LAND USE ANALYSIS AND COASTAL STRUCTURES: ADRIATIC COAST AS A CASE STUDY

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Abstract – Coastal areas are one of the most complex and vulnerable nature environments. Generally, these areas are densely populated, therefore pollution, habitat loss, coastal dynamics, and climate change make these areas prone to be vulnerable with a resulting high risk for the population who lives in those places. Moreover, these locations are often intensely anthropized and prone to intense transformative pressure that increases the exposure inducing a consequent increase in the risk of already compromised integrity of the ecosystems and their ecological function [21] For these reasons, the knowledge of the present mosaic of land use/cover might be an important instrument to analyze the morphodynamic processes and also, for the definition of the rules necessary for the sector planning (e.g., Coastal defense planning, water catchment planning). The main goal of the work is to analyze the current overview of land use at 1 km from the coastline investigating if there is a correlation with the deployment of coastal structures i.e., breakwaters, groins, etc. [18]. The study area has been defined using the concept of physiographic unit (i.e., the coastal area in which the sediment transport exchange with neighboring regions is zero) using the classification given by the Italian Institute for Environmental Protection and Research, ISPRA [8]. In this case, the coastal area between Conero Promontory to the north (Marche region) and that of Punta Aderci, to the south (Abruzzo region), with a total extension of approximately 200 km involving about 40 municipalities and 2 regions has been analyzed. The analysis has been carried out using the Copernicus Land Monitoring Services database products (i.e., land use) with high resolution [11]. Moreover, all coastal structures (groins, submerged and emerged breakwaters) have been surveyed using appropriate environmental, urban, and hydraulic indicators to identify a possible correlation or cause-to-cause relationship effect between the presence/absence of coastal defense, urban pressure, and soil use/cover mosaic. This procedure has made it possible to build an analytic picture of the analyzed physiographic units useful to identify critical areas with low permeability values and those in the opposite condition.

Introduction

Coastal areas represent one of the most inhabited and anthropized natural environments. Nowadays, about 40 % of the world's population lives in the coastal belt of 100 km, while 600 million people live in coastal areas with an altitude below 100 m above sea level, and for these reasons exposed to floods and seaquakes [10,15,17]. Good climate conditions together with greater accessibility to technological and transport services certainly influenced the highest population density. This fact is more evident in a country like Italy, in

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which the morphological aspect takes on a leading role in the geography of urban settlements. Flatlands, with the exclusion of the Po valley, regards essentially the coastal areas. The presence to the north of the Alps and the Apennines that crosses the peninsula from north to south, determine a limited presence of flatlands. In Italy, the municipalities overlooking the sea cover an area of about 42 600 km^2 (14 % of national soil), and people living there are over 16 500 000, about a third of the Italian population and corresponding to a population density of 400 inhab/km^2 twice the national value (200 inhab/km^2). The high anthropic pressure makes this system extremely vulnerable with significant losses of essential ecosystem services [6] and problems in the management of sandy beaches [13] where a large part of the touristic economies are concentrated [20]. This fact is even more true for the Adriatic coast, characterized mainly by long low, and sandy beaches alternating with rocky headlands only in some areas (e.g. Conero, Gargano e Punta Aderci). This geological conformation has led to the almost total disappearance of the original dune environment and its replacement with anthropic uses (agricultural, grazing, and urban) [21]. If the 1 km coastal belt is considered, today 65 % of this area is for agricultural (30 %) and urban (35 %) uses, the remainder has natural/semi-natural characters.

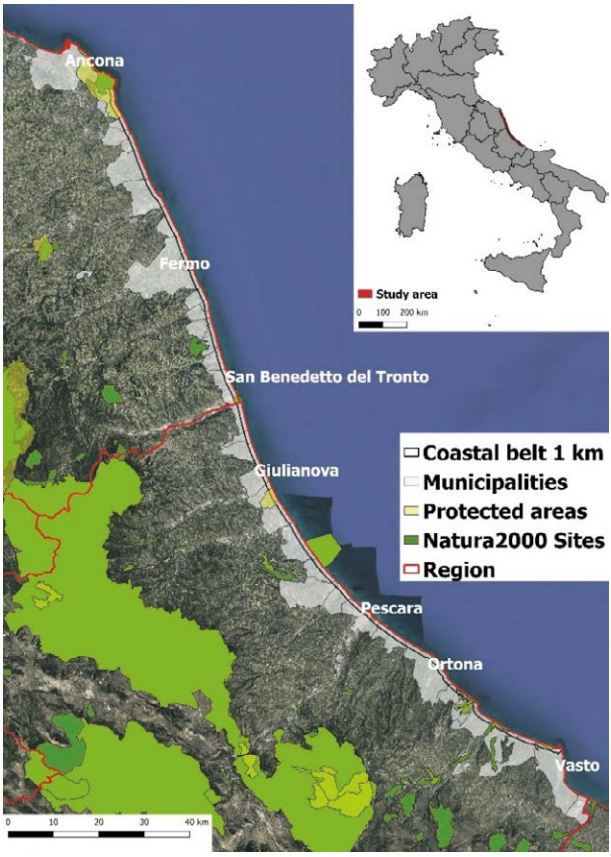

Figure 2 – Study area.

The Italian coasts have suffered in recent decades from important urbanization phenomena. In particular, the Adriatic coast, which is low and sandy coast, has suffered in recent decades from significant urbanization phenomena [21]. These transformations have profoundly altered the coastal dynamics, so much that there is a clear predominance of coastal erosion phenomena of predominantly anthropic origin. As reported by ISPRA [9], from 1950 to 1999, 46 % of low coasts have undergone changes of more than 25 meters, with stretches of coast in erosion superior to those in advance, the result is the loss of 5 km^2 of coastal soil. This has caused not only environmental and economic value loss [3,5] but also increased the risk of exposure to storms of housing, roads and railways to storms [2,13,16].

Nowadays, several projects related to these areas are focusing on both risk analysis (AnCoRa Project and SICoRA Project - https://www.regione.abruzzo.it/content/piano-di-difesa-della-costa) and integrated coastal zone management. This work focuses on the territory, corresponding to a physiographic unit [8], that extends from Monte Conero (municipality of Ancona) to the municipality of San Salvo in Chieti province. It consists of 200 km of coastline, equal to 14 % of the Adriatic coast, that involve 36 municipalities from 2 Regions (Marche and Abruzzo) (Figure 1). From a morphological and geological point of view, the beaches are sandy except for Conero and Punta Aderci promontories. In the considered municipalities, as derived from ISTAT data, over 780 000 people live there, 10 000 more than in the previous decade. The main variations are recognizable in almost the totality of Abruzzo municipalities, specifically in Vasto and Francavilla al Mare municipalities (just under 2000 more residents) and Montesilvano municipality which recorded an average annual increase of about 300 units. In the Marche region, the municipality of Civitanova Marche shows an increase of 1700 inhabitants. From an economic point of view, these areas are highly active, not only for the high concentration of services and infrastructures but also for their strong productive and tourist activity [4].

To better understand the importance of these areas for the local economies, the data on beach concessions have been analyzed. These data, updated to May 2021, come from the Ministry of Infrastructure and Transport website (http://www.dati.mit.gov.it/catalog/dataset).

In the studied coastal belt, there are more than 3300 concessions (about 17 per km), half of which were activated/renewed from 2012 onwards (450 is the maximum value recorded in 2014). The graph in Figure 2, shows the distribution percentage of the different types of state property concessions from 2012 to 2021. Over half of the concessions activated in the last decade concern recreational tourist uses and particularly, public and private bathing establishments, followed by those for various use (mooring points, renewable energy...) and productive and industrial uses. The analysis at the municipal level shows that San Benedetto del Tronto is the municipality with the higher number of concessions per km (just over 50) followed by the municipality of Alba Adriatica (about 30), while the remainder municipalities record values lower than 20 concessions/km. Therefore, not only the land-use change could have had an impact on the implementation of coastal defense but also on the growth of the number of beach concessions (Figure 2). The main aim of the present work is, on one hand, to identify a possible relationship between land-use changes and the system of the existing coastal defense [14] and on the other to assess how this system may have interacted with shoreline changes. The knowledge of these connections could reveal extremely important for the management of coastal belts.

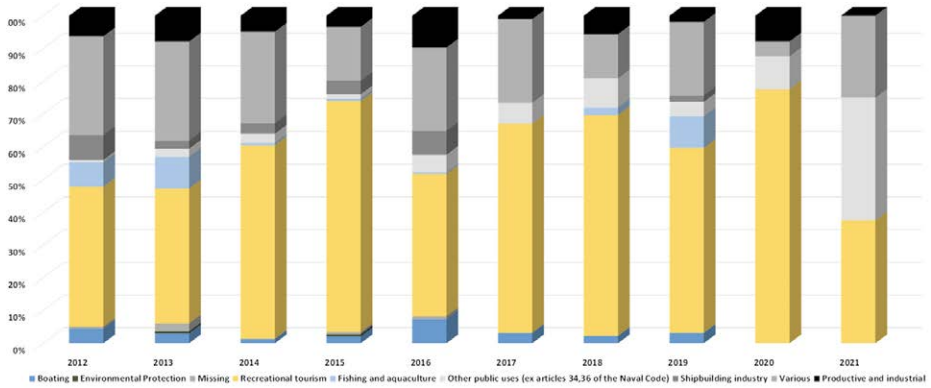

Figure 2 – Distribution percentage of state property concessions type from 2012 to 2021.

Materials and Methods

In this work, different kinds of data were used. Those on land use and land-use change (2012 -2018) are Coastal Zones. This high-resolution data (MMU 0.5 ha e MMW 10 m both for the status and the changes layers), is part of the European Project Copernicus-Land Monitoring Service (https://land.copernicus.eu/local/coastal-zones) with full European spatial coverage 10 km landward. In this work, the study area is the 1 km landward. This choice is motivated to the intense transformation of this area. The analysis of land-use changes was made at a municipal scale because, in the Italian planning landscape where strategic planning has a low cogency, municipalities are the main decision-making authorities on the transformations of territories [23,24]. Data on breakwaters and groins were digitalized, for both reference years, from Google Earth satellite images. Table 1 shows main parameters of used data. This allows assessing the shoreline coastal protection carried out during the investigated period.

Table 1 – Main parameters of used data.

Data	**Reference Period**	**Data Source**
Land use/Land Cover	2012-2018	Copernicus - Coastal Zones (https://land.copernicus.eu/local/coastal-zones)
Breakwaters and groins	2012-2018	Open street Map and Google earth pro (https://www.openstreetmap.org/)
Shoreline	2012-2018	Google earth pro
Buildings	2018	Italy Civil Protection (https://rischi.protezionecivile.gov.it/it/approfondimento/dataset-nazionale-degli-aggregati-strutturali-italiani)
State property concessions	2012-2018	Ministry of Sustainable Infrastructure and Mobility (https://dati.mit.gov.it/catalog/organization/m_inf)
Digital Terrain Model	2022	National Institute of Geophysics and Volcanology (https://tinitaly.pi.ingv.it/)

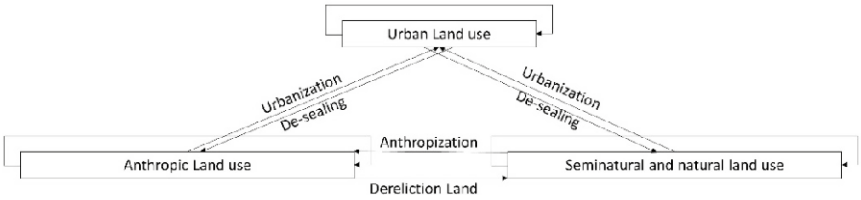

Figure 3 – Diagram of land-use transitions.

Coastal Zones legend is organized into 8 classes: 1: Urban; 2: Cropland; 3: Woodland and forest; 4: Grassland; 5: Heathland; 6: Open spaces with little or no vegetation; 7: Wetland; 8: Water. These categories have been grouped into three: Urban land use (1), Anthropic land use (2, 4), and Natural and semi-natural land use (3, 5, 6, 7, 8). This classification allows identifying land transformation drivers. As shown in Figure 3, "urbanization" consists of changes from any other land use to urban use that subtracts fertile soils and has direct negative impacts on environmental fragmentation, ecosystem services, climate, and hydrogeological effects [1, 7, 19].

In the abandonment process, a soil initially agricultural or for grazing regains natural aspects. In contrast, "anthropization" is the transformation from natural/semi-natural soil to agricultural or grazing land. Finally, "de-sealing" consists of the transformation from urban uses to agricultural/natural uses. Transformation from anthropic to natural uses has several positive consequences for example an increase in plant cover, a decrease in surface runoff, creation of new habitats [12, 25].

Moreover, to catch information about coastal dynamics, a diachronic analysis (considering only the sandy costs) based on the comparison of shorelines measured at different epochs has been performed. Consistently with the above (i.e., the observation period ranges between 2012 and 2018), the shorelines are referred to those periods. The digitalization has been performed using the historical images acquired by Google Earth Pro, appropriately georeferenced in Qgis. More in detail, the shoreline variation has been analyzed by considering the local variation (m) of the shoreline position between two different epochs ($\Delta S_{i,i+1}$). In order to compute $\Delta S_{i,i+1}$, the transversal direction to the shoreline and the (geographical) location of each i-th position needed to be evaluated.

In this case, sections have been drawn with a Δx of about 20 m (about 8800 sections in the 200 km of the physiographic unit extension). Figure 4 shows a sketch of the method used to evaluate the shoreline evolution.

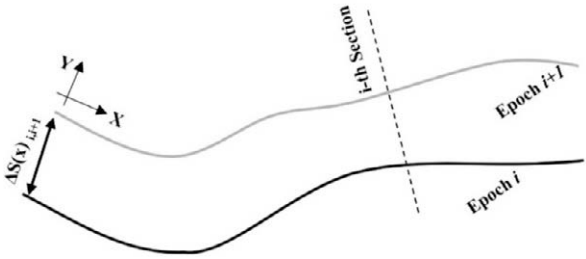

Figure 4 – Qualitative sketch of the method used for the study of the shoreline evolution.

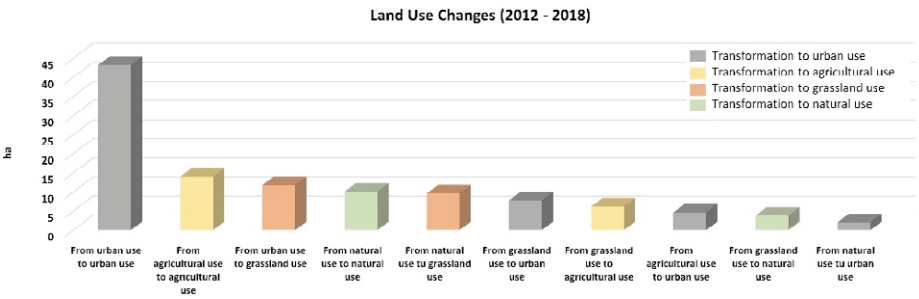

Figure 5 – Land use change occurred between 2012 and 2018 in the buffer of 1 km from the coastal line.

Results

Between 2012 and 2018 land use changes stand at 113 ha. The most extensive transformations are in the municipality of Giulianova (about 14 ha), Grottammare (12 ha), and Ancona (11 ha), while in 9 municipalities there is no change. Of these, the municipalities of Ortona, San Vito Chietino, and Rocca San Giovanni are in geographical continuity. Regarding the land-use change surface types, as shown in Figure 5, it results that 60 ha (53 % of the total) of 113 ha regard urbanization processes. Specifically, 45 ha are soil transitions within the urban soil category. More in detail, many areas that in 2012 were classified as "Construction sites" or "Land without current use" become "Dense or continuous urban fabric" or "Industrial, commercial, public units" to testify that, even if at different speeds, even now as in the past this transformation processes take place.

These processes are not virtuous urban regeneration/renovation phenomena but transformations that have completed urbanization processes started a few years before or that have converted green urban areas (Figure 6). The remaining 15 ha regard agricultural/natural

Figure 6 – Example of urban transformation with residential and receptive uses occurred between 2012 and 2018 in the study area.

soils. Abandonment phenomena have affected only 4 ha of the territory concentrated in the San Benedetto del Tronto municipality. There are also some passages to semi-natural soils on areas first used as a service for existing construction sites (about 12 ha). Anthropization processes consist essentially of "Vineyards, fruit trees and berry plantations" transformed into "Arable irrigated and non-irrigated land" for about 13 ha, and a further 9 ha from natural coverage (Sparse vegetation on sands, Sparse vegetation on rock) to "Semi-natural grassland", to witness the intensification of anthropic processes in the study area.

The intense transformative activity in the previous decades is confirmed by the reduced presence of the dune environment that today, is concentrated only in the border area between the municipalities of Vasto and San Salvo for a total area of 32 ha. In addition, it is important to point out the actual urbanization level which is equal to 43 %. This value is extremely high and much higher than the national one (10 %), with value peaks between 60 % and 80 % as shown in Figure 7. The morphology and lithology have had in the past and still have today a role of primary importance in orienting the transformative typologies along the Adriatic coast. The diagram in Figure 7 confirms this. Urbanization density below the study area average value is found especially in municipalities with rocky headlands, while in sandy sections this value rises significantly. The only exception is the southern sector of the Abruzzo's coast, where the presence of a Nature 2000 site has partially preserved the area.

The diagram in Figure 8 analyses the conditions detected along the study area. Specifically, it shows the percentage of free 200 m coastal belt (light blue bars), the percentage of length coast protected by breakwaters and groins (grey bars), the percentage of the coastal belt under environmental protection (Protected areas and Natura 200 sites, in green bars), the number of buildings in the 200 m of the coastal belt (table in shades of blue) and the number of beach concessions per km^2 (table in shades of red). The coastal sector from Ancona to Numana has the highest environmental protection level. From Porto Recanati to Martinsicuro the coastal belt free of urbanization is always lower than 40 % and the coastal protection, with a few exceptions, is always greater than 50 %, at the same time there are a few areas under environmental protection.

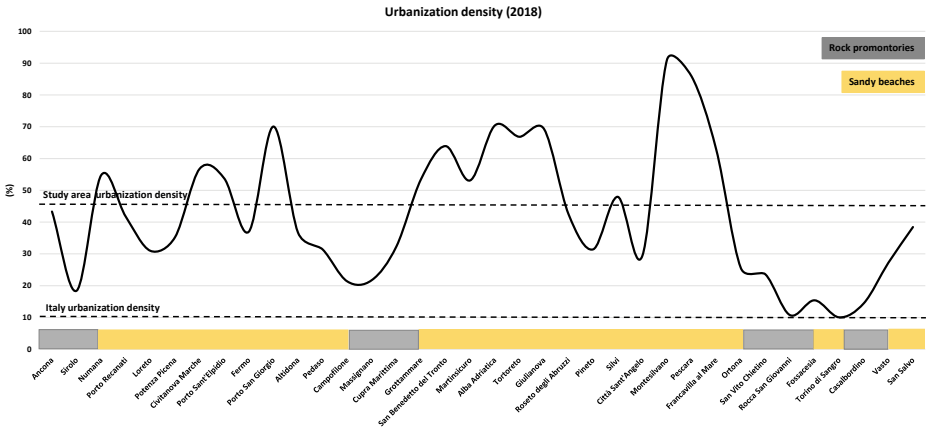

Figure 7 – Urban density in the section of the 1 km coastal belt for the study area.

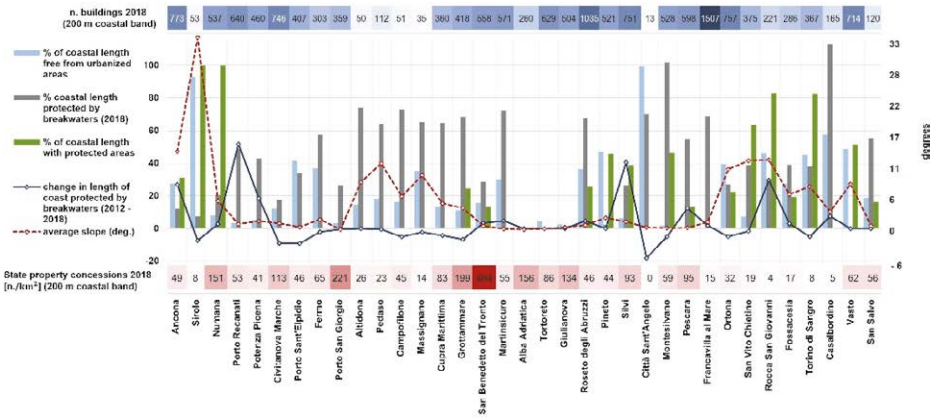

Figure 8 – Diagram of the coastal sector in the current condition.

The beach between the municipalities of Alba Adriatica and Giulianova has distinct characteristics from the other investigated sectors. As shown in the graph of Figure 7, in this littoral no groins or breakwaters are found, the coast is almost entirely urbanized (the territory is completely flat) and there is no protection from an environmental point of view. The sector from Roseto degli Abruzzi to Silvi has an environmental protection value higher than 20 % with large coastal sectors free from urbanization except for the municipality of Silvi, where one of the greatest increases in coastal protection was recorded. The territory portion from Montesilvano to Francavilla al Mare has the same urbanization condition as the previous coastal sector but with a substantial difference. Here, both environmental protection and coastal defense are significantly higher. The last sector from Ortona to San Salvo closes the considered physiographic unit. Here the morphological factor returns to be a limit for urban expansion but, at the same time a favorable element for the presence of ecological values evidenced by the percentage value of protected natural areas (always above 20 %). Beach concessions are limited if compared to the previous sectors. Only the municipalities of Vasto and San Salvo have comparable values with other coastal sectors. Also in this area, coastal defense assumes significant values (approximately 40 %) except for the municipality of Vasto. Here, more than half of the coastal perimeter remains free from urbanization and the free coastal belt coincides with the Special Protection Area "Punta Aderci - Punta della Penna". In line with the results obtained by a previous study [18] for the Abruzzo Region, the shoreline dynamics in the entire physiographic unit show an alternation of retreats and advance regardless of the presence of rigid protection structures. This well-balanced alternation between retreats and advances is confirmed by the shape of the frequency distribution of the ΔS (i-th sections) sample (≈ 8800 elements) that is not symmetric (skewness equal to 0.55) but not far from a normal distribution (kurtosis equal to 2.93). The mean and the median of the sample are about 0.6 m and 0.40 m respectively. This means that the advances tend to be slightly more than the retreats. The maximum and minimum ΔS values are 13 m and 12 m respectively, the 90th percentile is 3.5 m while the 10 % percentile is about -2 m. In this scenario, with extremely high values of coastal protection and no evidence of a positive or negative trend in coastal variations, a definite interpretation of the

role of the rigid structure as a measure against coastal dynamics is difficult and certainly not without ambiguity, as long as the considered temporal interval is relatively short compared to the characteristic period of beach morphodynamics.

Discussion and Conclusions

The proposed work has shown how the dynamics of coastal settlement, albeit with reduced intensity compared to the recent past, continue to erode soils of ecologically fragile environments. The analyses have shown that 50 % of the transitions concerned transformations to urban use, which represents soil use with greater negative effects in environmental terms. It should be added that the data used, although of high resolution, fails to detect the sprinkling development [21] that characterizes the coastal belt (Figure 9).

Figure 9 – Examples of building patterns along the investigated coastline not surveyed by Coastal Zones.

The strong economic energy and the weak mandatory local plans have encouraged the single building construction, due to their small size Coastal Zones do not identify them, despite this is a very-high-resolution data. For these reasons, the real phenomenon is of greater magnitude. If on one hand, there is an increase in the exposure of these areas, on the other hand, are more frequent technical and political actions trying to improve their resilience. Every year are several beach nourishment and new coastal defense systems to guarantee the operativity of the economic activities during the summer season. These types of interventions are part of the measures provided for in the coastal defense plans (updated in 2019 for the Abruzzo Region and in 2015 for the Marche Region). These plans, drawn up at the regional scale, address the problem of erosion risk and storm damage on the entire regional coastal to reduce hydraulic risk. The intervention areas concern the marine area and the overlooking sector of the beach/cliff. The combined analysis between protected areas (with rigid structures), and shoreline changes showed difficulty in assessing the role of the protection on the shoreline dynamics. The general pictures in the analyzed physiographic unit show a clear alternation between advances and retreat of the shoreline with a slight prevalence of advances. The area just behind the coastal area is still home to settlement interventions, an area that the urban planning tools often allocate to new building interventions. A previous study on the Romagna coast [24] shows that in the urban planning instruments of coastal municipalities, in the 1 km coastal belt, there are further 48 km^2 of land for urban functions not yet built. This fact underlines the importance to set up the planning tool mosaic of coastal municipalities belonging to the same physiographic unit

(cPTM – Coastal Planning Tool Mosaic). The cPTM would allow to set up the settlement scenario and to be aware of the intended use in the 1 km coastal belt. Therefore, it would be simpler and more effective to implement actions of use changes, relocation, and transfer of land rights through the equalization mechanisms to safeguard coastal areas. Moreover, this solution allows economic saving in the long term because the above-mentioned interventions may not be necessary. The integration of cPTM with the risk scenarios provided by the Coastal Defense Plans is certainly an effective measure in the management and protection of this important ecosystem.

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