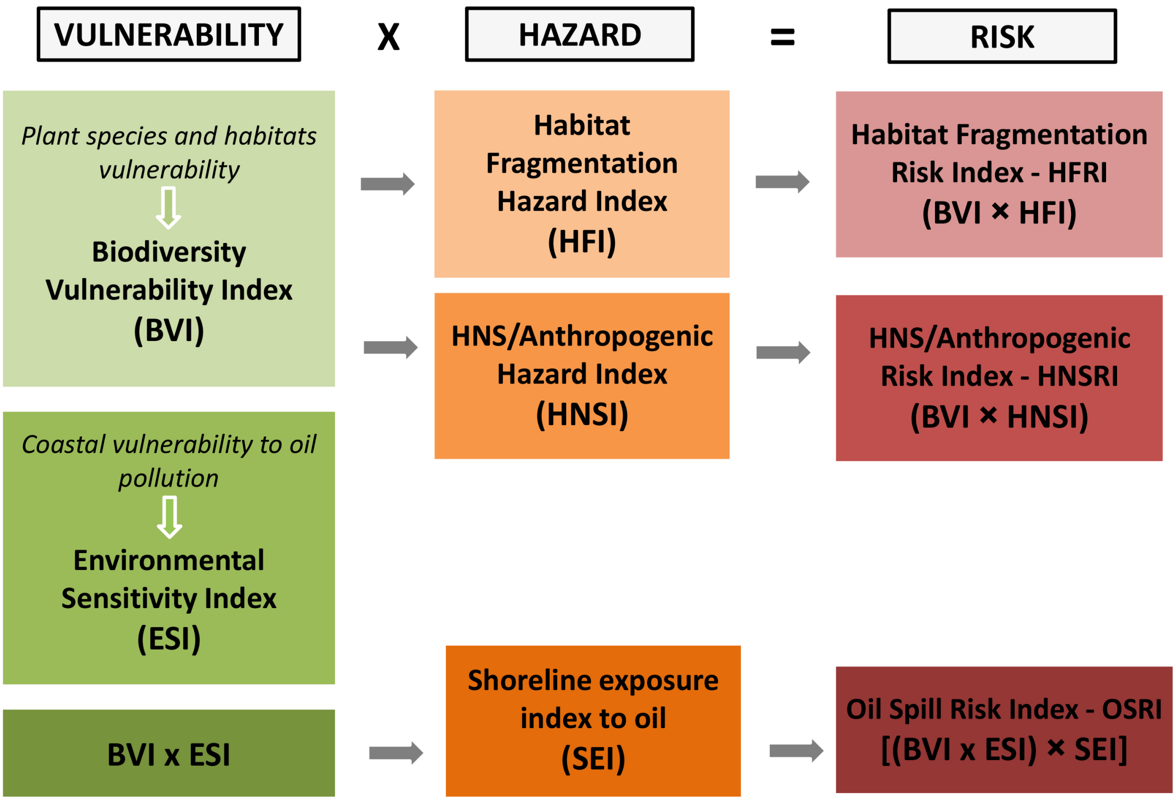


Figure 2.
Flowchart of the methodological approach.

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 figure 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 1x1 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 sq km for the IUCN red listing assessment (IUCN, 2016), a 1 sq km 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 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). 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. Shorelines 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, Mollo, and Capotorti 2011; Astiaso Garcia et al. 2013a; 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 (National Geomatics Center 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 seminatural habitats and their total length of borders (McGarigal et al. 2002). All landscape metrics refer to a standard spatial grid of 1x1 km, calculated using a 3x3 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 (Pyšek et al. 2004, 2005; Celesti-Grapow et al. 2009; Sebbens 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). Indices were calculated only for grid cells that are located along the coastline (Astiaso 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

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[1] http://www.enpicbcmed.eu/projects/library-of-deliverables and reports

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; Astiaso Garcia 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, to assign 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. Prioritizations were performed

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[2] http://www.greatmed.eu/joomla/component/content/article/reports-96

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 figure 2)

$$HFRI = BVI \times HFI$$

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 coherence of the results obtained at site vs pilot area level.

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 figure 2).

$$\mathrm{HNSRI} = \mathrm{BVI} \times \mathrm{HNSI}$$

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: $\mathrm{OSRI} = (\mathrm{BVI} \times \mathrm{ESI}) \times \mathrm{SEI}$

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

Table 1 Matrices adopted to prioritize the coastline for specific risks

HFRI or HNSRI		**A. Hazard Fragmentation Index (HFI) or HNS/Anthropogenic Hazard Index (HNSI)**				
		1	2	3	4	5
Biodiversity Vulnerability Index (BVI)	1	Very Low	Very Low	Low	Low	Medium
	2	Very Low	Low	Low	Medium	High
	3	Low	Low	Medium	High	High
	4	Low	Medium	High	High	Very High
	5	Medium	High	High	Very High	Very High
OSRI		**B. Shoreline Exposure Index to Oil (SEI)**				
		1	2	3	4	5
Biodiversity Vulnerability Index (BVI) x Environmental Sensitivity Index (ESI)	1	Very Low	Very Low	Low	Low	Medium
	2	Very Low	Low	Low	Medium	High
	3	Low	Low	Medium	High	High
	4	Low	Medium	High	High	Very High
	5	Medium	High	High	Very High	Very High

A) Combining BVI with HFI we obtained the prioritization of the coastline for the fragmentation hazard. For example, cells with the combination “Very High” identify the areas 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

B) Taking into account the morphological factors of the coastline (ESI).

3. Results

We produced the prioritization of the coastline for the three hazards analyzed, at site and area level, for the four countries (Figure 3)[3]. At the pilot area level we analyzed in Italy about 90 km of coastline, in France more than 150 km, about 80 km in Lebanon and more than 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. For the risk prioritization of fragmentation of natural ecosystems, a good correlation was observed among the results obtained at site *vs* pilot area level (205 cells; Spearman rank correlation, rho 0,74; p<0,001). The results were perfectly coherent for 72% of the cells: Lebanon cells were all coherent (100% of consensus), we observed some discrepancies in France (63% of consensus) and Italy (62% of consensus) while in Tunisia we observed a strong disagreement among the two ranking (consensus only for 21% of the cells). At the site level, the cells were assessed as more at risk/priority than at the area level for 21% of the cells and at a lower risk at the site level than at the area level for 7%.

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 more than

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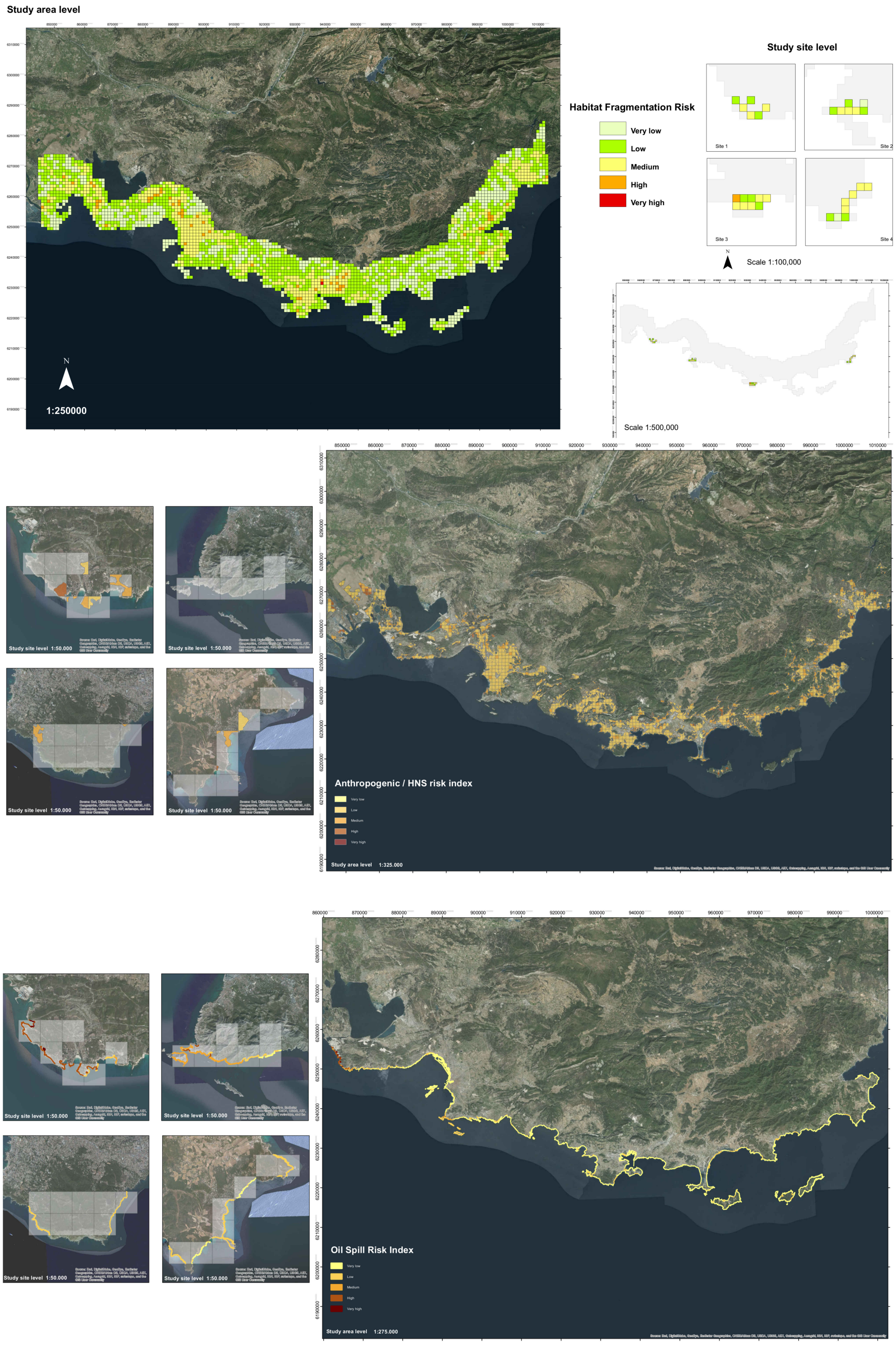
[3] A complete list and downloadable files of the produced maps are available at: http://www.greatmed.eu/joomla/component/content/article/maps-123

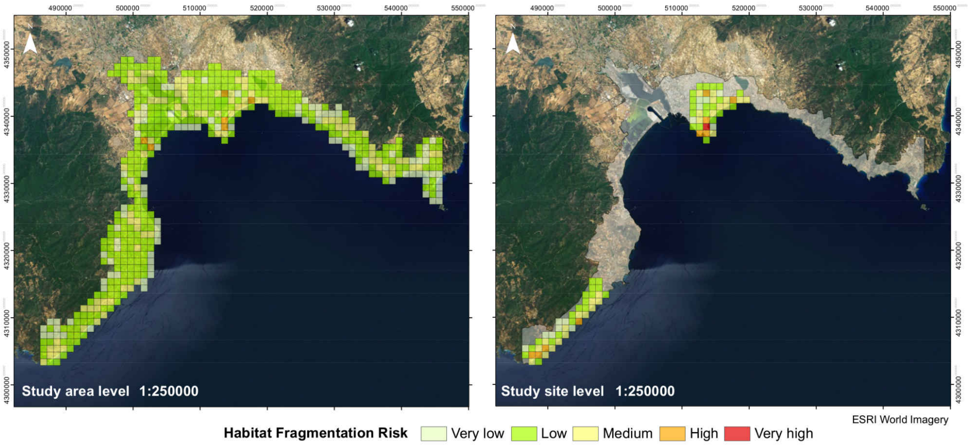
50% of the cells as "high-medium" level (in comparison to other countries accounting for less than 30%). For HNS, Lebanon and Tunisia showed the highest alert with a significant portion

Figure 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.

3a) France



3b) Italy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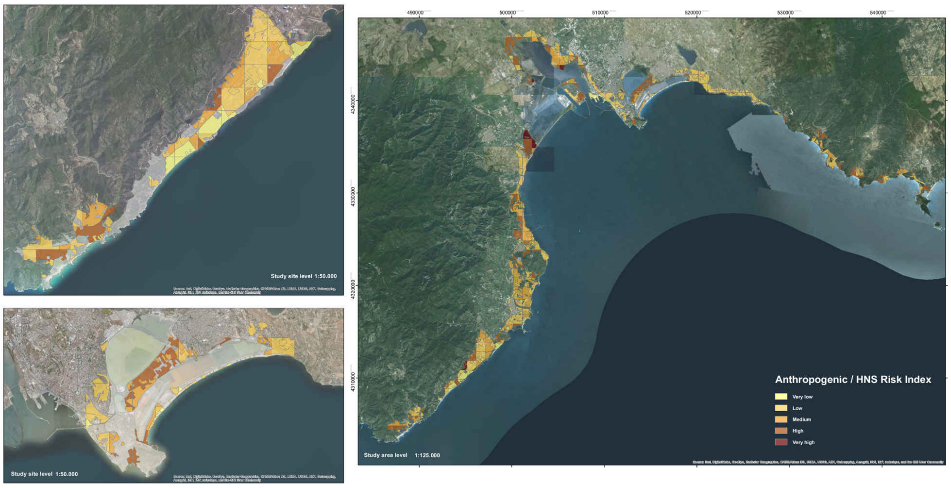
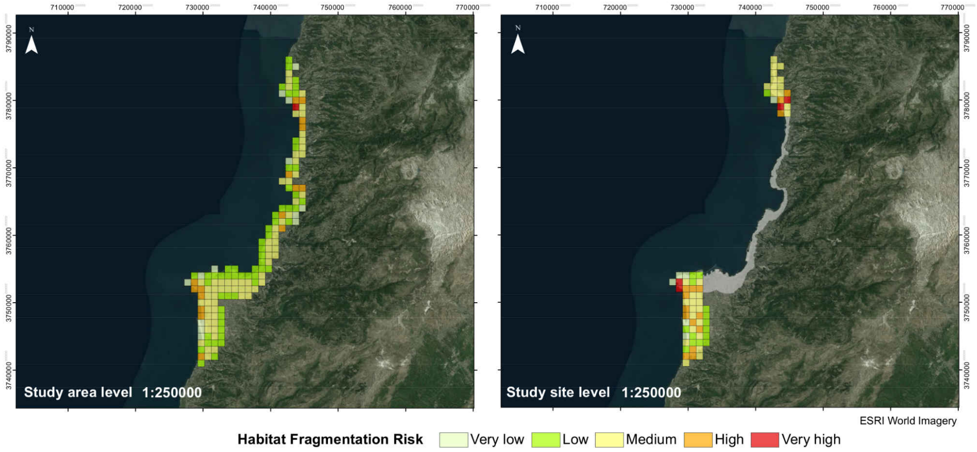
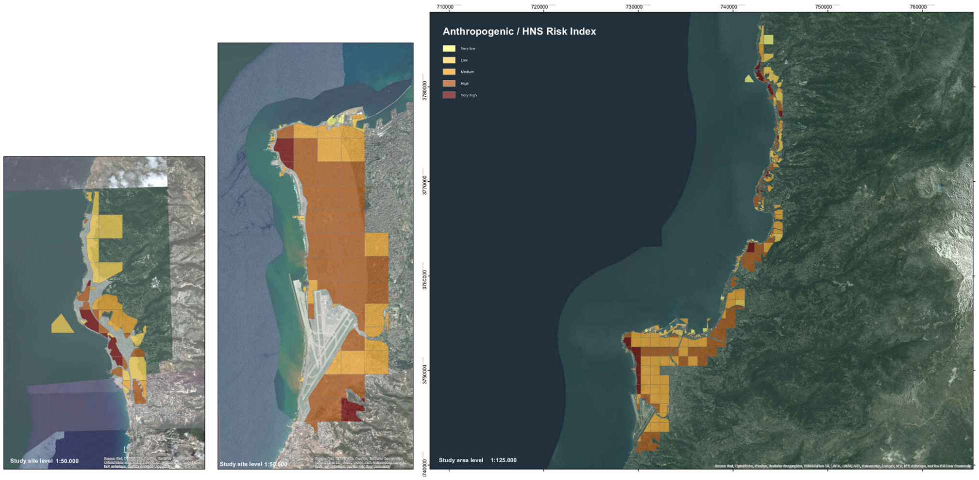
4310000
4300000
Study area level 1:250000
Study site level 1:250000
ESRI World Imagery
Habitat Fragmentation Risk
Very low
Low
Medium
High
Very high

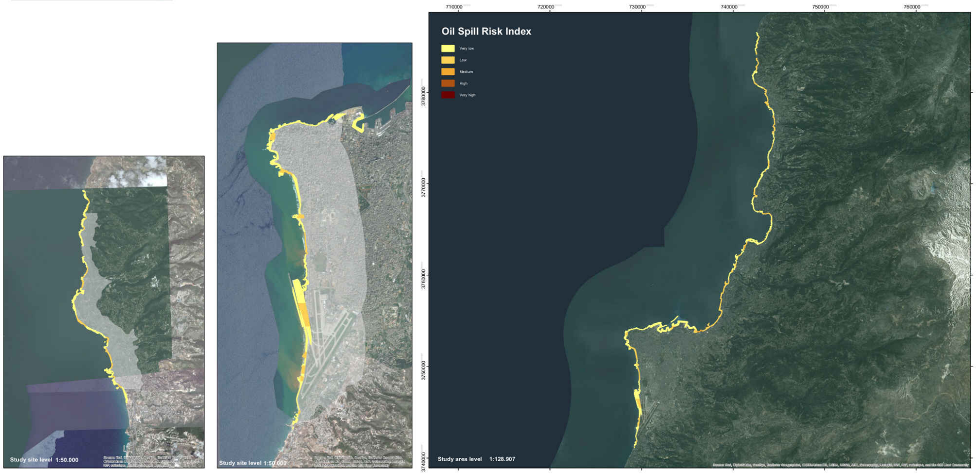

Study site level 1:50.000
Study site level 1:50.000
Anthropogenic / HNS Risk Index
Very low
Low
Medium
High
Very high
Study area level 1:125.000


Study site level 1:50.000
Study site level 1:50.000
Oil Spill Risk Index
Very low
Low
Medium
High
Very high
Study area level 1:125.000

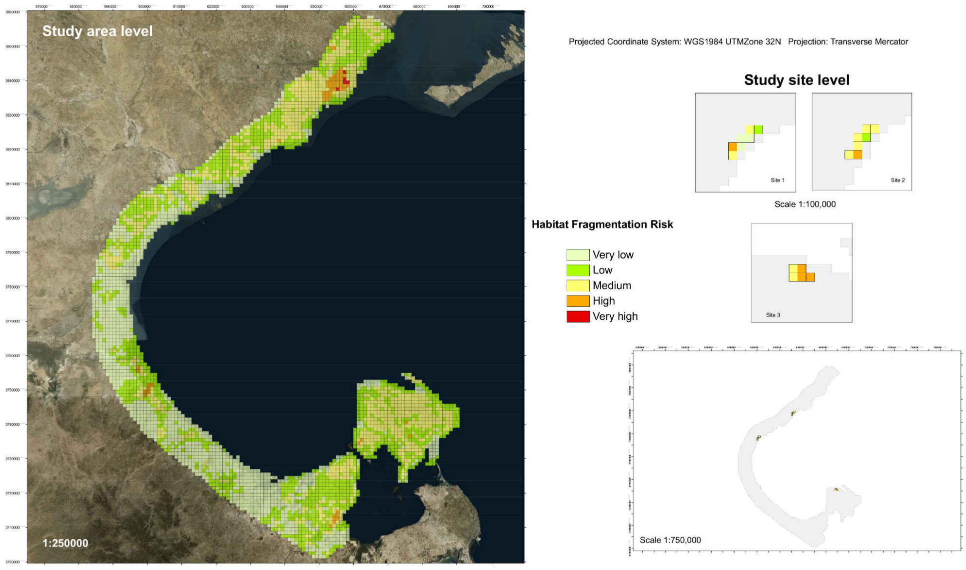
3c) Lebanon

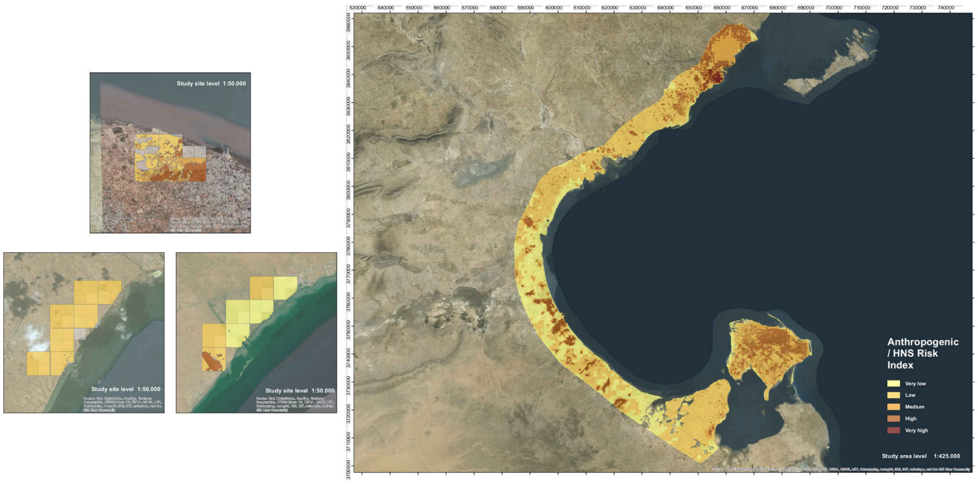

710000
720000
730000
740000
750000
760000
770000
3790000
3780000
3770000
3760000
3750000
3740000
N
Study area level 1:250000
Study site level 1:250000
ESRI World Imagery
Habitat Fragmentation Risk
Very low
Low
Medium
High
Very high

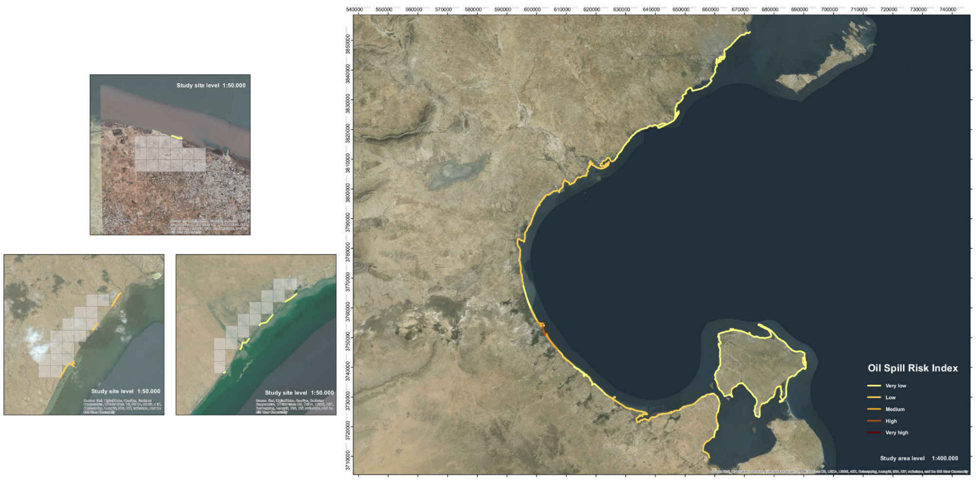

Anthropogenic / HNS Risk Index
Very low
Low
Medium
High
Very high
710000
720000
730000
740000
750000
760000
Study site level 1:50.000
Study area level 1:125.000


Oil Spill Risk Index
Very low
Low
Medium
High
Very high
710000
720000
730000
740000
750000
760000
Study site level 1:50.000
Study area level 1:128.907

3d) Tunisia


Study area level
1:250000
Projected Coordinate System: WGS1984 UTMZone 32N   Projection: Transverse Mercator
Study site level
Site 1
Site 2
Scale 1:100,000
Site 3
Habitat Fragmentation Risk
Very low
Low
Medium
High
Very high
Scale 1:750,000


Study site level 1:50.000
Study site level 1:50.000
Study site level 1:50.000
Anthropogenic / HNS Risk Index
Very low
Low
Medium
High
Very high
Study area level 1:425.000


Study site level 1:50.000
Study site level 1:50.000
Study site level 1:50.000
Oil Spill Risk Index
Very low
Low
Medium
High
Very high
Study area level 1:400.000

of areas ranked as very high-high priority (Tunisia 42%, Lebanon 25%) and less than 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 Figure 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).

Table 2 Relative ranking of the coastline according to the three different analyzed hazards: habitat fragmentation, HNS/anthropogenic substances and oil spill (data in percentage, pilot area level).

	Very High	**High**	**Medium**	**Low**	**Very low**
Habitat Fragmentation					
France	0,0	2,1	22,8	47,1	28,0
Italy	0,0	1,2	17,4	62,5	18,9
Lebanon	0,7	10,5	43,1	37,3	8,5
Tunisia	0,1	1,7	25,8	37,7	34,7
mean value	0,2	3,8	27,3	46,1	22,5
HNS/ Anthropogenic substances					
France	0,1	6,8	27,4	65,4	0,3
Italy	1,5	17,1	18,2	40,9	22,2
Lebanon	5,0	23,5	29,5	30,0	12,1
Tunisia	1,2	41,5	13,5	37,9	5,8
mean value	1,9	22,2	22,2	43,6	10,1
Oil spill					
France	0,8	2,0	0,9	21,7	74,5
Italy	0,1	6,7	9,6	33,1	50,4
Lebanon	0,0	0,0	1,4	41,4	57,3
Tunisia	0,0	23,1	18,3	36,2	22,4
mean value	0,2	8,0	7,5	33,1	51,2

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 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 to a specific hazard or to a specific element of the vulnerability (e.g. the presence of endemic species). Investigating three of the most common hazard threatening Mediterranean coastal areas, we could identify distinct areas and act properly for the singular examined hazard. For example in the Gulf of Cagliari (Italy) the areas most jeopardized by an Anthropogenic/HNS hazard are scattered along the whole coastline, with a significant part in the Molentargius Park. Oil spill risk is higher in the Western (Chia) and Eastern part of the Gulf (Villasimius) whereas, for urbanization the higher risk is located in the city of Cagliari, surrounding Capo Sant'Elia and the Poetto beach, an area under pressure for tourism exploitation all year round. When summarizing the three hazards, the Poetto area seems to be the most at risk for multiple hazards, but in a proper planning of risk management the one-action-fits-all approach is not appropriate. Therefore, to be more effective we should focus on the area surrounding Capo Sant'Elia for a strict limitation of urbanization growth, monitor the area of Molentargius for Anthropogenic/HNS hazard and invest in specific emergency planning for the occasional (but dangerous) chance of oil spill in Villasimius and Chia. In our approach, we decided to assess risks singularly, to reinforce the message that prioritization is about resource-allocation decisions, hence priority setting requires explicit and defensible objectives (Brown et al. 2015). In fact, decision science is founded on the concept that to set priorities we must at least define a clear objective and a set of actions, from which a subset will be chosen as priorities (Game et al 2013). Nevertheless, we acknowledge that a multiple hazard analyses, able to consider the cascading effects in a full multi-risk approach (e.g. Gill and Malamud 2017), could integrate the approach and improve its efficiency.

In the administration of the territory, managers frequently have to deal with multiple priorities and the request for a scientifically-sound solution is becoming increasingly pressing (Appelquist and Balstrøm, 2015; Valdor et al 2016): our flexible method can cope with different stressors (hazards) and can be weighted according to local necessities and specific urgencies. The prioritization, based on the risk assessment, will help in the ordinary and extraordinary management of those areas and assist in defining where and how to intervene in case of emergency. For example, in case of an environmental disaster (i.e. oil spill event), managers and local stakeholders will be better informed on the status of the coastline so to minimize the effect of the disaster and maximize the use of available resources. Ultimately, the adoption of this approach in different countries along with the elaboration of an integrated GIS database will provide comprehensive sensitivity, risk, and hazard layers that can be easily updated and integrated in future monitoring management programs in the Mediterranean Basin.

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 increasingly stressed, system such as the Mediterranean basin . Nevertheless, transdisciplinarity does not directly ensures management success, which depends also on the complexity of the problem and the difficulties to find 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.

Funding

The GREAT Med project was financed by the European Union (ENPI CBC Mediterranean Sea Basin Programme) through the European Neighborhood and Partnership Instrument. Its Grant Agreement is no. 39/2377.

Acknowledgments

We wish to thank Chiara D'Angeli for GIS and technical support; Mauro Fois and Selena Puddu for data and field work assistance; Claudia Cogoni for administrative and logistic assistance; Gianluigi Bacchetta for valuable suggestions during the project; Regione Sardegna - Assessorato della difesa dell’Ambiente (Servizio sostenibilità ambientale e Sistemi informativi; Servizio Tutela della natura e politiche forestali) for kindly providing the habitat maps of Natura 2000 sites for the Italian study area; the Conservatoire Botanique National Méditerranéen (Hyères, France) and Virgile Noble for extracting data from the SILENE database and Pierre-Jean Dumas for providing coastline data.

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