Ninth International Symposium

Monitoring of Mediterranean Coastal Areas: Problems and Measurement Techniques

Livorno (Italy) 14th - 16th June 2022

edited by
Laura Bonora, Donatella Carboni,
Matteo De Vincenzi, Giorgio Matteucci

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PROBLEMS AND MEASUREMENT TECHNIQUES

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APPLICATION OF STATISTICAL ANALYSIS TO ESTIMATE THE COASTAL HAZARD. A CASE STUDY IN LIGURIA REGION

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Abstract – Liguria Region is totally exposed to the action of the sea storms and too the natural evolution of the profile of the shoreline. The modification along the time of the shape of the shoreface is measured from the official administrative and technical offices of the Liguria Region and Italian Environmental Ministry, this information is available in shape format starting from 1944.

The phenomenon of coastal flood produces a direct damage represented by the loss of soil and an indirect damage correlated to the impact on tourism activity, social aspects, and damage to heritage buildings. In recent years another type of damage source must be considered, and this is the phenomenon of the increasing of the mean sea water level, known as Sea Level Rise (SLR). It is necessary to introduce this phenomenon in the hazard analysis and this is a direct and known consequence of the climate change.

Results from the hazard index encompass both the relative magnitude of erosion and/or coastal flooding, and the probability that these hazards may occur based on the distribution of the index using different scenarios. The paper analyzes a Liguria case study in which the effects of SLR is particularly critical in terms of heritage and economic and social activities hazard.

Introduction

The Ligurian coast is classified as "beach" or "rock", and, generally, area classified as beach erosion and/or sediment deposition is often frequent. Phenomenon not due to the natural circulation of the littoral currents, as natural non-maritime phenomena or as consequence of anthropogenic actions, for example new offshore works can modify the circulation of sediments. The principal phenomenon that may be analyzed is the increasing of the mean sea water level, known as Sea Level Rise (SLR), mainly forced by the climate change. In the Mediterranean area this phenomenon produces a negative effect like loss of soil on the coastal area where the main percentage of the population is present, and the principal economical and touristic activities and heritage elements are located.

According to the international literature [1], [2], [3], [4] a general coastal hazard index is calculated considering the following variables: shoreline type, habitats, relief, SLR, wind exposure and surge potential.

In the Liguria Region the data used to evaluate the exposure of the coast to wave actions are available in shape format and with indications of intensity and direction of the

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dominant sea states on the web site relevant to the official cartography. Another important data is the evaluation of the percentage of loss of soil knowing the value of the Run Up for various periods of return time of the marine storms. For the estimation of these values the Ligurian Region has adopted the Van der Meer equation in which it is introduced the value of slope as cumulative value relevant both submerged and emerged beach. All of these values are available along the coast of Ligurian Region for each longitudinal section defined in the Protection Plan for the Marine and Coastal Environment, [5].

It is necessary to highlight that the data and results reported in the PTAMC are binding instruments for the Liguria Region to be respected in every new project and /or intervention to refurbish the coastal area.

Results from the hazard index encompass both the relative magnitude of erosion and/or coastal flooding, and the probability that these hazards may occur based on the distribution of the index using different scenarios.

Materials and Methods

The coastal area environmental definition

Although the coastal environment represents in the common sense a territorial and landscape context that is quite clearly identifiable and historically defined, its spatial delimitation appears as a rather complex problem [6] and, in substance, inevitably subject to different nuances and variations depending on the point of view from which the definition is attempted.

The physical-environmental component is, in any case, the one most used to attempt to trace the borders to the coastal area: the hydrological and sedimentary cycles represent the processes that, in fact, determining the forms and morphogenesis of the coastal areas [7], [8]. These cycles are used to delimit this area, which tends to be configured as a territorial area that includes, physically, the coastal strip and the catchment areas at least of the first interrelation with the coastline. The land border of the coastal area therefore coincides with the line of the first coastal ridge. This definition, geographically quite intuitive and of relatively simple identification, also meets important interpretative doubts in those coastal stretches characterized by the coastal plains resulting from the sedimentation action of the most important watercourses.

In literature [1] the physical limits are used to delimit the coastal area, defining an area of sensitivity with respect to the maritime-coastal dynamics frequently used in the ICM, and an example is shown in Figure 1.

Compared to the problems of the SLR, we provide a definition of a coastal area not only related to the aspects linked to the landscape components or, more generally, to those determined by the uses of the soil, but rather to identify that strip of land in strictly environmental terms emerged that is more exposed to the weather-marine dynamics. In this sense, we propose to utilize a “sensible maritime coastal area” that takes few but fundamental physical-morphological factors:

- the slope, which makes it possible to distinguish between the high coast and the low coast and, within the low coast, the flat areas that we could define as the "first exposure coastal plain";

- the altimetry that, in addition to better defining the differentiation between high rocky / low coast, allows the identification of the areas most exposed to the sea waves action. These areas may even have a depth of some tens if not hundreds of meters in some cases (e.g. watercourse beds and / or areas with coastal elevation depression).

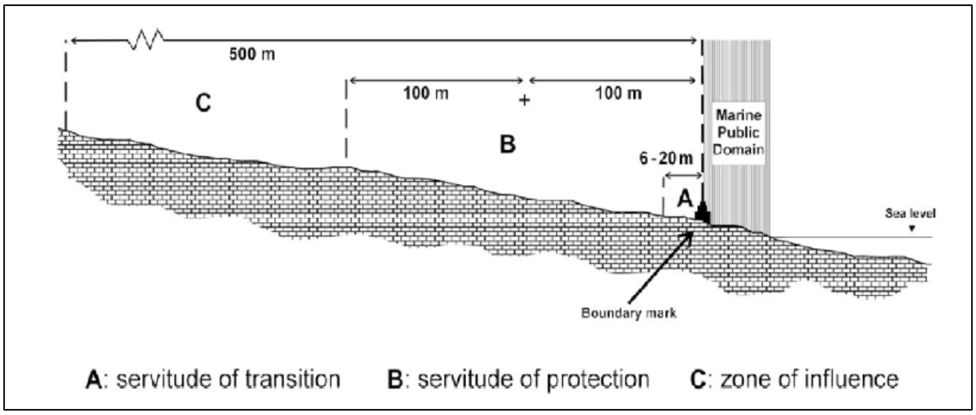

Figure 1 – Example of coastal area definition (from Belaguer, 2008).

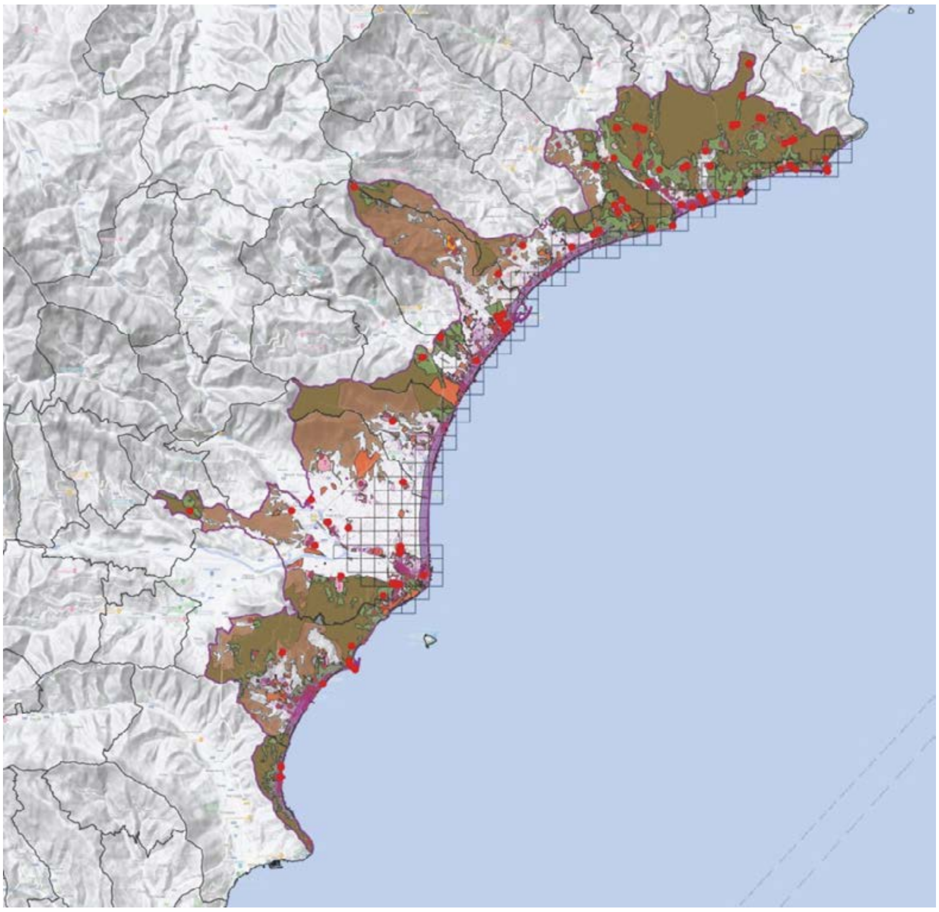
Figure 2 – The area of western Liguria under study.

The combination of these two morphological factors together with that of the coastal habitats allow to define a concept of exposed coastal plain that can be useful to introduce then the exposed elements of anthropic (and therefore patrimonial) nature that constitute the "functional" coastal area.

In this paper, the sensitive coastal maritime area is the result of the combination of flat areas (and therefore differentiated with respect to the stretches of rocky costs, where the cliff prevails) located below the 5 meter altitude. These are areas exposed to the risk of exposure, since climate change is progressively raising the average sea level and therefore, in the event of storm surges, the area of penetration of marine waters towards land (i.e. potential flooding) tends to increase.

In order to synthetically represent the anthropogenic (and therefore patrimonial) elements present in the coastal area (following a similar method already adopted by Koroglu [9]), we then tessellated the area under study with square cells oriented north-south of 500 meters on each side.

The settlement structure of coastal area

From the settlement point of view, coastal areas are often characterized by discontinuous uses in space and time: the maritime zone is increasingly characterized by fragmentation, porosity and discontinuity. On the other hand, the sea and the resources that can be traced in the coastal area are seen from an exploitation point of view in which the conditions external to the coastal territories themselves are increasingly preponderant and tend to reduce the "local production" processes to residual factors during the long historical duration. For these reasons the delimitation of the coastal strip under the settlement profile must considered, in addition to the physical morphologies, also the economies and the areas of influence generated by the functions that have been progressively localized there [10]. These economic conditions, in turn, influences the legal one, since the concentration of functions that are so different and with such significant impacts of human activity on an environment, that is somewhat delicate by its very nature, determines obvious problems of territorial governance.

Data utilized

The data utilized in the proposal analysis are available in the cartographic website of Liguria Region [4]. We have utilized the information relevant to the shape of the inland, the location of the principal line of communication utilized for the civil and public transport, the classification of civil structure according to their use public or private and, finally, the economic information relevant to the private enterprises. Important information utilized to estimate the hazard in each cell are extracted from different source areal or individual and relevant to the heritage elements.

Once the coastal maritime area was defined and the risk area delimited, the characteristics of the settlement were identified by calculating an index that expresses the patrimonial value present in each cell of the previously constructed grid.

In order to reach a synthetic value that expressed the territorial and patrimonial value of each cell, the presence (or non-presence) of some elements grouped into three main categories was analyzed: a) physical elements; b) specific elements that express functions or uses of the land of public interest and c) elements that represent a patrimonial value (normally linked to characteristics of landscape value recognized by planning tools).

The first category of variables includes: the presence of roads or linear infrastructures of territorial scale (example: railway lines); coastal defence works. The second category includes the historic centers, the areas of archaeological value, the areas recognized as areas of high landscape value. Finally, the third category includes punctual or public access services and private (such as rental points) and public services on a neighbourhood scale (essential for daily life).

Results

Coastal hazard

The risk is defined using the following relationship [11]:

$$R = H*V*E \quad (1)$$

in which H is the hazard correlated to the probability that the event occurs, V is the vulnerability of the system involved in this event and E is the value of the elements present in this system and exposed at this event.

Then it is necessary first to define the system in which you wish to estimate the different components of the risk equation, and then the typology of the event and its return time. Our analysis started from the approach of Kantamaneni [12], Benassai et al. [13] and Gallina [14], and we have divided the shore line in square grid with side of 500 m, to produce an estimation of vulnerability and exposure for each grid realized.

Approach proposed to estimate of coastal hazard

Coastal hazard refers to flooding and erosion caused by storms and sea level rise acting upon shorelines. In literature the most used methods for assessing coastal vulnerability are based on the Coastal Vulnerability Index (CVI) [15], which combines the changing susceptibility of the coastal system with its inherent response to a changing environment.

The variables usually taken into account to evaluate the CVI are mean elevation, geology, coastal landform, shoreline, wave height and tidal range. In the area under examination, we don't consider the tidal effect because it is not present and in general the effect of the erosion is not significant.

Obviously now it is important to develop a CVI to specifically assess the impacts induced by SLR, knowing the values for the future climate change scenario.

The habitats present along the coast can provide different level of coastal protection (erosion and coastal flood), the hazard index ranks the habitats based on differences in their morphology and observe ability to provide protection from erosion and flooding by dissipating wave energy and/or attenuating storm surge. Using a GIS it is possible to identify if some part of the coast has or not a "natural protection" and if this buffer overlap the land in which are present vulnerable elements.

Generally, wave exposure is calculated using a numerical model and the input data are the intensity and dominant direction of wind and the bathymetry of the region analyzed. In Liguria Region these data are available for part of the territory in shape format.

In literature are available technical descriptions of different methods to evaluate the extension of coastal flood area, both as the effect of run-up of sea waves and of the sea-level rise as direct consequence of the trend of climate change.

In this paper we apply a static approach, that it develops starting from the following the knowing variables as Run_Up for 50 year of return period and of structural protection of the coast.

The Run-Up values are available on the WebGIS system of Liguria Region and are official data [5]. For the values of the SLR we have adopted the maximum projection relevant to the condition described and correlated to the RCP 8.5, that represent the scenario with the increase of global sea mean surface temperature of 2 °C and the highest future pathway that will produce a radiative forcing of 8.5 W/m^2 in 2100. Models available in literature [16] indicates that for the Mediterranean Sea at 2100 the maximum values of SLR corresponding to the scenario of RCP8,5 is 0,8 meter, values that will be used in the following.

In the following Figure 3 we shown the part of cell submerged in presence of the actual Run Up indicated as red cells (4.00 meters) and the future scenario of SLR indicated as yellow cells (4.80 meters).

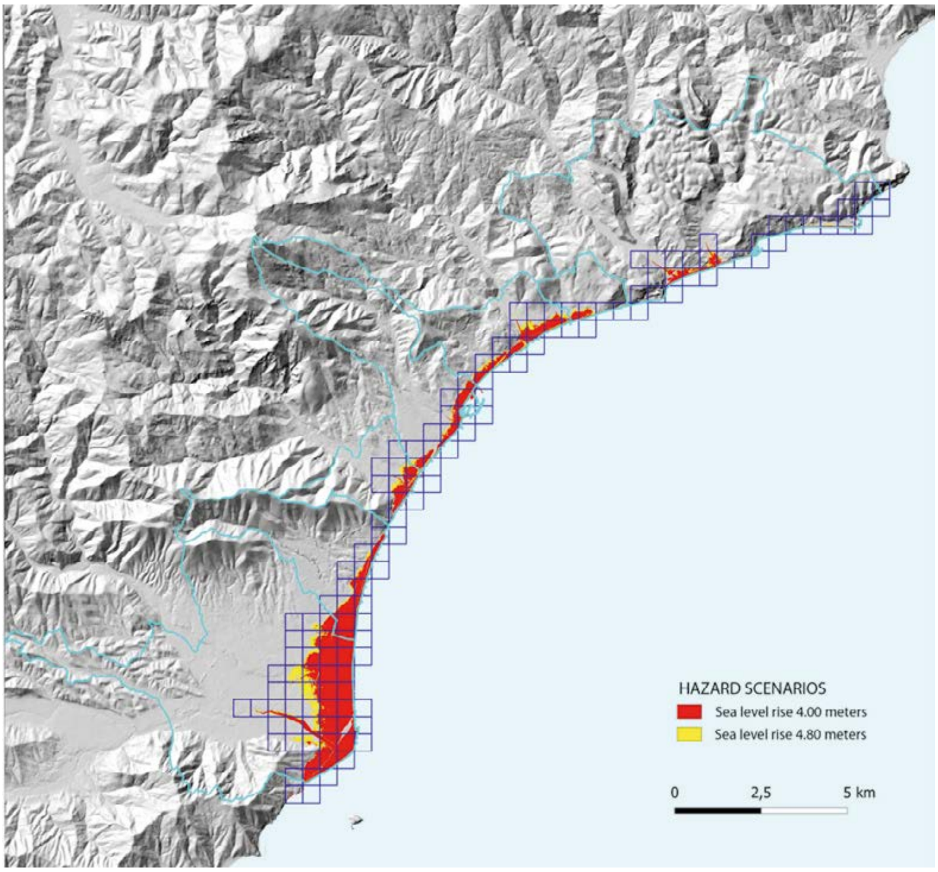

Figure 3 – Hazard scenarios in the study area.

We have assigned a different value of hazard and vulnerability at each cell according to the percentage of surface submerged from sea storm now and in the future scenario applying SLR value. The following step is to apply the sea-level rise and to evaluate, always using a GIS system, the loss of soil and the hazard for the different elements exposed on the part of the territory analyzed. The variables here proposed are indicated in the following Table 1:

Table 1 – Variables considered in the estimation of hazard.

Coefficient	Variable	Criterium	Vulnerability Index
a	Submerged area of cell	0 %	0
		50 %	1
		100 %	3
b	Erosion	Present	3
		Not present	0
c	Structure to protect the coast	Present	0
		Not present	3
d	Heritage elements	Present	3
		Not present	0
e	Communication way	Present	3
		Not present	0
f	Commercial structures	Present	3
		Not present	0
g	Private and public structures	Present	3
		Not present	0

Using this approach, the minimum value of vulnerability/hazard of the coast is 0 and the maximum value is 21, considering that we apply the following equation for our proposal CVI (pVI), relative to the values of Run Up for a return time of 50 years:

$$pCVI = a+b+c+d+e+f+g \qquad 2$$

Then we can classify the coast in the usual range from very low to very high pCVI, using a classical semaphore color, as indicated in the Table 2:

Table 2 – Vulnerability values.

Classification	Very low	Low	Mean	High	Very High
pCVI	< 4	4 -8	9- 12	13-18	>18

The same approach can be applied in the condition of presence of the maxim values of SLR in the area examined and the result can be indicated as future proposal CVI (fpCVI), relative to the scenario correlated to the Rappresentative Conventrate Pathway 8.5 (in the following RCP8.5) [17].

Discussion and conclusions

The vulnerability is represented in the territory submerged by the analyzed scenarios by the different elements as streets, civil and public buildings and enterprises present.

The area examined is a part of the Liguria Region, in West part (see Figure 2) and in Figure 3 it is shown the results for the actual situation, relevant to the estimation of the hazard along the coast examined and the future considering the effect of SLR.

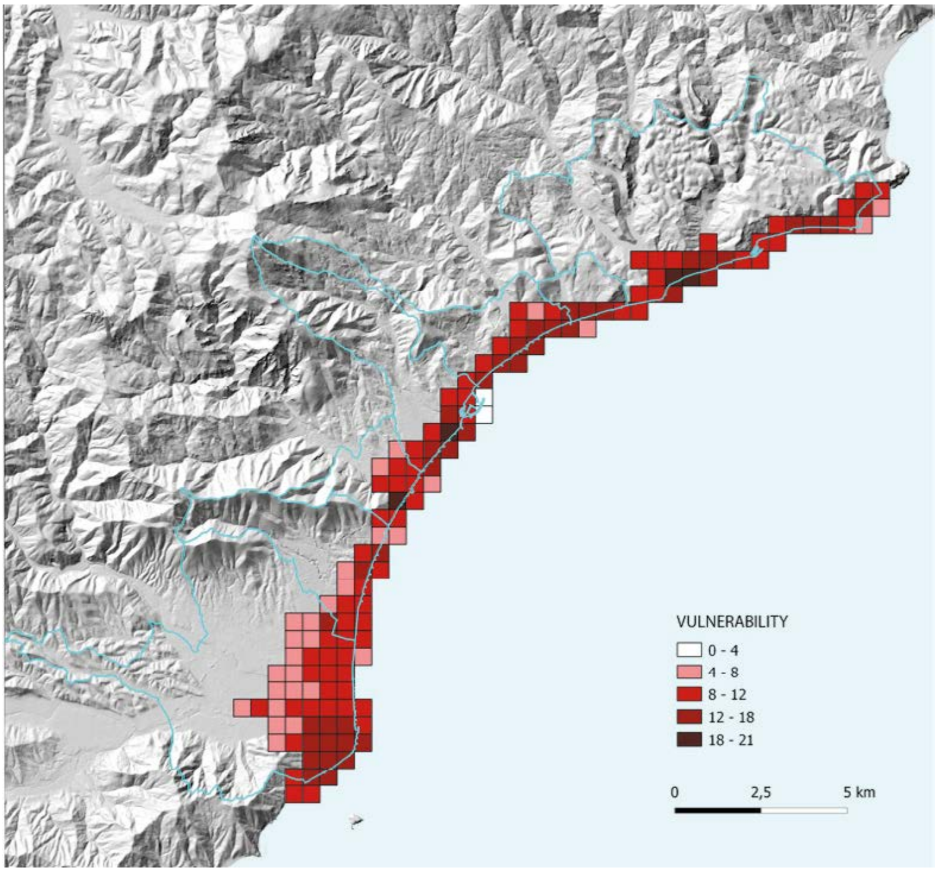

Figure 4 – Vulnerability in the 4.00 meters scenario.

By adopting the proposed static approach, the first result is the estimation of the loss of soil without taking into account the value of the elements exposed to the flood phenomenon as consequence of the SLR, for the scenario of 0.8 m of SLR the loss of soil is equivalent to 40 % of total coastal area considered in the 4.00 meters scenario. This value becomes 45 % in the 4.80 scenario.

What emerges from this first study is the impact that the rise of mean sea level caused by climate change (even in the most conservative assumptions), that is significant for the coastal area analyzed. In fact, Liguria, as well as numerous other regions of the Mediterranean area, has been affected in the past decades by an intense process of urbanization, which has concentrated not only a large amount of physical elements on the coast (roads, railways, buildings), but also an important component of the regional economy. On the other hand, the coastal area itself is the one where the highest density and frequency of elements of patrimonial value (linked above all to elements of historical-archaeological value and above all to coastal landscapes) is found. This concentration in the space of a few hundred meters from the coastline, determines a strong exposure of values with respect to the risk induced by coastal floods. The areas most at risk are those where urbanization has pushed to the seashore and, in order to prevent what could be significant economic losses, expensive adaptation programs will have to be set up in the coming years. Finally, we must consider how the most exposed element obviously consists of low and flat beaches. These constitute one of the fundamental bases that support the entire tourism value chain and the fact that they are extremely vulnerable leads to a more general vulnerability also to the general economy of coastal activity.

The development of the present work will have to consider the action of the wave motion run-up starting from the new mean sea water level modified by the expected SLR as a consequence of the climate change.

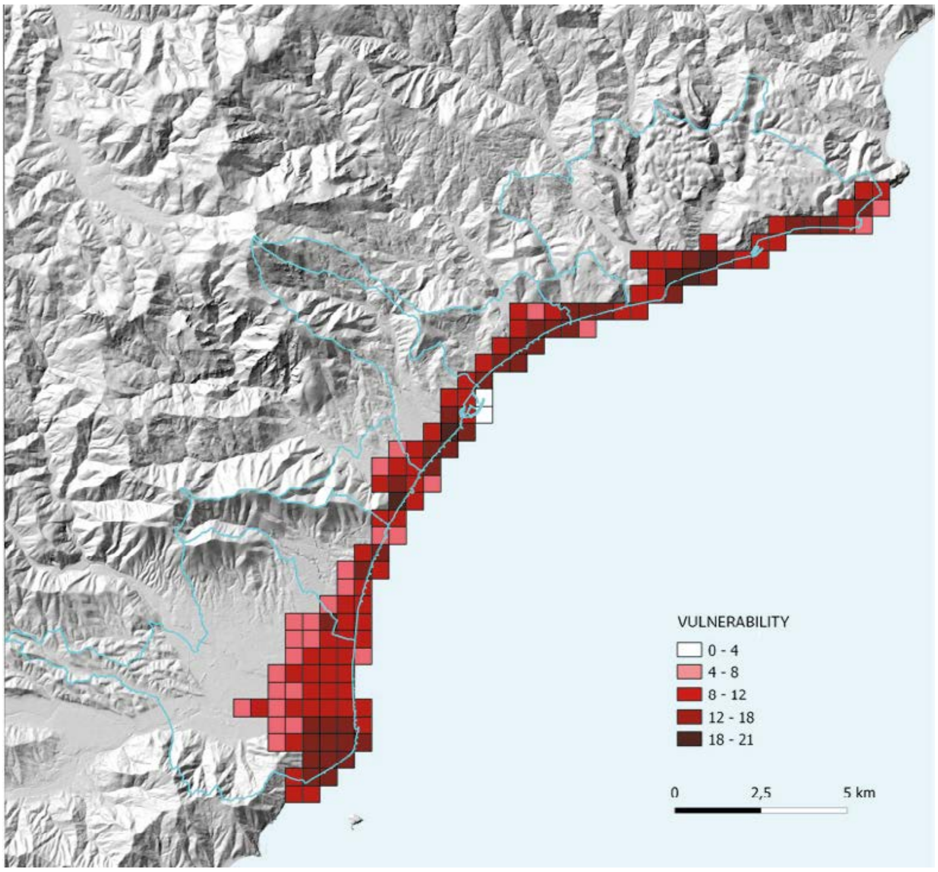

Figure 5 – Vulnerability in the 4.80 meters scenario.

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MONITORING OF MEDITERRANEAN COASTAL AREAS:

PROBLEMS AND MEASUREMENT TECHNIQUES

The 9th International Symposium *Monitoring of Mediterranean Coastal Areas: Problems and Measurements Techniques* was organized by CNR-IBE in collaboration with *Italian Society of Silviculture and Forest Ecology*, and *Natural History Museum of the Mediterranean* and under the patronage of *University of Florence, Accademia dei Lincei, Accademia dei Georgofili, Tuscany Region, The North Tyrrhenian Sea Ports System Authority, Livorno Municipality* and *Livorno Province*. In the Symposium Scholars had illustrated their activities and exchanged innovative proposals, with common aims to promote actions to preserve coastal marine environment. Despite the COVID 19 pandemic, the success of this edition is attested by the 170 contributions selected by the Scientific Committee from among those received. Participation involved all the thematic lines envisaged by the sessions, involving many countries of the Mediterranean Sea. A big endeavor for a costal environment of paramount importance but threatened by global changes. The importance of this Proceedings is attested by the fact that this volume is the first issue of a new FUP Series.

Laura Bonora is researcher at Institute of BioEconomy - National Research Council (CNR-IBE) of Italy. Her main research activities are concerned Natural Resources Management, environmental risk analysis, ecosystems biodiversity and Remote Sensing.

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