Journal of Environmental Management 187 (2017) 187–200

Contents lists available at ScienceDirect

Journal of Environmental Management

journal homepage: www.elsevier.com/locate/jenvman

Research article

Implications of adopting a biodiversity-based vulnerability index versus a shoreline environmental sensitivity index on management and policy planning along coastal areas

G. Harik [a], I. Alameddine [a], R. Maroun [a], G. Rachid [a], D. Bruschi [b], D. Astiaso Garcia [b], M. El-Fadel [a,*]

[a] Department of Civil & Environmental Engineering, American University of Beirut, Lebanon
[b] Department of Astronautics, Electrical & Energetics Engineering, Sapienza University of Rome, Italy

ARTICLE INFO

Article history:
Received 20 May 2016
Received in revised form
14 November 2016
Accepted 17 November 2016
Available online 28 November 2016

Keywords:
Coastal zone management
Mediterranean coastlines
Stress and vulnerability indices
Anthropogenic pollution

ABSTRACT

In this study, a multi-criteria index was developed to assess anthropogenic stressors along the Mediterranean coastline. The index aimed at geo-locating pollution hotspots for informed decision making related to coastal zone management. The index was integrated in a Geographical Information System based geodatabase implemented at several pilot areas along the Northern (Italy and France), Eastern (Lebanon), and Southern (Tunisia) Mediterranean coastlines. The generated stressor maps were coupled with a biodiversity richness index and an environmental sensitivity index to produce vulnerability maps that can form the basis for prioritizing management and mitigation interventions towards the identification of pollution hotspots and the promotion of sustainable coastal zone management. The results identified significant differences between the two assessment methods, which can bias prioritization in decision making and policy planning depending on stakeholders' interests. The discrepancies emphasize the need for transparency and understanding of the underlying foundations behind vulnerability indices and mapping development.

1. Introduction

Coastal zones are sensitive ecosystems, highly vulnerable to both natural and anthropogenic hazards. While sea level rise, tsunamis and floods are well recognized as the main natural hazards for coastal areas, anthropogenic coastal developments cause pollution, overexploitation, and fragmentation (Angelidis and Kamizoulis, 2005; Finkl and Makowski, 2013). Various methods, tools, and approaches have been developed in an effort to assess, manage, and evaluate coastal vulnerability, hazards, and risks (Appelquist and Balstrøm, 2015; EU, 2003; Komendantova et al., 2014). To date, the Coastal Vulnerability Index (CVI) remains the most commonly used index/indicator for areas with poor data (Pendleton et al., 2005; Ramieri et al., 2011; Thieler and Hammar-Klose, 2000a, b). Recent work has focused on developing coastal hazard assessment tools that go beyond the largely physical-based CVI. The integration of socioeconomic factors alongside physical and environmental features has been shown to present a more holistic characterization of coastal vulnerabilities (Boruff et al., 2005; Ceia et al., 2010; Thatcher et al., 2013; Wamsley et al., 2015). Yet, the adoption of such an approach is still limited (Boruff et al., 2005), largely due to data constraints. Moreover, recent vulnerability characterization efforts have made use of data derived from Geographic Information Systems (GIS), remote sensing, and dynamic computer models (Butt and Li, 2015; Hassaan, 2013; Musaoglu et al., 2015; Pendleton et al., 2005; Szlafsztein and Sterr, 2007; Taubenböck et al., 2008; Thumerer et al., 2000); however the use of such models has also been limited by the lack of spatial data and/or the need for specialized expertise (Mcleod et al., 2010; Ramieri et al., 2011).

While hazard assessment- in the sense of identifying and evaluating the potential degree of harm for each type of hazard (EU, 2003)- is not new, the main focus has often been constrained to natural hazards or to specific types of anthropogenic activities i.e. oil spills or industrial pollution (Bakkensen et al., 2016; Castanedo et al., 2009). Cost Action 620 under the European Water Framework Directive can be singled out for its comprehensive methodology

* Corresponding author.
E-mail address: mfadel@aub.edu.lb (M. El-Fadel).

http://dx.doi.org/10.1016/j.jenvman.2016.11.038
0301-4797/

Fig. 1. Pilot areas (White highlights designate boundaries of assessed zones).

that aims to quantify both anthropogenic and natural hazards. However, its applicability has so far been limited to studying vulnerabilities and risks associated with carbonate aquifers (EU, 2003).

Historically, the Mediterranean has witnessed intense human activities due to its strategic location between three continents. The coastline has thus been affected by high maritime traffic along with a wide range of anthropogenic stressors, including industrialization, urbanization, tourism, agriculture, fishing, and over-exploitation of resources. These stressors have led to pollution, loss of species and habitats, as well as the degradation and fragmentation of ecosystems. While such stressors are encountered all along the Mediterranean, their frequency, intensity and impacts

Table 1
Generated thematic layers characterizing potential anthropogenic pollution stressors (attributes in bold are those used for stress quantification).

Hazard	Attributes
Agriculture	Name, Type, **Intensity (Fallow/Organic/Light Conventional/Moderate Conventional/Heavy Conventional),** Area (in km^2), Fertilizer Use (Yes/No)
Urban areas	Name, **Urbanization intensity (Rural/Moderate/Heavy)**, Area (in km^2), Presence of sewage network (Yes/No), Waste Water Treatment Plant (WWTP) (Yes/No), WWTP Treatment technology (None/Primary/Secondary/Tertiary), Number of outfalls
Tourism establishments	Name, **Area (in km^2),** Connected to sewage network (Yes/No), Presence of a WWTP (Yes/No), WWTP treatment technology (None/Primary/Secondary/Tertiary), Numbers of outfalls, Volume of wastewater discharge (m^3/day), Presence of a Marina (Yes/No), Includes sea filling activities (Yes/No)
Ports and marinas	Name, **Type (Wharf/Marina in resort/Marina/Oil Terminal),** Size (Small/Medium/Large), **Area (in km^2),** Connected to sewage network (Yes/No), Presence of a WWTP (Yes/No), Vessels, Includes sea filling activities (Yes/No), Storage tanks (Yes/No), Activity level (arrivals/day)
Industries	Name, Type, **Size (Small/Medium/Large),** Area, Sewage network connection (Yes/No), Outfall Number, **Storage tanks (Yes/No)**, Inclusion of Port (Yes/No), Work Status (Active/Closed), Polluting Status (Yes/No)
Airport	Name, **Area (in km^2),** Storage tanks (Yes/No)
River mouth[a]	Name, flow, watershed area
Landfill	Name, Status (Closed Landfill/Active Landfill/Closed Open Dump/Active Open Dump), **Area (in km^2),** Leachate discharge (Yes/No), Presence of a WWTP (Yes/No)
Outfall	Name, Type (Domestic/Industrial/Agricultural), Discharge Rate (in m^3/day), Onshore outlet (Yes/No), Offshore outlet (Yes/No), Length in sea (in meters), Depth (in meters)
Waste water treatment plant	Name, **Treatment type (Primary/Secondary/Tertiary/Inactive),** Area (in km^2), **Volume treated (in m^3/day)**
Oil platforms	Name, Type (Drill barge/Drill ship/Jack up/Platform/Semisub), Status (Drilling/Production/Inspection), **Production rate (in m^3/day),** Accident (Yes/No), Age
Maritime traffic	Accident (Yes/No), Length of line (in Km), **Traffic volume (vessels/day)**
Oil and HNS tanks	Name, Type, **Volume (in m^3),** Frequency of filling (per month)

[a] River mouths may not be an evident source of coastal pollution. Yet in the Mediterranean, they are classified as such because according to UNDP-MAP (2012) and UNEP-MAP-RAC/SPA (2010), the four major rivers flowing into the Mediterranean (Ebro, Rhone, Po, and the Nile) along with tens of other smaller rivers are invariably point sources of pollution, as these rivers carry untreated domestic and industrial wastewaters and agricultural runoff from upstream areas to estuaries and into the sea. In this study, a panel of technical experts under the GREAT MED project was consulted about their understanding of river-based pollution. All members across the four countries opined that river mouths are a potential land based source of pollution. As such, the river mouth was considered an anthropogenic stressor.

Table 2
ESI value and coast Type (Modified NOAA classification adapted from De Santoli et al. (2011)).

ESI designation	Coast description
1A	Exposed high rock shores
1B	Exposed artificial coastal structures
2	Exposed low impermeable shores
3	Compact clay or muddy sand beaches
4	Sandy beaches
5	Mixed sand and gravel beaches
6A	Gravel and pebbles beaches
6B	Shores with big natural rocks
6C	Artificial reef
7	Exposed tidal flats
8A	Sheltered high rocky shores
8B	Sheltered artificial coastal structures
8C	Sheltered low impermeable shores
9	Sheltered tidal flats
10	Marshes and brackish shores

vary spatially and temporally. Hence, it is important to develop a spatial stressor index that considers the totality of pollution from anthropogenic sources (industrial, agricultural, residential, maritime traffic, tourism) along Mediterranean coastlines. Such an index aims at facilitating the identification of hotspots and forming the basis for stress mapping, both of which are integral elements towards promoting informed coastal zone management.

While various methods have been developed for pollution hazard assessment (Appelquist and Balstrøm, 2014; Komendantova et al., 2014; Mcleod et al., 2010; Ramieri et al., 2011; Thieler and Hammar-Klose, 2000a, b), they have often been limited by the lack of data availability and field verification. This study, carried out within a European Neighborhood Policy (ENP) funded project (GREAT Med), combines primary and secondary sources of data with an expert elicitation process to develop a multi-criteria pollution index that quantifies the totality of anthropogenic stressors along coastal areas. The index is then coupled with a Biodiversity Richness Index (BRI) and an Environmental Sensitivity Index (ESI) to quantify coastal anthropogenic vulnerabilities. The proposed method is implemented at several pilot areas along the Mediterranean coastline as a means to highlight its potential applicability and transferability. Differences between the two generated vulnerability maps are highlighted to illustrate potential liabilities associated with adopting such indices by governmental bodies for coastal zone management and to emphasize the need for transparency.

2. Material and methods

2.1. Definition of pilot areas

The Mediterranean coast consists of about 46,000 km of

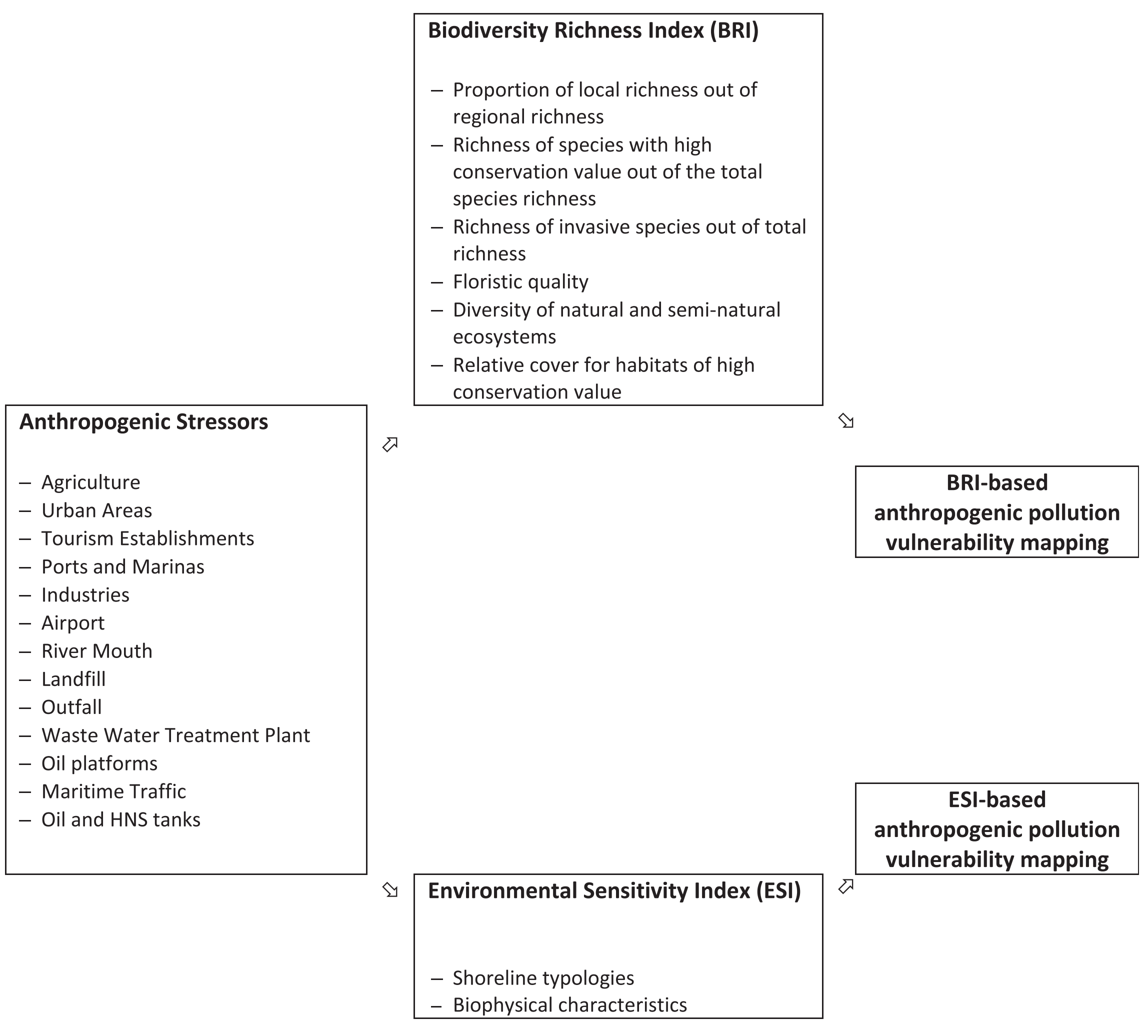


Fig. 2. Coastal hazard and vulnerability mapping framework.

shorelines that stretch along southern Europe, western Asia and northern Africa, encompassing 21 basin countries. In this study, four pilot coastal areas along the Mediterranean in France, Italy, Lebanon, and Tunisia were targeted (Fig. 1). In France, the Provence-Alpes-Côte d'Azur (PACA) region was selected. It is characterized by several protected sites (national parks, wetlands and sustainable agriculture) and houses four oil refinery plants, a thermal power plant, the port of Marseille, and the harbor of Toulon (Provence Alpes Côte-d'Azur, 2014). In Italy, the Gulf of Cagliari was chosen. It is rich in archaeological sites and includes sensitive and natural protected areas besides being a prime touristic destination. Cagliari also harbors many anthropogenic stressors including an oil refinery, petrochemical plants, petroleum storage tanks, a gasification combined cycle power plant, a port, and an airport. The pilot area in Lebanon stretched from the densely urbanized metropolitan of Beirut up north to Byblos, a UNESCO world heritage site. The 50 km coastal stretch is dotted with fuel storage tanks, industrial complexes, and thermal power plants, along with important archaeological and natural sites. Finally, the Gulf of Gabes in Tunisia was selected given its highly productive fishing area that is characterized by a rich diversity of landscapes. Gabes also embraces multiple oil terminals and offshore oil and gas platforms.

2.2. Anthropogenic stress index

Along the coastal zones of the four countries, anthropogenic pollution stressors were defined as any potential source of contamination, damage or destruction resulting from human activities. These stressors included both land and marine-based pollution sources (Flax et al., 2002). A total of 13 hazards were identified based on a systematic approach that encompassed a literature review, pilot field assessments, an expert elicitation process, and then extensive field surveys (GREATMed, 2015a). For each hazard type, specific attributes were pursued and used in the subsequent stress quantification. Table 1 summarizes the attributes adopted for each hazard type. The stress data were then collected through secondary and/or primary data sources. Coastline surveys were undertaken to identify coastal stressors and collect/verify needed attributes. Site visits to specific coastal facilities were also carried out to collect relevant data. The geographic locations of identified hazards were then digitized and mapped using ESRI's ArcGIS 10.3 (ESRI, 2015). Each stress type consisted of a polygon feature class incorporated within a national geodatabase. Country-specific expert panels from the four study sites were then asked to validate the generated databases. A more detailed discussion of pollution source identification is presented in a recently published report (GREATMed, 2015a).

Data collected for each stress type (Table 1) were then used to better characterize the pollution potential of each facility on the coastal environment. In an effort to compare the severity of various stressors, the opinion of an expert panel of 18 environmental and chemical engineers, scientists and practitioners was elicited. Each expert was asked to rate the severity of identified stressors based on a scale from 1 to 10, with 1 representing the lowest stress and 10 the highest. Before each elicitation, the experts were briefed by the interviewer about the typical pollution concerns associated with each stressor. They were then asked to consider the environmental degradation associated with 100 hypothetical coastal sites along the Mediterranean that are impacted by the stressor of interest. The experts were then requested to compare those hypothetical sites to a pristine site that is devoid of anthropogenic stress as well as to a degraded site that has lost its biodiversity and has been physically disturbed and is beyond recovery. The experts were then asked individually to rank the worst as well as the least disturbed of the 100 hypothetical sites on a semi-quantitative scale ranging from 1 to 10, with 1 representing the pristine site and 10 corresponding to the impaired site. They were then invited individually to rank the median hypothetical site on the same scale. The same procedure was conducted for all 13 stressors. The adopted approach provides meaningful guideposts and ensures that the stressors are ranked on the same semi-quantitative scale. This in turn allows for comparing stressors against each other. Note that the relative scores between the different stressor groups is more important than the assigned absolute score. The elicitation data were then combined across experts to generate one unified scale for each stressor type. Aggregation across experts was conducted by averaging expert defined median, minimum, and maximum scores for each stressor.

Table 3
Anthropogenic stressors statistics based on expert elicitation (Hazard scale ranges between 1 and 10 with larger values signifying higher stressors).

Anthropogenic activity	Average	Mode	Minimum	Maximum
Industries	8.2	8	4.6	9.8
Urban areas	7.0	6	4.1	8.8
Ports and marinas	7.6	8	4.8	9.3
Landfills	7.8	8	5.3	9.5
HNS storage tanks	7.2	8	4.9	9.3
Fuel storage tanks	7.2	8	4.7	9.2
Oil rigs/wells	7.0	8	5.3	9.1
Maritime traffic routes	7.0	6	4.5	8.6
Outfalls	7.0	6	4.2	8.8
Tourism	6.6	6	3.8	8.1
Airports	6.0	6	3.8	7.6
River mouths	5.8	6	3.3	7.9
Agricultural areas	5.6	6	3.3	7.3
WWTPs	5.6	6	3.4	7.8

A subset of attribute(s) was selected to act as a surrogate of the underlying environmental threats posed by each anthropogenic stressor. The selection of attributes was based on data availability and the ability of the attribute to capture the relative polluting intensity for that category. Given data limitations across the four countries, important attributes were not usable. A linear interpolation approach was then adopted to map between the collected attribute data and the expert-defined stress ranges, which ensures that the maximum score for a given pollution source is assigned to the facility/area associated with the highest set of negative attributes. Similarly, the minimum stress score elicited through the experts was assigned to the facility/area that had the lowest pollution status in a given category. Note that in the event that multiple attributes were used to quantify the hazard, the selected attributes were given equal weights. A different apportionment of weights could be conducted based on an expert elicitation process as part of a Multi Criteria Decision Analysis approach.

2.3. Biodiversity richness index – BRI

Biodiversity indicators were based on a biodiversity database generated for the four pilot areas within the GREAT Med project. The database quantified biodiversity as a function of species richness, richness of species with high conservation value, diversity of natural and semi-natural ecosystems, and relative cover of habitats of high conservation value (GREATMed, 2015b). The BRI scored the biodiversity of coastal areas on a scale between 1 and 10, with 1 representing the least diverse sites and 10 the sites with the highest diversity. The scores were reported at a scale ranging between 0.5 and 3 km, depending on the site and the biodiversity aspect considered.

2.4. Environmental sensitivity index – ESI

A modified version of the Environmental Sensitivity Index (ESI)

Table 4
Quantification of stress levels for anthropogenic activities linked to one attribute.

Anthropogenic activity	Attribute	Attribute value	Stress
Urban areas	Intensity	Rural	4.1
		Moderate	6.4
		Heavy	8.8
Landfills	Area (km^2)	0.068	5.3
		0.685	9.5
Oil and HNS tanks	Storage Volume (m^3)	0.5	4.7
		84200	9.3
Oil rigs	Production rate (m^3/day)	2	5.3
		48	9.1
Tourism establishments	Area (km^2)	0.008	3.8
		0.252	8.1
Maritime traffic	Traffic Volume (vessels/day)	0.34	4.5
		6.84	8.6
Airports	Area (km^2)	0.251	3.8
		9.713	7.6
Agricultural areas	Intensity	Fallow	3.3
		Organic	4.3
		Light Conventional	5.3
		Moderate Conventional	6.3
		Heavy Conventional	7.3

Table 5
Quantification of anthropogenic stressors for the anthropogenic pollution sources linked to two sets of attributes.

Anthropogenic activity	Attribute 1	Attribute value	Attribute 2	Attribute value	Stress
Industries	Size	Small (2.3)	Storage tanks (m^3)	N (2.3)	4.6
				Y (4.9)	7.2
		Medium (3.6)		N (2.3)	5.9
				Y (4.9)	8.5
		Large (4.9)		N (2.3)	7.2
				Y (4.9)	9.8
Ports and marinas	Type	Wharf (2.4)	Area (km^2)	0.0002 (2.4)	4.8
				3.975 (4.65)	7.0
		Marina in resort (2.96)		0.0002 (2.4)	5.4
				3.975 (4.65)	7.6
		Marina (3.52)		0.0002 (2.4)	5.9
				3.975 (4.65)	8.2
		Ports and Marinas (4.1)		0.0002 (2.4)	6.5
				3.975 (4.65)	8.7
		Oil Terminal (4.65)		0.0002 (2.4)	7.0
				3.975 (4.65)	9.3
WWTPs	Treatment	Inactive (1.7)	Treatment volume (m^3/day)	260 (1.7)	3.4
				175000 (3.9)	5.6
		Tertiary (2.43)		260 (1.7)	4.1
				175000 (3.9)	6.3
		Secondary (3.17)		260 (1.7)	4.9
				175000 (3.9)	7.1
		Preliminary (3.9)		260 (1.7)	5.6
				175000 (3.9)	7.8

developed by the National Oceanic and Atmospheric Administration (NOAA) was also used to quantify environmental vulnerability of the coastline to pollution sources. The ESI primarily assesses coastal sensitivity towards oil pollution based on shoreline biophysical characteristics[1] (Michel et al., 2002; IPIECA-IMO-OGP, 2012). In this study, a Mediterranean-specific ESI index was adopted to define the coastal sensitivity based on 15 coastal typologies (Table 2) as compared to NOAA's original 28 typologies encountered along the US shores. Both indices rate coastal sensitivity on a scale between 1 and 10, with 1 representing the lowest sensitivity and 10 for sites deemed to have the highest sensitivity. In this study, coastal typology and associated sensitivity were assessed using high-resolution satellite and aerial images as well as field observations. High resolution images were based on Google Earth and ESRI's World Imagery that provide satellite and aerial imagery at a spatial resolution between 0.5 and 15 m. These images are a combination of IKONOS, Quickbird, and the coarser eSat data. Moreover, georeferenced aerial photographs of the coastline were consulted when available. Shoreline typology and sensitivity were digitized and integrated in the vulnerability analysis.

2.5. Mapping pollution vulnerable areas

Coastal vulnerability maps were generated for the four pilot areas by integrating the multi-criteria anthropogenic stress index with the BRI and ESI layers separately (Fig. 2). Vulnerabilities were quantified as the product of the stressor and the associated sensitivity/richness. In this study, vulnerability was defined based on the framework proposed by Füssel (2007) with respect to identifying the system of interest, its attribute(s) of concern, the hazards (or

[1] Based on slope and substrate type, as well as exposure to waves and tidal energy which can dilute or dissipate pollution.

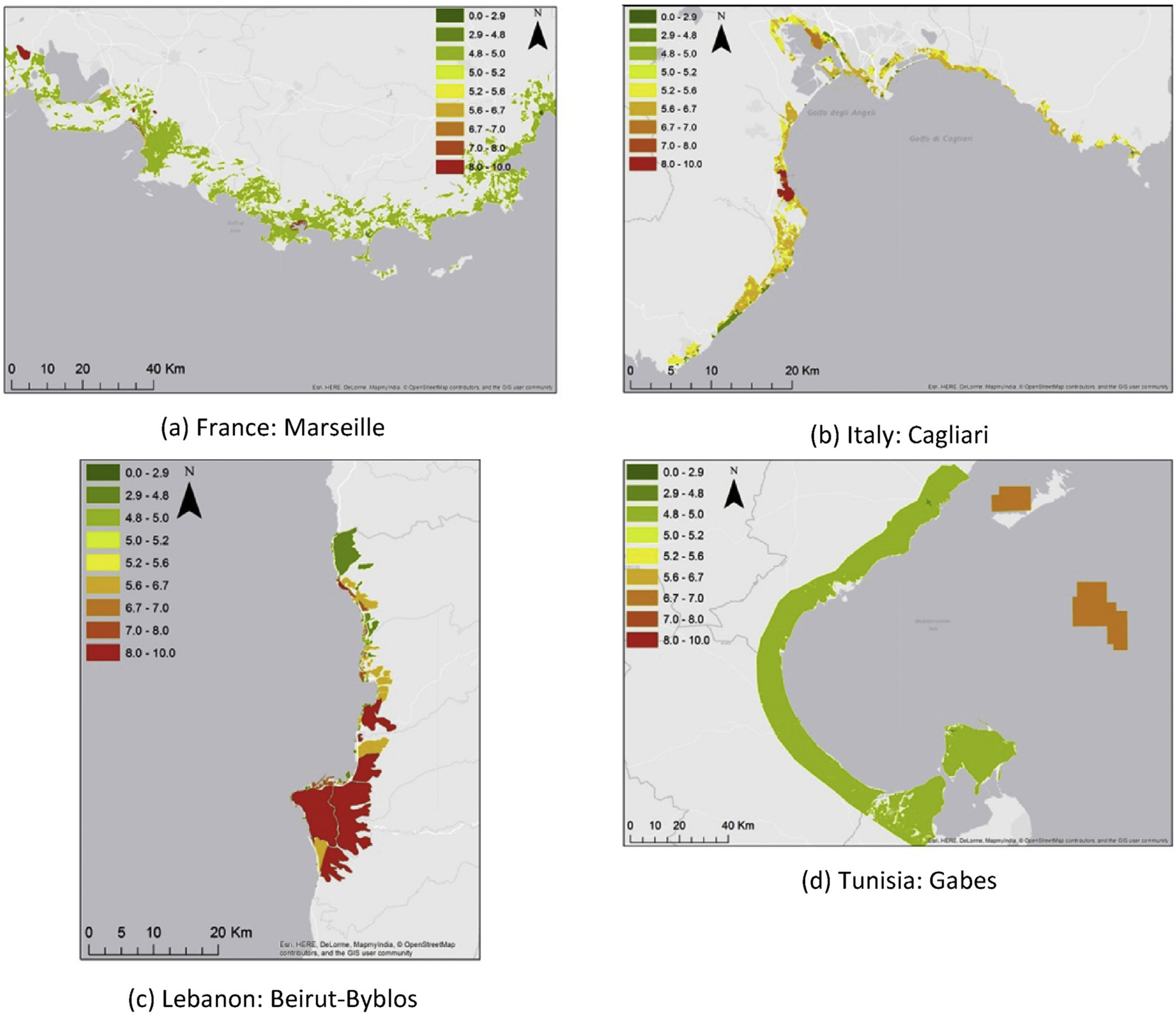


Fig. 3. Anthropogenic stress mapping (Green color represents low stress; red color represents high stress). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

stressors), and the temporal reference of the study. The Wilcoxon test, a non-parametric paired rank-based test, was used to assess the similarity between the two generated vulnerability assessment maps. Note that coastal vulnerabilities have been assessed on the basis of physical and environmental factors exclusively (Ashraful Islam et al., 2016; Bagdanavičiūtė et al., 2015; Doukakis, 2005; Gornitz, 1990; Gornitz et al., 1994; Kumar and Kunte, 2012; Nageswara Rao et al., 2008; Pendleton et al., 2005; Shaw et al., 1994; Thieler and Hammer-Klose, 1999; Yin et al., 2012) or with the integration of socioeconomic factors (Boruff et al., 2005; Devoy, 2008; Kunte et al., 2014; Mahapatra et al., 2015; ManiMurali et al., 2013; Szlafsztein and Sterr, 2007). In this study, the adopted assessment of coastal vulnerability towards anthropogenic pollution is based purely on physical and environmental factors. Socioeconomic factors that may ameliorate/compound the overall vulnerability of a system were not included due to the paucity of uniform data on these metrics across the four countries representing the study area. The integration of social vulnerability has often been limited due to difficulties in quantification (Bakkensen et al., 2016; Cutter et al., 2003). Recent studies have highlighted the importance of accounting for resilience when assessing vulnerabilities to natural hazards that are expected to intensify with a changing climate (Adger et al., 2005; Beatley, 2012; Nicholls and Branson, 1998; Orencio and Fujii, 2013). Yet, the quantification of coastal resilience towards anthropogenic stressors is difficult (Montefalcone et al., 2011).

3. Results and discussion

3.1. Anthropogenic stressor index

The expert elicitation allowed for the rating of anthropogenic stressors on a quantifiable scale. Industrial activities received the highest mean stressor rating, while agricultural areas and WWTPs received the lowest mean hazard (Table 3). Note that the experts reported a wide range of potential pollution related stress intensities for each category reflecting the importance of collecting site-specific data to better distinguish between facilities within a given group. The stress score for anthropogenic activities at the four pilot areas was based on the relevant attribute of collected data

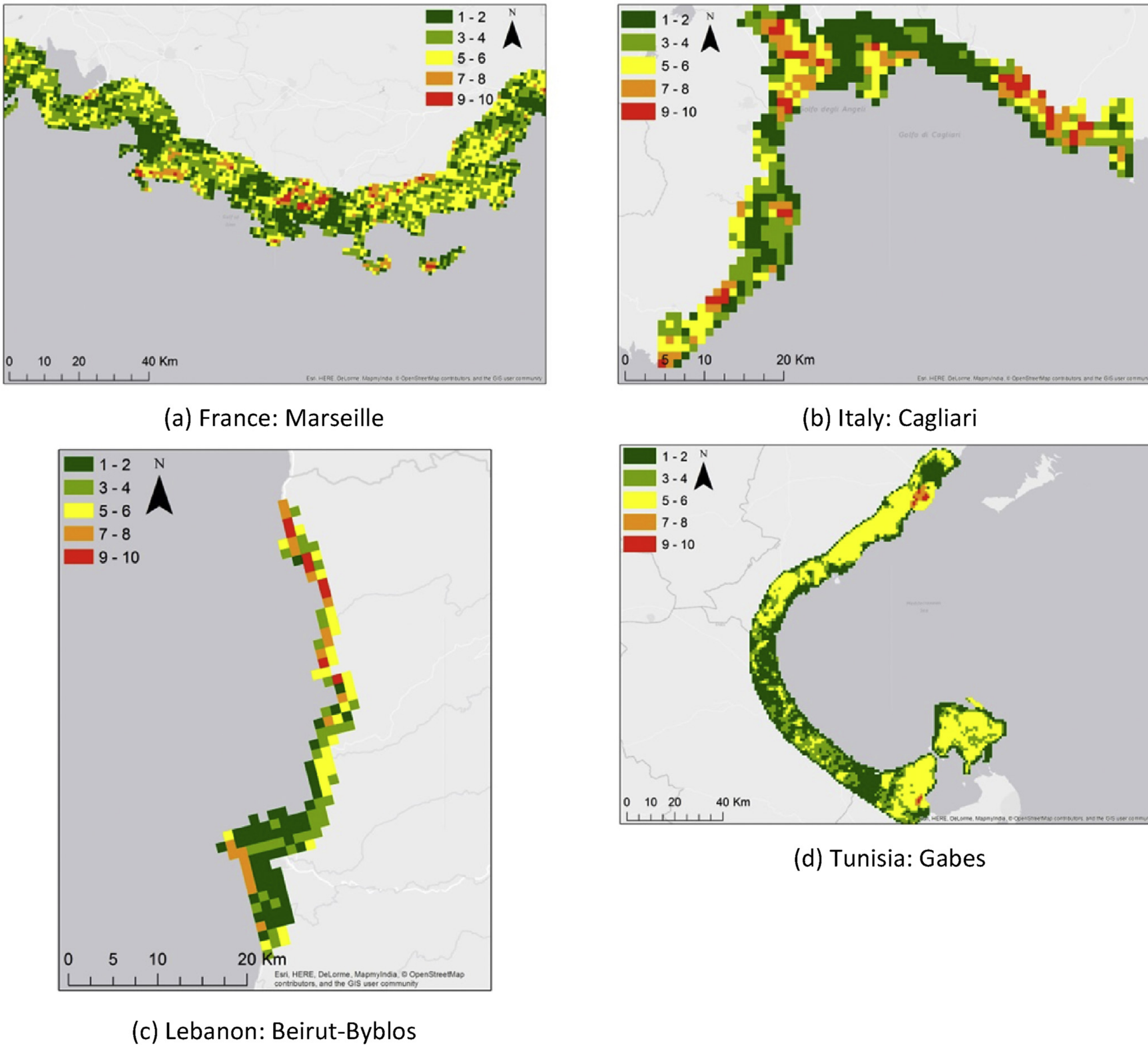


Fig. 4. BRI-vulnerability mapping.

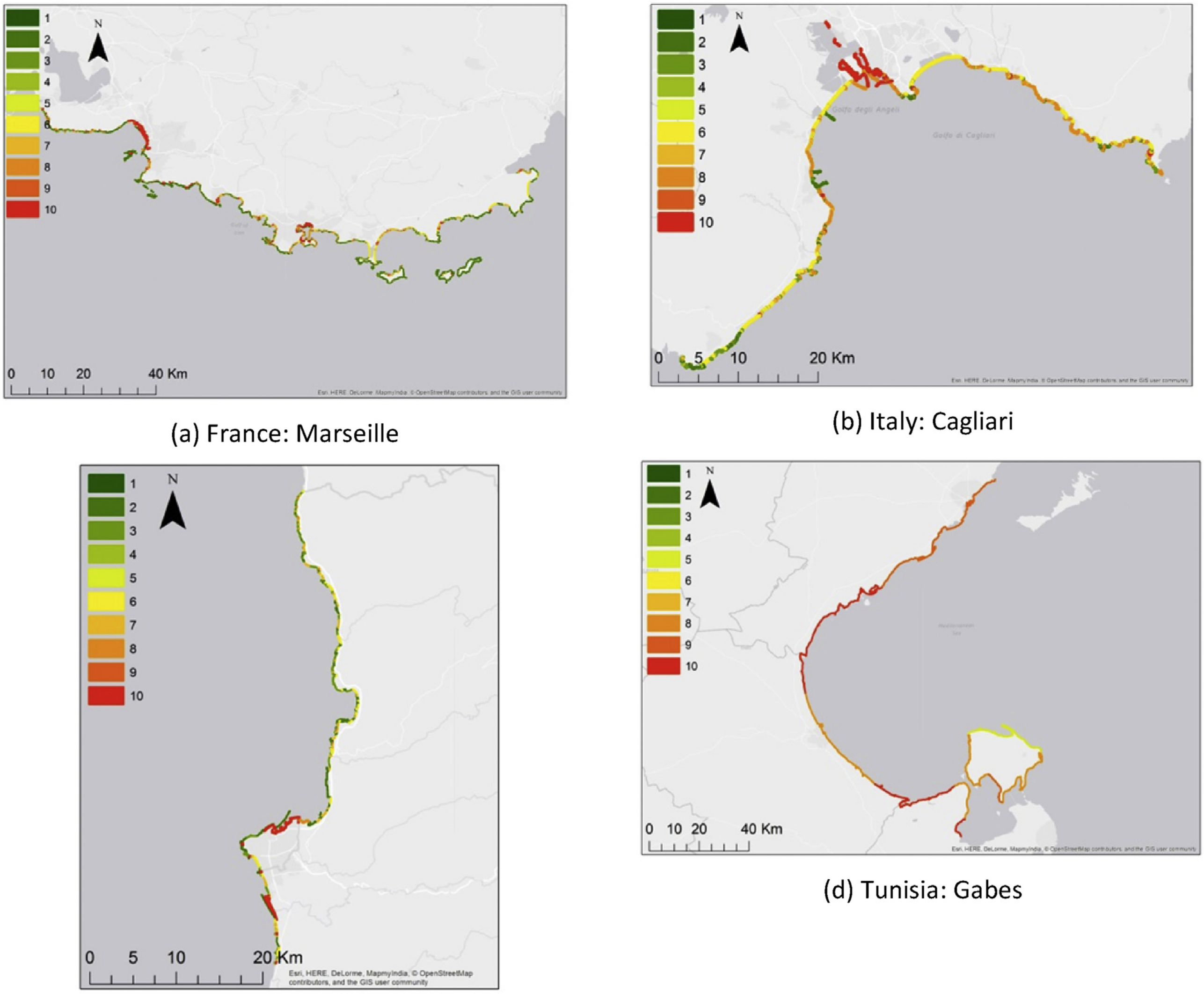
(Tables 4 and 5). The site-specific stressors were then mapped across the four study sites. Areas with a high potential for anthropogenic pollution along the French coast (Fig. 3a) were limited to the port of Marseille Fos, the port of Toulon, and the Marseille Provence airport. Overall, the French coastline had a mean stress index of 6.8. Along the Italian coastal zone (Fig. 3b), the highest stress indices were encountered mostly along the Western parts of Cagliari; that section of the island is associated with large industries, ports, marinas and fuel storage tanks especially in the port of Cagliari and Sarroch oil refinery, which reflected the highest hazard in the area. Along the eastern shorelines, moderate anthropogenic stressors dominated; urbanized and agricultural areas were the main sources of stress in that section of the bay. Along the Lebanese coastal zone, locations in the vicinity of Beirut city had elevated pollution stress due to intense urbanization, lack of operational WWTPs, and the presence of fuel storage tanks. Moving northward towards Byblos, the levels of pollution dropped as light agricultural activities replaced urbanization and industrialization activities (Fig. 3c). In Tunisia, stress levels were moderate across large segments of the bay of Gabes (Fig. 3d); this is largely attributed to the dominance of agricultural activities (overall mean index = 5.0). Sites with a high potential pollution level in Gabes were limited to the oil and gas operations within the bay especially in the Gharbi Island.

3.2. Biodiversity richness index — BRI

The BRI mapping (Fig. 4) showed that the pilot areas had highly biodiverse segments (Table 6). Unlike the anthropogenic stressor

Table 6
Summary of BRI statistics.

BRI	France	Italy	Lebanon	Tunisia
Minimum	2	2	2	2
Maximum	10	10	10	10
Mean	4.3	4.6	4.4	4.1
Standard deviation	2.0	2.5	2.4	1.8



(a) France: Marseille

(b) Italy: Cagliari

(c) Lebanon: Beirut-Byblos

(d) Tunisia: Gabes

Fig. 5. ESI mapping.

maps, where scores are comparable across sites, the BRI are based on regional richness and as such are country specific. Along the French shorelines, biologically diverse areas were concentrated around natural sites and traditional villages like Goudon, where national parks exist. Agricultural lands were co-located with areas that had relatively low to medium biodiversity sites. As for urban and industrial sites, they were shown to be less diverse. Certain sites along the Italian study area, located mainly at agricultural or fallow lands, reflected high diversity. Stagno Di Cagliari, a recognized wetland site of international importance under the Ramsar Convention, is another biologically important location near the port of Cagliari. To the east of the wetland, the most biodiverse area is located between Terra Mala and Torre Delle Stelle, where large swaths of vegetated areas occur. Similarly to the west, biologically diverse areas were concentrated around forested sites. Richness along the Lebanese coast was found to be very fragmented. Highest biodiversity levels were encountered between the cities of Jounieh and Byblos, where urbanization slows down. Along the Tunisian coast, areas with high biodiversity were few and mostly located in the vicinity of agricultural lands, especially south of the industrial zone of Sfax. The latter had low biodiversity levels.

3.3. Environmental sensitivity index – ESI

Fig. 5 presents the outcome of the environmental sensitivity

Table 7
Summary of ESI statistics.

ESI	France	Italy	Lebanon	Tunisia
Minimum	1	1	1	3
Maximum	9	10	8	9
Mean	3.8	4.4	2.9	6.8
Standard deviation	2.6	2.1	1.9	1.8

Table 8
Summary of BRI-based vulnerability statistics.

Vulnerability	France	Italy	Lebanon	Tunisia
Minimum	5.89	7.6	6.1	6.9
Maximum	59.8	70.0	100.0	49.8
Mean	18.6	25.9	30.5	22.2
Standard deviation	8.6	14.0	17.2	8.9

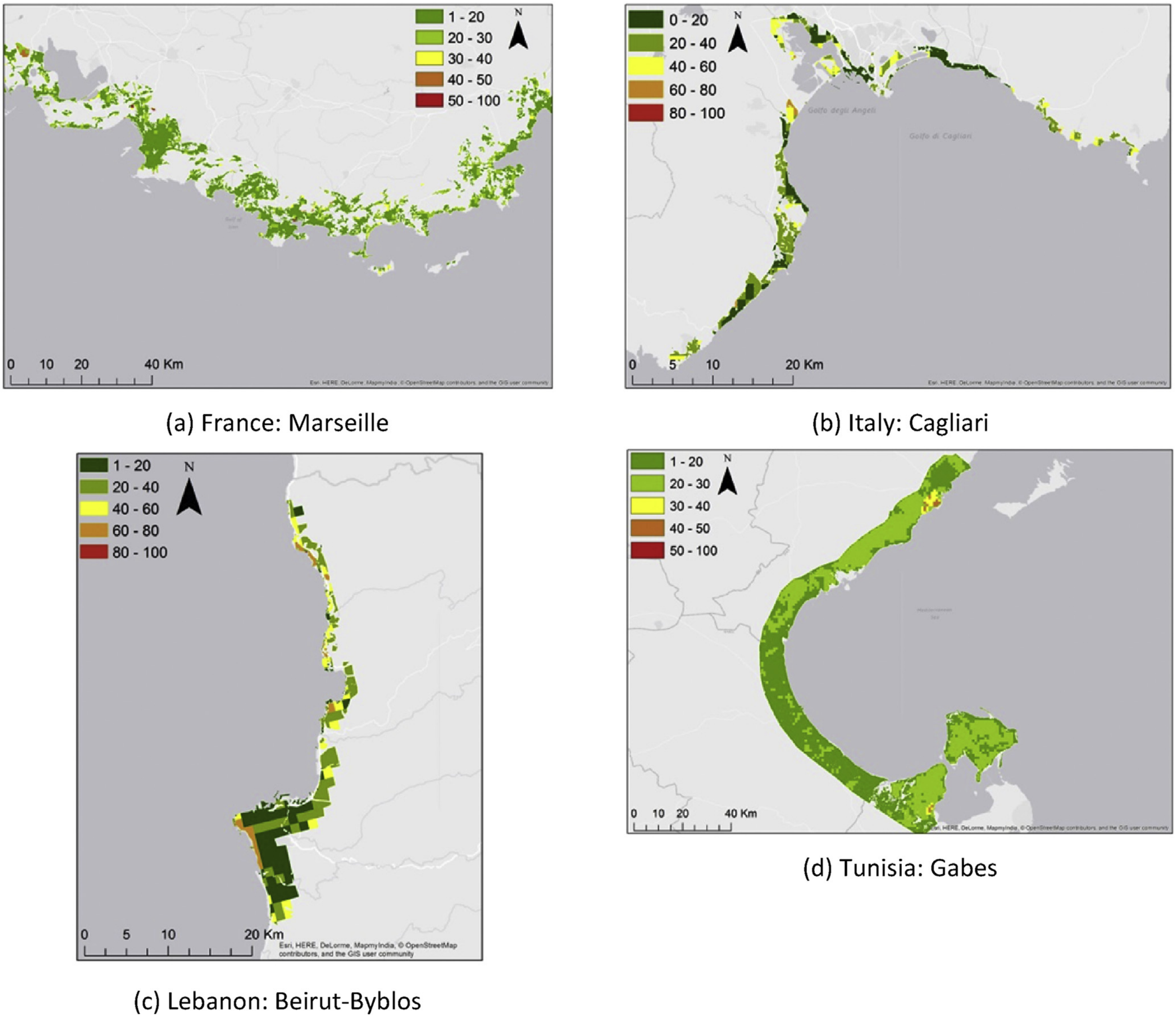


Fig. 6. BRI-based vulnerability mapping (Vulnerability increases over a range from 1 to 100).

mapping based on the NOAA modified ESI for the four pilot areas. The French coastline had predominantly low mean sensitivity due to the frequent occurrence of 'exposed high rocky shores' and 'exposed low impermeable shores' (Fig. 5a). On the other hand, the overall mean sensitivity index along the Italian study area was relatively high (Fig. 5b) due to the predominance of sandy beaches and shores with natural rocks. In Lebanon, the low shoreline sensitivity can be attributed to the fact that large segments of the coastline had undergone anthropogenic change with swaths of once sandy beaches now converted to 'exposed artificial coastal structures' or to 'exposed low impermeable shores', both of which are associated with a low ESI (Fig. 5c). Gabes in Tunisia had a relatively high mean sensitivity index due to the prevalence of vulnerable mud flats and natural rocky shores (Fig. 5d). A summary of ESI values for the four pilot areas is presented in Table 7.

Table 9
Summary of ESI-based coastline vulnerability to anthropogenic stressors.

Vulnerability	France	Italy	Lebanon	Tunisia
Minimum	5.0	2.0	1.6	15.0
Maximum	76.0	80.0	80.0	45.0
Mean	45.4	20.1	22.5	34.2
Standard deviation	21.2	17.0	26.8	8.1

3.4. *Defining vulnerable areas*

3.4.1. *BRI-based vulnerability assessment*

Summary statistics of BRI-based vulnerability values for the four pilot areas are presented in Table 8, with corresponding vulnerability index mapping illustrated in Fig. 6. The vulnerability maps, which were generated by multiplying anthropogenic index with the underlying biodiversity vulnerability, ranged between 1 and 100. Along the Italian pilot area, a number of segments around the port of Cagliari were identified to have high vulnerability (>40) (Fig. 6b) due to the colocation on sensitive environments with highly polluting anthropogenic activities. Medium and low vulnerability were largely found around agricultural and urban areas on both sides of the port of Cagliari. While some industries, located in the proximity of the port, exhibited high vulnerability,

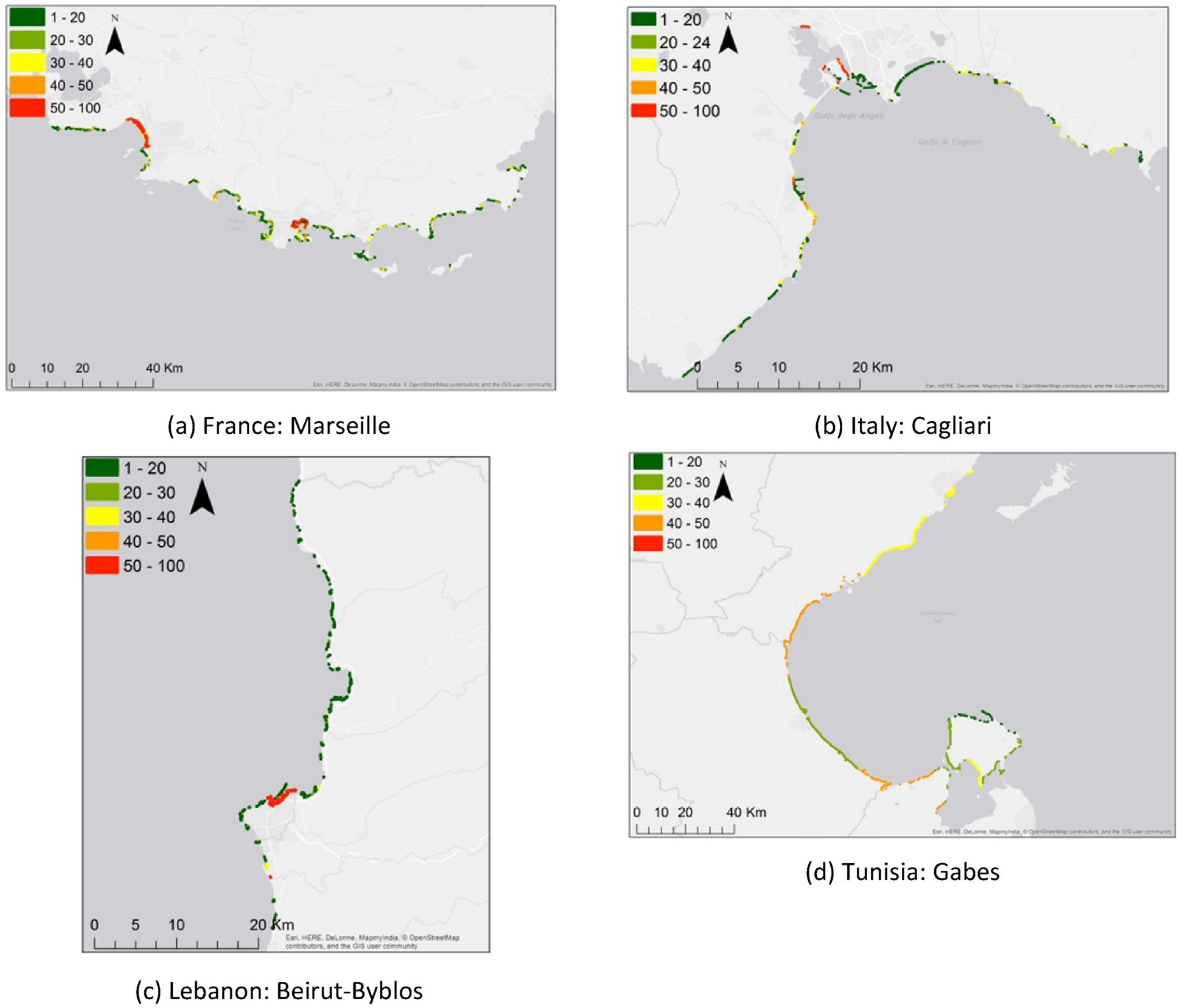


Fig. 7. ESI-based vulnerability mapping (Vulnerability increases over a range from 1 to 100).

others had medium to low vulnerability, largely due to their low biodiversity score. Along the Lebanese coastline, Beirut had an overall low vulnerability value even though it had one of the highest anthropogenic stressors, which is a direct reflection of the poor biodiversity within the densely urbanized city. Other parts of the Lebanese coastline had medium vulnerability, although they were associated with high anthropogenic stress, due to the degraded status of much of the coastline. To the north of Beirut, biological vulnerability is high due to the presence of highly diverse regions that are being encroached upon by tourism and urbanization (Fig. 6c). These regions will probably transition to areas with low biological value in the near future, as they will lose their biodiversity to uncontrolled coastal development. In contrast, along the French and Tunisian pilot areas, vulnerability along the entire shoreline was relatively low and homogenous over space as compared to the Italian and Lebanese coastlines (Fig. 6a and d).

3.4.2. ESI-based vulnerability

Summary statistics of ESI-based vulnerability values for the four pilot areas are presented in Table 9 with corresponding mapping based on shoreline sensitivity illustrated in Fig. 7. The results showed that along the French pilot area, a number of segments around the port of Marseille showed high vulnerability to potential anthropogenic stressors (Fig. 7a). These areas were largely located in highly sensitive sheltered artificial coastal structures with highly polluting activities. In Cagliari-Italy, the area in the vicinity of the port was associated with an elevated pollution-based vulnerability (Fig. 7b) due to the colocation of sensitive environments like sheltered artificial coastal structures and sheltered low impermeable shores with highly polluting anthropogenic activities. The distribution of coastline vulnerability along the other segments of the Cagliari coast is similar to the distribution of the ESI maps because of the relatively homogenous anthropogenic stressor distribution in the study area. Along the Lebanese coastal pilot area, high-vulnerability values were restricted to the area around the Beirut Port, where high stressors are in the vicinity of highly sensitive sheltered artificial coastal structures (Fig. 7c). Other parts of the Lebanese coastline had medium vulnerability, although they were associated with high anthropogenic stressors, due again to the degraded coastline that had a low environment sensitivity. In Tunisia, shoreline vulnerability to pollution stressors along the entire study area were relatively homogenous over space (Fig. 7d),

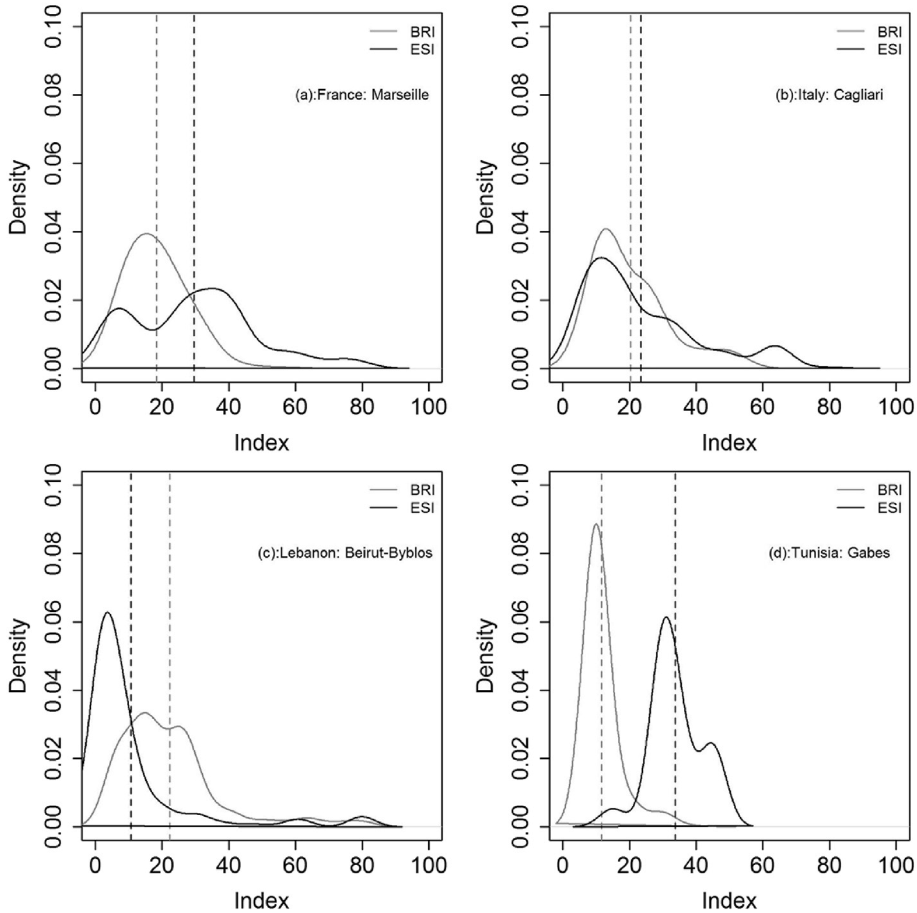


Fig. 8. Distribution densities of ESI- and BRI- based coastline vulnerability (Vertical lines represent the mean scores based on the BRI and ESI indices).

given the uniformity observed both in shoreline type (55% are of mudflat and sandy type, and the rest are rocky shores) and anthropogenic stressors.

3.4.3. Comparing BRI- and ESI-based coastline vulnerabilities

A comparison between the BRI and ESI based vulnerability assessments showed that the two methodologies exhibited statistically significant differences across the four pilot areas (p-value < 0.05). The two vulnerability maps were mostly similar in Cagliari with highest vulnerable areas concentrated around the port of Cagliari (Figs. 6b and 7b). Minor differences were evident to the west of the port, where low ESI-based vulnerabilities were associated with medium to low BRI-vulnerability. Ninety five percent (95%) of the differences between ESI and BRI-based vulnerabilities ranged between −22 and 29% (Fig. 9b). In France, ESI-based vulnerabilities were generally more conservative as compared to those predicted by the BRI-based index (Fig. 8a). Corresponding differences ranged between −20 and 47%, for 95% of the study area (Fig. 9a). The largest differences were encountered near the ports of Marseille and Toulon, where sensitive shoreline typology did not correspond with high biodiversity richness levels (Figs. 6c and 7c). Unlike Italy and France, in Lebanon the BRI-based vulnerability proved to be more conservative than that based on ESI (Figs. 8c and 9c), which is largely due to the heavily altered state of the shoreline. Overall, 95% of the differences between ESI- and BRI-based vulnerabilities ranged from as low as −46 to as high as 24% (Fig. 9c). In Tunisia, ESI-based vulnerabilities were consistently larger than those predicted by the BRI-index (Fig. 8d). Differences between the two vulnerability indices ranged from as low as 5% to as high as 35%, 95% of the time (Fig. 9d). This consistent bias is largely due to the homogeneity of the Gabes shoreline and its invariably low BRI.

3.5. Management/policy planning implications and conclusions

Several coastal management frameworks and international agreements have been developed over the years with the aim of controlling coastal pollution along the Mediterranean coastline. One of the most significant agreements is the Barcelona Convention, which was ratified by 22 countries,[2] including the four pilot areas (UNEP and UN-HABITAT, 2005). The convention targets the protection of the Mediterranean Sea against coastal pollution from open dumping, pollution from shipping, over-exploitation of the seabed, pollution from land-based sources, as well as the handling of hazardous wastes. While member countries ratified these protocols, land and marine based pollution sources still constitute serious stressors. For instance along the Italian study area, untreated or secondary treated wastewater outfalls are found along with untreated agricultural runoff (Clemente, 2012). Along the French pilot area, 24% of outfalls discharge untreated wastewater into the Mediterranean Sea including agricultural run-off, raw sewage and industrial discharge. This region is also considered to

[2] Albania, Algeria, Bosnia and Herzegovina, Croatia, Cyprus, Egypt, France, Greece, Israel, Italy, Lebanon, Libya, Malta, Monaco, Montenegro, Morocco, Slovenia, Spain, Syria, Tunisia, Turkey.

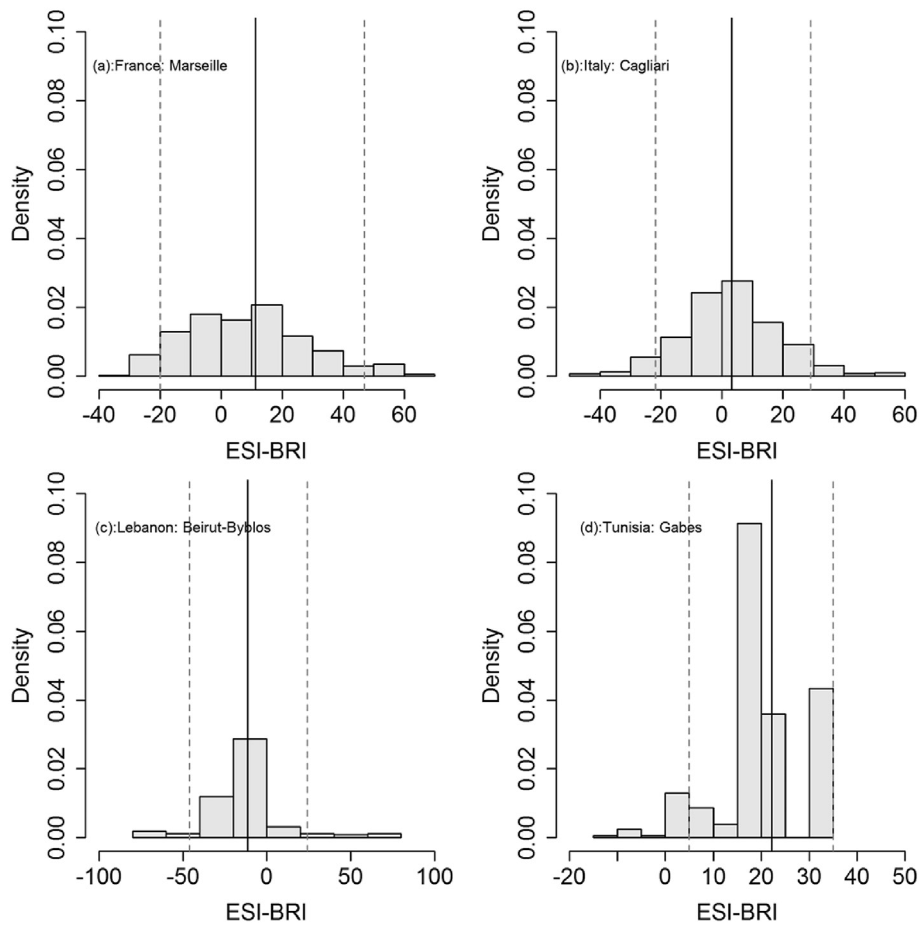


Fig. 9. Differences between ESI- and BRI- based coastal vulnerabilities across the four pilot areas (Mean vulnerability difference is shown as a solid black vertical line; Vertical dashed lines show the 95% variability around the mean difference).

be among the most exposed areas to erosion in Europe (Monfort Climent and Terrier, 2010). Outfalls discharging untreated or primary treated wastewater and/or leachate are common along the Lebanese pilot area with similar concerns associated with industrial effluents, agricultural runoff, and coastal erosion (Abi Rizk, 2005). In the Gulf of Gabes, agricultural runoffs and oil rigs present major challenges (Boukhris et al., 2015), with equally high vulnerability to coastal erosion particularly at the islands of Kerkennah, Kneis and Djerba (MEDD and UNDP, 2007). It is evident that all along the northern, eastern, and southern shores of the Mediterranean much remains to be desired by signatory countries to fulfill obligations under the Barcelona Convention. Management and mitigation measures towards this purpose can be prioritized using vulnerability indices similar to those developed in this study. In this context, different stakeholders may emphasize different indices depending on their interest leading to different intervention priorities as evidenced for instance in the observed differences between BRI- and ESI-based vulnerability maps. The former vulnerability index is based solely on vegetation-based richness; thus it disregards the physical characteristics of the coastline that are known to attenuate water-based pollution. It also overlooks the susceptibility of the coastline to erosion. Therefore, basing management actions on BRI-based vulnerability maps only will inevitably lead to prioritizing sites with high endemic vegetation richness, while disregarding important coastal stretches that may have low vegetation cover but are incapable of a swift recovery, following a pollution incidence. Sheltered sites and tidal coastal segments will therefore have a high risk of being overlooked. On the other hand, ESI-based vulnerabilities tend to overlook important areas of high land-based biodiversity, if they happen to be co-located along segments of rocky beaches. As such, coniferous forests, common along coastal cliffs of the Mediterranean coastline, can be misleadingly assigned low priorities. The two metrics appear to be consistent in highly urban coastal segments (e.g. coastal airports, large ports, reclaimed land), where anthropogenic development is known to concurrently reduce vegetation biodiversity and change the coastline from its natural state to an exposed artificial coastal strand. This is typical at locations like Beirut and its suburbs, where urban planning is weak and land reclamation is widespread. These activities violate the PAP/RAC initiatives that aim to promote sustainable development along the Mediterranean coastline.

Resolving discrepancies between different vulnerability indices will remain a challenging task, as each index is developed to summarize information relevant to a specific facet of a complex system. It is therefore imperative that the different developed indices clearly state their objectives in an effort to facilitate validation and better educate decision makers with regards to their use (Bakkensen et al., 2016). Equally important is the integration of socioeconomic indicators that constitute additional elements for future work, which are critical for modulating vulnerability. Many studies try to resolve these differences by averaging across indices (McLaughlin and Cooper, 2010); yet this practice may not be conservative enough as it obscures high risks in any of the indices (Rygel et al., 2006). More conservative approaches could involve using Pareto ranking (Rygel et al., 2006), adopting the geometric mean instead of the arithmetic mean, or prioritizing sites that exceed an expert elicited threshold irrespective which index is responsible for that violation. Ultimately, irrespective of which indices are adopted and/or how they are combined, the potential risk of misuse by decision makers cannot be completely abated. Indices are by definition simplifications of complex processes that aim to assist in management decisions. The only way to make use of them, while guaranteeing no misapplication, is through a transparent disclosure of their foundations, assumptions and limitations. Similarly, the empirical validation of indices can help assess the performance of indices (Bakkensen et al., 2016). Subject matter experts should always be consulted in an effort to map between the developed indices and the management task at hand.

Acknowledgments

The work presented in this article was developed within the GREAT Med project financed by the European Union (ENPI CBC Mediterranean Sea Basin Programme) through the European Neighborhood and Partnership Instrument under the Grant Agreement no. 39/2377.

References

Abi Rizk, E., 2005. Evolution du trait de côte Libanais entre 1962–2003. Conservatoire National des Arts et Métiers Ecole Supérieure des Géomètres et Topographes, Beirut, Lebanon.
Adger, W.N., Hughes, T.P., Folke, C., Carpenter, S.R., Rockström, J., 2005. Social-ecological resilience to coastal disasters. Science 309, 1036–1039.
Angelidis, M.O., Kamizoulis, G., 2005. A rapid decision-making method for the evaluationof pollution-sensitive coastal areas in the Mediterranean sea. Environ. Manag. 35, 811–820.
Appelquist, L.R., Balstrøm, T., 2014. Application of the coastal hazard wheel methodology for coastal multi-hazard assessment and management in the state of Djibouti. Clim. Risk Manag. 3, 79–95.
Appelquist, L.R., Balstrøm, T., 2015. Application of a new methodology for coastal multi-hazard-assessment & management on the state of Karnataka, India. J. Environ. Manag. 152, 1–10.
Ashraful Islam, M., Mitra, D., Dewan, A., Akhter, S.H., 2016. Coastal multi-hazard vulnerability assessment along the Ganges deltaic coast of Bangladesh–A geospatial approach. Ocean Coast. Manag. 127, 1–15.
Bagdanavičiūtė, I., Kelpšaitė, L., Soomere, T., 2015. Multi-criteria evaluation approach to coastal vulnerability index development in micro-tidal low-lying areas. Ocean Coast. Manag. 104, 124–135.
Bakkensen, L.A., Fox-Lent, C., Read, L.K., Linkov, I., 2016. Validating resilience and vulnerability indices in the context of natural disasters. Risk Anal. http://dx.doi.org/10.1111/risa.12677. Epub ahead of print.
Beatley, T., 2012. Planning for Coastal Resilience: Best Practices for Calamitous Times. Island Press.
Boruff, B.J., Emrich, C., Cutter, S.L., 2005. Erosion hazard vulnerability of US coastal counties. J. Coast. Res. 932–942.
Boukhris, A., Laffont-Schwob, I., Mezghani, I., El Kadri, L., Prudent, P., Pricop, A., Tatoni, T., Chaieb, M., 2015. Screening biological traits and fluoride contents of native vegetations in arid environments to select efficiently fluoride-tolerant native plant species for in-situ phytoremediation. Chemosphere 119, 217–223.
Butt, M.A., Li, S., 2015. UML-based requirement modeling of Web online synchronous collaborative public participatory GIS. Appl. Geomatics 7, 203–242.
Castanedo, S., Abascal, A., Medina, R., Fernandez, F., Liste, M., Olabarrieta, M., 2009. Development of a GIS-based Oil Spill Risk Assessment System, OCEANS 2009-EUROPE. IEEE, pp. 1–6.
Ceia, F.R., Patrício, J., Marques, J.C., Dias, J.A., 2010. Coastal vulnerability in barrier islands: the high risk areas of the Ria Formosa (Portugal) system. Ocean Coast. Manag. 53, 478–486.
Clemente, R.R., 2012. Report on the Mediterranean Sea Pollution Situation Addressed by the Horizon 2020 Program of the ENPI, and Challenges in the Research Domain. Mediterranean Innovation and Research Coordination Action, Barcelona, Spain, pp. 1–35.
Cutter, S.L., Boruff, B.J., Shirley, W.L., 2003. Social vulnerability to environmental hazards. Soc. Sci. Q. 84, 242–261.
De Santoli, L., Cumo, F., Garcia, D.A., Bruschi, D., 2011. Coastal and marine impact assessment for the development of an oil spill contingency plan: the case study of the east coast of Sicily. WIT Trans. Ecol. Environ. 149.
Devoy, R.J., 2008. Coastal vulnerability and the implications of sea-level rise for Ireland. J. Coast. Res. 325–341.
Doukakis, E., 2005. Coastal vulnerability and risk parameters. Eur. Water 11, 3–7.
ESRI, 2015. ArcGIS Desktop: Release 10.3. Environmental Systems Research Institute, Redlands, CA.
European Union (EU), 2003. Vulnerability and risk mapping for the protection of carbonate (Karst) aquifers: scope-goals-results. In: Zwahlen, F. (Ed.), COST Action 620. European Union, Luxembourg.
Finkl, C.W., Makowski, C., 2013. The Southeast Florida Coastal Zone (SFCZ): a cascade of natural, biological, and human-induced hazards. In: Finkl, W.C. (Ed.), Coastal Hazards. Springer Netherlands, Dordrecht, pp. 3–56.
Flax, L.K., Jackson, R.W., Stein, D.N., 2002. Community vulnerability assessment tool methodology. Nat. Hazards Rev. 3, 163–176.
Füssel, H.-M., 2007. Vulnerability: a generally applicable conceptual framework for climate change research. Glob. Environ. Change 17, 155–167.
Gornitz, V., 1990. Vulnerability of the East Coast, USA to future sea level rise. J. Coast. Res. 9, 201–237.
Gornitz, V.M., Daniels, R.C., White, T.W., Birdwell, K.R., 1994. The development of a coastal risk assessment database: vulnerability to sea-level rise in the U.S. Southeast. J. Coast. Res. 327–338.
GREATMed, 2015a. O5.1 Report on the State of the Art of Human Pressures along the Mediterranean Coast: GREAT Med Study Areas. American University of Beirut, Beirut, Lebanon, p. 69.
GREATMed, 2015b. Proposal of a Procedure for Site Prioritization for Conservation of Plant Diversity. Sapienza University of Rome, Rome, Italy.
Hassaan, M., 2013. GIS-based risk assessment for the Nile Delta coastal zone under different sea level rise scenarios case study: Kafr EL Sheikh Governorate, Egypt. J. Coast. Conserv. 17, 743–754.
The global oil and gas industry association for environmental and social issues (IPIECA), International Maritime Organization (IMO), International Association of Oil & Gas Producers (OGP), 2012. Sensitivity Mapping for Oil Spill Response. United Kingdom, London.
Komendantova, N., Mrzyglocki, R., Mignan, A., Khazai, B., Wenzel, F., Patt, A., Fleming, K., 2014. Multi-hazard and multi-risk decision-support tools as a part of participatory risk governance: feedback from civil protection stakeholders. Int. J. Disaster Risk Reduct. 8, 50–67.
Kumar, A.A., Kunte, P.D., 2012. Coastal vulnerability assessment for Chennai, east coast of India using geospatial techniques. Nat. Hazards 64, 853–872.
Kunte, P.D., Jauhari, N., Mehrotra, U., Kotha, M., Hursthouse, A.S., Gagnon, A.S., 2014. Multi-hazards coastal vulnerability assessment of Goa, India, using geospatial techniques. Ocean Coast. Manag. 95, 264–281.
Mahapatra, M., Ramakrishnan, R., Rajawat, A., 2015. Coastal vulnerability assessment using analytical hierarchical process for South Gujarat coast, India. Nat. Hazards 76, 139–159.
ManiMurali, R., Ankita, M., Amrita, S., Vethamony, P., 2013. Coastal Vulnerability Assessment of Puducherry Coast, India, Using the Analytical Hierarchical Process.
McLaughlin, S., Cooper, J.A.G., 2010. A multi-scale coastal vulnerability index: a tool for coastal managers? Environ. Hazards 9, 233–248.
Mcleod, E., Poulter, B., Hinkel, J., Reyes, E., Salm, R., 2010. Sea-level rise impact models and environmental conservation: a review of models and their applications. Ocean Coast. Manag. 53, 507–517.
Ministère de l'Environnement et Du Développement Durable (MEDD), United Nations Development Programme (UNDP), 2007. Etude de la vulnérabilité environnementale et Socio-économique du littoral Tunisien face à une élévation accélérée du niveau de la mer due aux changements climatiques et identification d'une stratégie d'adaptation, Phase I. Ministère de l'Environnement et du Développement Durable, Tunis, Tunis, p. 469.
Michel, J., Zengel, S., White, M., Lord, C., Plank, C., 2002. Environmental Sensitivity Index Guidelines- Version 3.0. NOAA, Columbia, SC.
Monfort Climent, D., Terrier, M., 2010. Projet ALDES: synthèse de typologie de la côte méditerranéenne française. In: Belvaux, M. (Ed.), Projet ALDES. BRGM. France, Orleans, p. 42.
Montefalcone, M., Parravicini, V., Bianchi, C.N., 2011. Quantification of Coastal Ecosystem Resilience. Academic Press, Waltham, MA, USA, pp. 49–70.
Musaoglu, N., Tanik, A., Dikerler, T., Buhur, S., 2015. Use of remote sensing and geographic information systems in the determination of high-risk areas regarding marine traffic in the Istanbul Strait. Environ. Hazards 14, 54–73.
Nageswara Rao, K., Subraelu, P., Venkateswara Rao, T., Hema Malini, B., Ratheesh, R., Bhattacharya, S., Rajawat, A.S., Ajai, 2008. Sea-level rise and coastal vulnerability: an assessment of Andhra Pradesh coast, India through remote sensing and GIS. J. Coast. Conserv. 12, 195–207.
Nicholls, R.J., Branson, J., 1998. Coastal resilience and planning for an uncertain future: an introduction. Geogr. J. 164, 255–258.
Orencio, P.M., Fujii, M., 2013. A localized disaster-resilience index to assess coastal communities based on an analytic hierarchy process (AHP). Int. J. Disaster Risk Reduct. 3, 62–75.
Pendleton, E.A., Thieler, E.R., Williams, S.J., 2005. Coastal Vulnerability Assessment of Cape Hatteras National Seashore (CAHA) to Sea-level Rise. Citeseer.
Provence Alpes Côte-d'Azur, 2014. Schéma régional d'aménagement et de développement durable du territoire, diagnostic prospectif, Le Schéma Régional d'Aménagement et de Développement Durable du Territoire. Conseil régional de Provence-Alpes-Côte d'Azur, Marseille, France.
Ramieri, E., Hartley, A., Barbanti, A., Santos, F.D., Gomes, A., Hilden, M., Laihonen, P., Marinova, N., Santini, M., 2011. Methods for Assessing Coastal Vulnerability to Climate Change. European Environment Agency, European topic centre on climate change impacts, vulnerability and adaptation.
Rygel, L., O'sullivan, D., Yarnal, B., 2006. A method for constructing a social vulnerability index: an application to hurricane storm surges in a developed country. Mitig. Adapt. Strategies Glob. Change 11, 741–764.
Shaw, J., Taylor, R., Forbes, D., Ruz, M., Solomon, S., 1994. Sensitivity of the Canadian coast to sea-level rise. In: Wells, P.G., Ricketts, P.J. (Eds.), Coastal Zone Canada

'94, Cooperation in the Coastal Zone. Coastal Zone Canada Association, Bedford Institute of Oceanography, Dartmouth, NS, Canada, p. 2,377. Studies in Avian Biology 332, 149–187.

Szlafsztein, C., Sterr, H., 2007. A GIS-based vulnerability assessment of coastal natural hazards, state of Pará, Brazil. J. Coast. Conserv. 11, 53–66.

Taubenböck, H., Post, J., Roth, A., Zosseder, K., Strunz, G., Dech, S., 2008. A conceptual vulnerability and risk framework as outline to identify capabilities of remote sensing. Nat. Hazards Earth Syst. Sci. 8, 409–420.

Thatcher, C.A., Brock, J.C., Pendleton, E.A., 2013. Economic vulnerability to sea-level rise along the northern U.S. Gulf coast. J. Coast. Res. Special Issue 63, 234–243.

Thieler, E.R., Hammar-Klose, E.S., 2000a. National Assessment of Coastal Vulnerability to Sea-level Rise; Preliminary Results for the US Gulf of Mexico Coast.

Thieler, E.R., Hammar-Klose, E.S., 2000b. National Assessment of Coastal Vulnerability to Sea-level Rise; Preliminary Results for the US Pacific Coast.

Thieler, E.R., Hammer-Klose, E.S., 1999. National Assessment of Coastal Vulnerability to Sea-level Rise: Preliminary Results for the U.S. Atlantic Coast. United States Geological Survey (USGS), Woods Hole, MA.

Thumerer, T., Jones, A., Brown, D., 2000. A GIS based coastal management system for climate change associated flood risk assessment on the east coast of England. Int. J. Geogr. Inf. Sci. 14, 265–281.

United Nations Development Programme (UNDP), Mediterranean Action Plan (MAP), 2012. State of the Mediterranean Marine and Coastal Environment. UNEP/MAP – Barcelona Convention, Athens, Greece.

United Nations Environment Programme (UNEP), United Nations Human Settlements Programme (UN-HABITAT), 2005. Coastal Area Pollution the Role of Cities, Nairobi, Kenya, p. 4.

United Nations Environment Programme (UNEP), Mediterranean Action Plan (MAP), Regional Activity Centre for Specially Protected Areas (RAC/SPA), 2010. In: Bazairi, H., Ben Haj, S., Boero, F., Cebrian, D., De Juan, S., Limam, A., Lleonart, J., Torchia, G., Rais, C. (Eds.), The Mediterranean Sea Biodiversity: State of the Ecosystems, Pressures, Impacts and Future Priorities, p. 100. Tunis, Tunis.

Wamsley, T.V., Collier, Z.A., Brodie, K., Dunkin, L.M., Raff, D., Rosati, J.D., 2015. Guidance for developing coastal vulnerability metrics. J. Coast. Res. 31, 1521–1530.

Yin, J., Yin, Z., Wang, J., Xu, S., 2012. National assessment of coastal vulnerability to sea-level rise for the Chinese coast. J. Coast. Conserv. 16, 123–133.