Article

Effects of Anthropogenic Pressures on Dune Systems—Case Study: Calabria (Italy)

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Abstract: During the second half of the last century, considerable anthropization processes were observed throughout most of the Italian territory. These processes have altered the equilibrium conditions of several river and coastal ecosystems, causing the destruction of numerous dune systems. This issue is particularly important in territories such as Calabria, a region in southern Italy subject to considerable anthropogenic pressures and characterized by over 700 km of coast. The aim of the paper was to evaluate the effects of anthropogenic pressures on the Calabrian dune systems, especially in regard to the triggering of coastal erosion processes. For this purpose, historical and current cartographic data, such as shapefiles, cartography, and satellite imagery, were analyzed using QGIS. This evaluation was carried out through the comparison between the current extension of the dune systems and their extensions after the Second World War, before the anthropogenic pressures. This evaluation was also carried out through the analysis of shoreline changes in coastal areas, where dune systems are currently present, and in coastal areas where dune systems have been partially or totally destroyed by anthropogenic causes, compared to the 1950s, thus excluding coastal areas without dune systems in the 1950s, and analyzing what was built in place of the destroyed dune systems. Two criteria were defined to identify the levels of destruction of the dune systems and to identify the coastal erosion processes. The analysis showed a strong correlation between the destruction of dune systems by anthropogenic causes and the triggering of coastal erosion processes.

Keywords: dune systems; anthropogenic pressure; shoreline changes; coastal erosion; historical cartography; satellite imagery; QGIS; Calabria

1. Introduction

Coastal areas are systems between land and sea, in constant evolution, often directly exposed to wave action. Most coastal areas are particularly important due to the presence of residential settlements, infrastructure, economic activities, archaeological sites, ecological systems, dunes, etc. [1–3]. Among these, the dunes are habitats of important environmental and landscape values. Moreover, dunes form natural coastal defenses because they act both as a reserve of sand and as a physical barrier to protect landward territories [4–7].

The anthropization process that began in the second half of the last century, represented mainly by urban expansion and by industrial and tourism activities, has considerably modified the natural and environmental characteristics of several coastal and river ecosystems, causing intense erosive processes and the destruction of numerous dune systems [8–12]. Indeed, 30% of the world's coasts are currently eroding [13–15] and, in Europe alone, dune systems have decreased by 70% [16]. Furthermore, climate change can increase these processes through sea level rise [17–20].

Generally, dune systems are in flat coastal areas, the seabeds of which have low slopes. These systems consist of sediments of both alluvial and marine origin, and they are continuously subjected to the combined action of multiple physical, chemical, and biological agents, essential for genesis and structuring phases. Dune systems are a highly

dynamic environment, whose morphology varies spatially and temporally under the action of both natural and anthropogenic factors [21–24].

From the temporal point of view, there are long-term, middle-term, and short-term variations. Long-term variations are mainly correlated to the Pleistocene deposition of the dune systems. Middle-term variations are of the order of tens of years and depend on alterations in coastal, wind, and river sedimentary balance [25–28]. Often these alterations are caused by anthropogenic factors, such as the construction of buildings, infrastructure, ports, and coastal defense works in coastal areas [29–31] and the construction of hydraulic structures interfering with fluvial dynamics, such as levees, dams, and inert drains from riverbeds [32–35]. On the other hand, short-term variations are mainly related to natural factors, such as single sea storms [36], clusters of sea storms [37,38], extreme flood events [39], or concurrent events [40–42], which cause coastal flooding [43]. A full dune recovery can take several decades [44].

From a spatial point of view, the erosive processes of the dune systems can vary greatly along the coast for various reasons, the main ones being linked to the geomorphological characteristics of the area and to the variability of the wave climate and of the longshore transport [45,46].

Quantitative measurement of the intensity of impact that human activity has on coastal ecosystems can help us better understand the interaction between humans and dune systems, promoting scientific management of the ecological environment and improving the scientific and orderly development of coastal zones [47]. In this regard, the analysis of morphological changes of coastal dunes and the analysis of the related causes is much analyzed in the scientific literature by analyzing case studies [48], with laboratory experiments [49–53] and applying analytical and numerical models [54–56]. Indeed, these variations can be analyzed in probabilistic terms [57,58] to identify critical thresholds of sea storms that cause dune erosion [59], and in terms of the beach response to the action of the most intense sea storms [60]. Furthermore, the analysis of the causes of erosive phenomena [61] is of fundamental importance to quantify and predict the vulnerability of dune systems on different timescales and to correctly plan any interventions on dunes and beaches [62–70].

The aim of the paper was to evaluate the effects of anthropogenic pressures on the Calabrian dune systems, especially in terms of the triggering of coastal erosion processes. This evaluation compares the current and past dune system extension, stretching back to the 1950s, while also analyzing what was built in place of the destroyed dune systems, and in the analysis of the possible correlations between the destruction of dune systems by anthropogenic causes and coastal erosion.

2. Materials and Methods

2.1. Site Description

Calabria is a region in southern Italy with a narrow and elongated morphology, which has been subject to a considerable coastal extension, exceeding 700 km (Figure 1). The coastal areas are characterized by an alternation of beaches, mainly sandy and pebbly, and high coasts, especially in the promontories of Capo Rizzuto, on the Ionian coast, and of Capo Vaticano, on the Tyrrhenian coast. Calabria is bordered by two seas, Tyrrhenian and Ionian, by the Strait of Messina and by the Gulf of Taranto. Tyrrhenian and Ionian coasts are characterized by different climatic conditions and by different fetch extensions. These differences lead to a remarkable variability of meteorological and marine conditions between the different areas of Calabria.

From a morphological point of view, Calabria is mainly characterized by hills and mountains, with a percentage of less than 10% of plains. Much of the Tyrrhenian coast is characterized by reliefs generally located a short distance from the coast and by very few coastal plains. Instead, on the Ionian coast, the reliefs are further away from the coast than the Tyrrhenian coast.

Figure 1. Location of Calabria region (highlighted by the red fill) in Southern Italy in the center of the Mediterranean Sea.

From a hydrological point of view, most of the Calabrian rivers (called *fiumare*) are characterized by high slopes, modest corrivation times, and a torrential regime, so floods occur suddenly [71,72]. For these reasons, river sediment transport is mainly related to soil erosion by water [73,74], which also influences shoreline evolution [75,76].

Furthermore, Calabria is characterized by considerable anthropogenic pressures, concentrated mostly in the second half of the last century after the Second World War. These pressures have encompassed both the construction of towns and infrastructures and the construction of numerous tourist activities and bathing establishments, which make the coastal areas of fundamental importance in the regional economy.

2.2. Methodology

The proposed methodology has two main aims, and it can be divided into five phases, according to the flow chart shown in Figure 2. This methodology was applied at the municipality level. In Calabria, there are 116 coastal municipalities, 71 are on the Ionian coast, 3 on the Strait of Messina, and 42 on the Tyrrhenian coast. Among these municipalities, those with negligible coastal lengths of less than 1 km were excluded. Therefore, 10 municipalities were excluded, 8 of them are in the Ionian coast and the other 2 are in the Tyrrhenian coast. Therefore, the analyzed municipalities are 63 on the Ionian coast, 3 in the Strait of Messina, and 40 on the Tyrrhenian coast.

Regarding the aims, the first of them concerns the comparison between the current extension of the dune systems and their extension after the Second World War, before the considerable anthropic pressures described above. The second aim concerns the analysis of shoreline changes, excluding only the municipalities without dune systems in the 1950s.

The five phases were all developed in QGIS and concerned:

1. Acquisition of historical and current cartographic data available, such as shapefiles, cartography, and satellite imagery;
2. Comparison between past and present dune systems;
3. Analysis of what was built in place of the destroyed dune systems, for example, inhabited centers, promenades etc.;

4.　　　Analysis of the shoreline changes in municipalities where dune systems are currently present and where dune systems have been partially or totally destroyed by anthropogenic causes;

5.　　　Analysis of the possible correlations between the destruction of dune systems by anthropogenic causes and the triggering of coastal erosion processes.
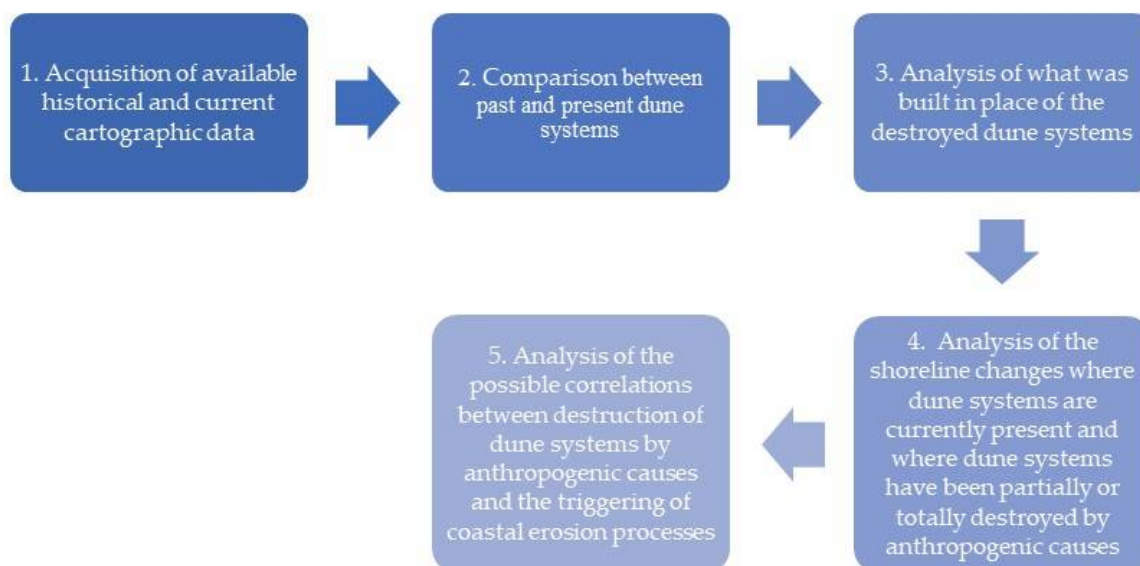

Figure 2. Flow chart of the proposed methodology.

Regarding the first phase, the input data were shapefiles, cartography, and satellite imagery. In detail, the following have been analyzed: the shapefile of the shoreline and the shapefiles of the inhabited centers, both dated 1954, and both digitized based on CASMEZ, "*Cassa del Mezzogiorno*", cartography of 1954, in scale 1:10,000; the shapefile of the dune systems in 1959, digitized starting from Geological cartography of 1959 in scale 1:25,000; the shapefile of the Corine Land Cover fourth level of 2018, where the current dune systems and the inhabited centers are highlighted; shapefiles of the municipal boundaries. These data are available in the Open Data section of the Calabrian Geoportal (http://geoportale.regione.calabria.it/opendata, accessed on 15 December 2021), with the exception of the Corine Land Cover, available in the Open Data section of the Italian Higher Institute for Environmental Protection and Research (https://groupware.sinanet.isprambiente.it/uso-copertura-e-consumo-di-suolo/library/copertura-del-suolo/corine-land-cover/corine-land-cover-2018-iv-livello, accessed on 15 December 2021). Other input data used included the most recent Google satellite imagery. The coverages of these data are not temporally homogeneous, but the images are from between 2019 and 2021, depending on the location examined.

Regarding the resolution of the input data, the Corine Land Cover was obtained through photointerpretation of satellite images in the land thematic area of the Copernicus program and characterized by a minimum cartographic unit for the coverage of 25 hectares and by a minimum width of the linear elements of 100 m. Moreover, the level of detail of both CASMEZ and geological cartographies is not very high, as they have scales of 1:10,000 and 1:25,000, respectively. Therefore, digitization errors would be in the order of meters, especially in geological cartographies. However, this accuracy is consistent with the aims of the paper, which concern the evaluation of the order of magnitude of the extension of past and present dune systems.

In the second phase, the shapefiles of the dune systems of the 1950s were superimposed on the Corine Land Cover fourth level of 2018 to verify which dune systems present in the 1950s are still present, and to quantify and compare the relative extensions.

In the third phase, the shapefiles of the inhabited centers of the 1950s were superimposed on the Corine Land Cover fourth level of 2018, and on the most recent Google

satellite imagery, to verify which inhabited centers were built in place of the dune systems of the 1950s, and to analyze what was built in place of the destroyed dune systems, for example, inhabited centers, promenades, ports, etc. It should be noted that the municipalities analyzed are characterized by different morphological and anthropic conditions. We focused on man-made areas with buildings, infrastructure, promenades, ports, and coastal structures, and on areas without them. The criterion adopted to define the level of destruction of the dune systems was the following: intact dune systems if the current extension was the same as that of the 1950s or if the reduction do not exceed 10%; dune systems partially destroyed if this reduction was between 10 and 90%; dune systems totally destroyed if this reduction was greater than 90%.

The analysis of the shoreline changes carried out in the fourth phase involved the comparison between the 1954 shoreline and the shoreline digitized starting from the most recent Google satellite images. The analysis was carried out in coastal areas where dune systems are currently present and in coastal areas where dune systems are partially or totally destroyed by anthropogenic causes compared to the 1950s; thus, excluding coastal areas without dune systems in the 1950s. The results were aggregated at the municipality level. The digitalization of the missing shorelines was carried out using the spatial analysis tools of Google Earth Pro at an eye altitude of 200 m, corresponding to a scale higher than 1:1000. Moreover, transepts were traced, with an average spacing of the order of a hundred meters, and the related baselines were identified for each transept. These lines identify the upper limit of the beach and correspond to promenades, roads, and structures. Shorelines, transepts, and baselines were saved as kml files then saved on QGIS as shapefiles. Baselines were used on QGIS as control points to confirm the accuracy of the procedure.

Generally, the uncertainties in the digitization phase concern georeferencing, the orthorectification process, the resolution of the different imagery sets, the digitizing uncertainty, the uncertainty in the identification of the wet/dry line, and any error caused by a variation in some factors affecting the shoreline change, such as the seasonal cycle of erosion and deposition, the tide excursion, and the impact of storms [77–82]. In this case, the reference line chosen was the wet/dry line. Moreover, the cartography data are all related to the summer period, and no storm conditions were observed in any of the data, so the effects of seasonal variation and individual storms on shoreline change are of limited importance. To estimate the tide excursions, the recordings of the tide gauges of Crotone and Reggio Calabria were analyzed, the Tide Tables of the Italian Marine Hydrographic Institute [83] and the scientific papers were consulted, especially that of Sannino et al. [84]. The maximum-recorded tide height values are about 25 cm in Reggio Calabria and over 80 cm in Crotone; the minimum recorded tide height values are over 50 cm in Reggio Calabria and over 70 cm in Crotone and the average recorded tide height values are less than 30 cm in Reggio Calabria and about 50 cm in Crotone. The maximum tide height value reported in the Tide Tables is 25 cm. Therefore, Calabria is a microtidal environment where the effects on the variation of the shoreline position are of limited importance. The shoreline digitized based on the CASMEZ Cartography of 1954 on a scale of 1:10,000 is affected by a scanning error of less than one meter. On the other hand, regarding the georeferencing error of the Google Earth shorelines, the use of baselines as control points contained the error within a few tens of cm. Finally, the physical component of the error was estimated using the formula of Allan et al. [85]. The error was estimated, starting from the average and maximum values of the tide height and from the beach slope. This last parameter was estimated using the QGIS Profile tool plugin based on the 1 m side square mesh LIDAR DTMs available on the Italian Geoportal (http://www.pcn.minambiente.it/mattm/, accessed on 15 December 2021). The beach slope values of the examined locations varied between 5 and 15% so that the estimated error, assuming maximum tide height conditions, was between 5 and 15 m, and the estimated error (assuming minimum tide height conditions) was between 4 and 14 m. However, these are very precautionary values, as the times of the satellite image was not known and, consequently, it is not possible to know the tide conditions at these times. Furthermore, most of the examined locations were subject to tidal

excursions lower than the maximum ones. Therefore, in most of the examined locations, the uncertainties in the shoreline position are in the order of a few meters. This accuracy is compatible with the aims of the paper, which concern the evaluation of the erosion and advancement trends, and not their precise quantification.

In the last phase, a cross-statistical analysis of the results of the previous phases was carried out to verify whether there was a correlation between the destruction of dune systems by anthropogenic causes and the triggering of coastal erosion processes. Through this analysis, the number and the percentage of municipalities where dune systems were present or absent were firstly evaluated. Subsequently, the number of municipalities where dune systems were intact compared to the 1950s, or had been partially (or totally) destroyed by anthropogenic causes, was evaluated. Furthermore, the number of municipalities with shoreline erosion or advancement was evaluated by classifying the erosive processes according to their intensity.

The criterion adopted to identify the coastal erosion processes was the following. For each municipality, the maximum value of the shoreline retreat was considered, not counting retreat of the order of a few meters. Furthermore, the coastal erosion intensity was classified according to a scale with four classes: slight erosion, for maximum retreat of up to 20 m; moderate erosion, for maximum retreat between 20 and 50 m; intense erosions, for maximum retreat between 50 and 100 m; severe erosion, for maximum retreat exceeding 100 m. The same for shoreline retreat, the shoreline advancement was also identified. For each municipality, the maximum value of the shoreline advancement was considered, not counting the advancement of the order of a few meters.

3. Results

The results were aggregated at the municipality level, and they are summarized in Tables 1–4. In detail, Table 1 shows a summary of the dune system condition (intact, partially, or totally destroyed by anthropogenic causes) and of the maximum shoreline retreat of advancement values for each of the 84 analyzed municipality, ordered clockwise from the Ionian coast to the Tyrrhenian coast. Table 2 shows the number of municipalities where dune systems are present or absent both in the 1950s and today. Table 3 shows the comparison between the dune systems in the 1950s and today, highlighting the number of municipalities where these systems are intact and where they were partially (or totally) destroyed by anthropogenic causes. In addition, this table shows the number of municipalities where erosion or shoreline advancement was observed. Finally, Table 4 shows the erosive process classification based on their intensity.

The analysis has shown that, in the 1950s, dune systems were present in most of the Calabrian coastal municipalities. Indeed, most of the inhabited centers were in inland areas, except for the provincial capitals, such as Reggio Calabria and Crotone, and for the larger towns. Dune systems were present in 84 out of 106 municipalities, corresponding to a percentage of 79% and covering an area of about 120 km^2. Consequently, the municipalities without dune systems were just 22 out of 106, corresponding to a percentage of 21%. Of these 22 municipalities without dune systems, 10 are located on the Ionian coast, 3 in the Strait of Messina, and 9 on the Tyrrhenian coast. In contrast, of the 84 municipalities with dune systems, 54 are located on the Ionian coast and the other 30 are located on the Tyrrhenian coast. However, the Ionian coast extends for about 450 km while the Tyrrhenian coast extends for about 250 km. Therefore, in relation to the coastal extension, the dune systems were well divided between the Ionian and Tyrrhenian coasts while most of the municipalities without dune systems lay on the promontory of Capo Vaticano and in the Strait of Messina area.

Table 1. Summary of the dune system condition (intact, partially, or totally destroyed by anthropogenic causes) and of the maximum shoreline retreat of advancement values for each of the 72 analyzed municipality (ordered clockwise from the Ionian coast to the Tyrrhenian coast). Legend: Max Ret. = maximum retreat; Max Ad. = maximum advancement.

Municipality	Dune Condition	Max Ret. (m)	Max Ad. (m)	Municipality	Dune Condition	Max Ret. (m)	Max Ad. (m)
Rocca Imperiale	Intact	-	170	Marina di Gioiosa Ionica	Totally	70	-
Roseto Capo Spulico	Totally	15	-	Siderno	Partially	55	-
Amendolara	Partially	30	-	Locri	Partially	30	-
Trebisacce	Intact	-	25	Sant'Ilario dello Ionio	Partially	60	-
Villapiana	Intact	-	60	Ardore	Partially	30	-
Cassano allo Ionio	Intact	-	80	Bovalino	Partially	40	-
Corigliano Calabro	Partially	60	-	Bianco	Intact	-	70
Rossano	Partially	20	-	Africo	Intact	-	50
Crosia	Partially	60	-	Ferruzzano	Intact	-	10
Calopezzati	Partially	50	-	Brancaleone	Partially	25	-
Pietrapaola	Partially	20	-	Palizzi	Partially	30	-
Mandatoriccio	Partially	70	-	Condofuri	Intact	-	15
Cariati	Partially	50	-	Ricadi	Totally	20	-
Crucoli	Partially	40	-	Parghelia	Partially	75	-
Cirò	Partially	40	-	Zambrone	Totally	75	-
Cirò Marina	Partially	50	-	Curinga	Intact	-	105
Strongoli	Partially	-	70	Lamezia Terme	Intact	-	65
Crotone	Partially	90	-	Gizzeria	Partially	70	-
Isola Capo Rizzuto	Intact	-	5	Falerna	Partially	25	-
Cutro	Partially	-	15	Amantea	Totally	160	-
Botricello	Intact	-	40	Belmonte	Partially	25	-
Cropani	Intact	-	15	Longobardi	Partially	25	-
Sellia Marina	Partially	50	-	Fiumefreddo Bruzio	Partially	60	-
Simeri Crichi	Partially	50	-	Falconara Albanese	Totally	20	-
Borgia	Partially	20	-	San Lucido	Partially	70	-
Squillace	Partially	40	-	Paola	Totally	25	-
Stalettì	Partially	25	-	Fuscaldo	Partially	70	-
Montepaone	Totally	40	-	Guardia Piemontese	Totally	150	-
Soverato	Partially	-	40	Acquappesa	Totally	80	-
Sant'Andrea Apostolo dello Ionio	Intact	-	50	Cetraro	Totally	80	-
Santa Caterina dello Ionio	Intact	-	30	Diamante	Partially	30	-
Guardavalle	Partially	15	-	Grisolia	Intact	-	80
Monasterace	Partially	90	-	Santa Maria del Cedro	Totally	25	-
Camini	Partially	30	-	San Nicola Arcella	Totally	20	-
Riace	Partially	-	30	Praia a Mare	Partially	-	70
Stignano	Intact	-	55	Tortora	Totally	100	-

Table 2. Summary of the municipalities with dune systems present or absent in the 1950s and today, and a summary of the dune system extension in the 1950s and today.

Dune Systems	Municipality		Area	
	1950s	Today	1950s	Today
Present	84 (79%)	70 (66%)	120 km^2	25 km^2
Absent	22 (21%)	36 (34%)	-	-

Table 3. Summary of the comparison between the dune systems in the 1950s and today and a summary of the number of municipalities where shoreline erosion or advancements have been observed, or where shoreline changes are due to other non-anthropogenic causes.

Dune Systems	1950s–Today	Erosion	Advancement	Shoreline Changes Due to Other Non-Anthropogenic Causes
Intact	18	0	17	1
Partially destroyed	52	36	5	11
Totally destroyed	14	14	0	0

Table 4. Summary of the classification of coastal erosion processes according to their intensity.

Dune Systems/Erosion	Slight	Moderate	Intense	Severe
Intact	0	0	0	0
Partially destroyed	1	18	17	0
Totally destroyed	1	6	4	3
Total	2	24	21	3

On the other hand, dune systems are today present in 70 out of 106 municipalities, corresponding to a percentage of 66% and cover an area of about 25 km^2 with a reduction of 14 municipalities and about 100 km^2 compared with the 1950s. Most of these municipalities are in the Tyrrhenian coast, 11 out of 14 to be precise; therefore, dune systems are currently present in 51 municipalities on the Ionian coast and in just 19 municipalities on the Tyrrhenian coast. Consequently, the municipalities without dune systems are 36 out of 106 today, corresponding to a percentage of 34%. Of these 36 municipalities, 13 are located on the Ionian coast, 3 in the Strait of Messina and 20 on the Tyrrhenian coast. Therefore, currently most of the dune systems are located on the Ionian coast.

The comparison between the dune systems between the 1950s and today highlights that, currently, only in 18 out of 84 municipalities are the dune systems intact compared to the 1950s. In contrast, in 52 out of 84 municipalities, the dune systems have been partially destroyed and most of these municipalities are in the Ionian coast, precisely 36 out of 52. On the other hand, in 14 out of 84 municipalities, the dune systems have been totally destroyed and most of these municipalities are in the Tyrrhenian coast, 11 out of 14 to be precise.

Shoreline changes were analyzed in 72 out of 106 municipalities. The 22 municipalities without dune systems in the 1950s, and the 12 municipalities where the destruction of dune systems is not caused by anthropogenic action, but by other non-anthropogenic causes, such as erosion at river mouths and the construction of ports were excluded from the comparison. In the first case, all the dune systems present in the 1950s near the river mouths, in areas subsequently eroded and, therefore, currently covered by the sea, have been included. Indeed, between the 1950s and today, significant retreat of the shoreline has been observed at the mouths of many Calabrian rivers such as Allaro, Petrace, Mesima, Angitola, even of the order of hundreds of meters (Figure 3). On the other hand, the construction of ports, despite being an anthropogenic cause, was considered as a separate cause, as it can create an obstacle to longshore transport by creating both accumulation and erosion areas and, thus, altering the coastal balance. This analysis showed that, in 50 municipalities, there is

erosion, while in 22 municipalities there is advancement. Furthermore, in no municipality where the dune systems are intact is there erosion and in almost all, as many as 17 out of 18, there is advancement, while in only 1 municipality the shoreline changes are due to other non-anthropogenic causes. In contrast, in all 14 municipalities, where the dune systems were totally destroyed between the 1950s and today, erosions are observed. Finally, regarding the 52 municipalities where the dunes have been partially destroyed between the 1950s and today, in 36 municipalities there is erosion, and only in 5 municipalities is there advancement, while in 11 municipalities the shoreline changes are due to other non-anthropogenic causes.
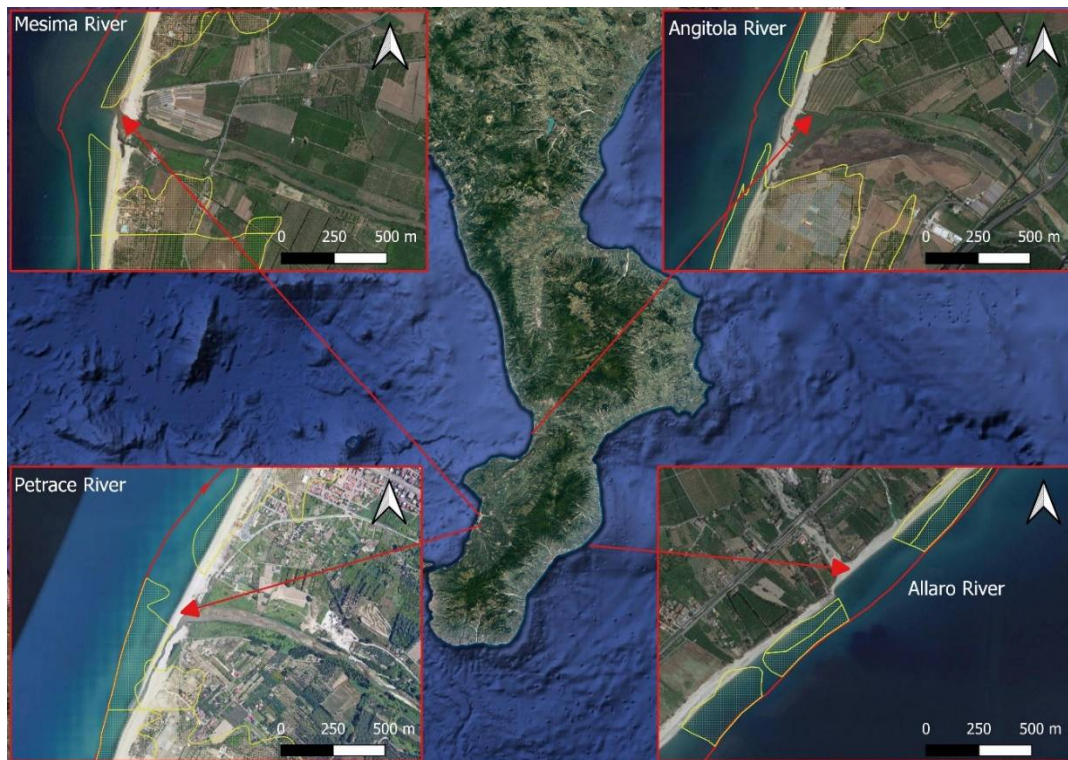

Figure 3. Shoreline erosions near river mouths. Legend: red line = shoreline of 1954; yellow dotted area = dune systems of 1950s; background = most recent Google satellite images.

In the 50 municipalities where erosions were observed, their intensity was also evaluated, according to the scale described above, highlighting that in most of the municipalities, 45 out of 50, there are moderate or intense erosion while only in 2 municipalities are there slight erosions, while in 3 municipalities there are severe erosions. However, severe erosions have been observed only in municipalities where dune systems have been totally destroyed and these municipalities are all on the Tyrrhenian coast. The maximum advance is observed in Rocca Imperiale on the Ionian Sea, with a value of 170 m, and another significant advance is observed in Curinga on the Tyrrhenian Sea, with a value greater than 100 m. The maximum retreat is observed in Amantea, with a value of 160 m in a coastal area not affected by the construction of the port (Figure 4), and another significant retreat is observed in Guardia Piemontese, with a value of 150 m (Figure 5), and in Tortora, with a value of 100 m. Finally, for each of the 65 municipalities with partial or total destruction of the dune systems, what was built in place of the dunes was analyzed. In detail, in almost all municipalities, new settlements have been built or existing ones have been expanded. A total of 42 new towns have been built, while scattered dwellings have been built in another 21 municipalities, the only exceptions being the municipalities of Sant'Ilario dello Ionio, where only a promenade with no inhabited center was built, and Bruzzano, where a railway

was built. Finally, in 44 out of 65 municipalities, a promenade has also been built in the new inhabited centers.

Figure 4. Amantea: overlap between CASMEZ cartography and most recent Google satellite image. Legend: red line = shoreline of 1954; yellow dotted area = dune systems of 1950s.
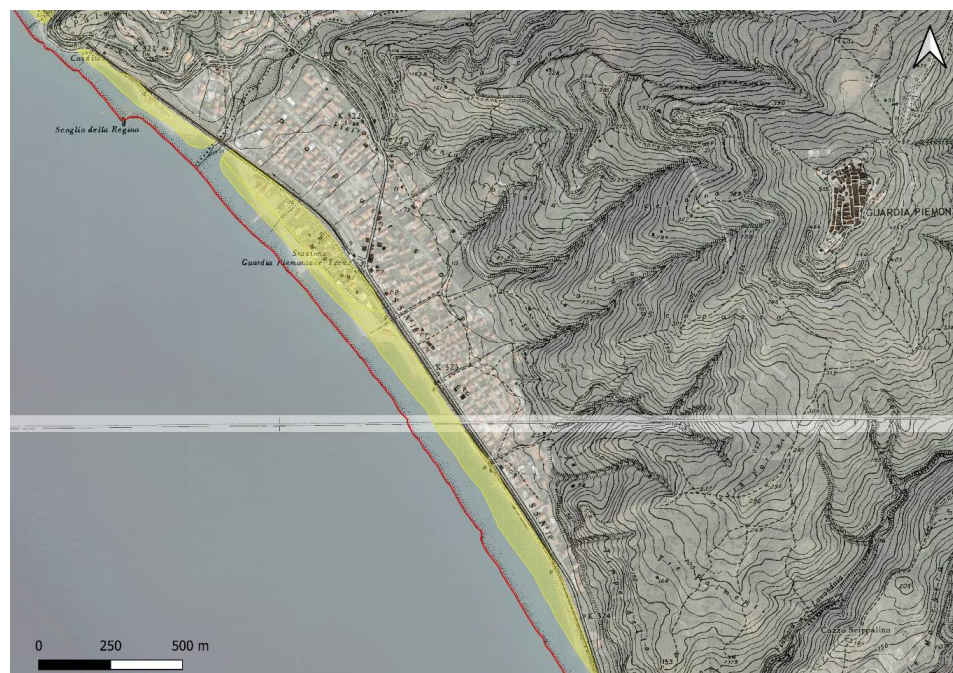

Figure 5. Guardia Piemontese: overlap between CASMEZ cartography and most recent Google satellite image. Legend: red line = shoreline of 1954; yellow dotted area = dune systems of 1950s.

4. Discussion

The paper analyzes the effects of anthropogenic pressures on dune systems, especially in terms of the triggering of coastal erosion processes, using Calabria, a region in southern Italy, as a case study. This issue is particularly topical and important because, during the second half of the last century, considerable anthropization processes were observed in many territories around the world [10–12]. On the other hand, Calabria is an interesting case study for the considerable anthropogenic pressures and for its geomorphological peculiarities. Among these peculiarities, two are highlighted: the border with two different seas, the Ionian and the Tyrrhenian, each of them exposed to very different meteorological and marine conditions from the other, and the presence of numerous coastal areas where sea and mountains are very close, especially along the Tyrrhenian Sea.

The analysis showed that these anthropogenic pressures had strong impacts on the Calabrian dune systems, which are currently greatly reduced from 120 km^2 in the 1950s to just 25 km^2 today. This significant reduction is also visible by analyzing on a municipalities scale. Indeed, 79% of the municipalities where dune systems were present in the 1950s are currently characterized by partially (62%) or totally (17%) destroyed dune systems, while in the remaining 21% the current dune systems are intact compared with those of the 1950s. In place of the destroyed dune systems, entire inhabited centers or small hamlets have been built.

No municipality where the current dune systems are intact compared to the 1950s show shoreline retreats. Indeed, in almost all these municipalities, the shoreline is advanced. In contrast, all the municipalities where the dune systems were totally destroyed between the 1950s and today show shoreline retreats. It should be noted that all three locations with severe erosions are located on the Tyrrhenian Sea. These locations are Amantea, Guardia Piemontese, and Tortora, with maximum retreat equal to 160, 150, and 100 m, respectively. Finally, in the municipalities where the dune systems were partially destroyed between the 1950s and today, the shoreline retreats prevail, and only in five municipalities did the shoreline advanced.

A total of 12 municipalities were excluded from this analysis because the shoreline changes were not due to the destruction of the dune systems, but to other non-anthropogenic causes. These localities include Catanzaro, Isca sullo Ionio, Badolato, Caulonia, Roccella Ionica, Bruzzano Zeffirio, Palmi, Gioia Tauro, San Ferdinando, Nicotera, Pizzo, and Nocera Terinese. Among these localities, those with erosion near the river mouths are Caulonia near the Allaro River, Bruzzano Zeffirio near the Bruzzano River, Palmi, and Gioia Tauro near the Petrace River, San Ferdinando and Nicotera near the Mesima River and Pizzo near the Angitola River and, in the latter, there is a dam. On the other hand, the other locations are close to ports. In detail, Isca sullo Ionio is located near the port of Badolato, which was built in a straight coastal area causing considerable shoreline variations on the two sides of the port. Specifically, there are shoreline advancements exceeding 150 m from the Badolato side and shoreline retreats of about 50 m from the Isca side. Moreover, Nocera Terinese is located near the port of Amantea. Like the port of Bodolato, the construction of the port of Amantea caused shoreline retreats in Nocera Terinese and shoreline advancements in Amantea. Only in San Ferdinando was a shoreline advancement observed, while in the other 10 municipalities, there was shoreline retreat. San Ferdinando is located near the port of Gioia Tauro, which is an inland port that has two breakwaters extending over 200 m from the shoreline, thereby causing a groin-like effect on the adjacent coast.

The anthropization process, with consequent destruction of the dune systems, is more present on the Tyrrhenian coast than on the Ionian one and can be correlated to the morphology of the territory. Indeed, the short distance between the reliefs and the coast may have facilitated the anthropization of the few flat coastal areas, often destroying the existing dune systems, as in the case of Tortora (Figure 6). In the 1950s, in fact, the town of Tortora was located only in the hills, while on the coast, there was an extensive dune system of over 650,000 m^2, with only a few sporadic buildings. Currently, instead of the dune system, the Tortora Marina town has been built, with a promenade and several buildings built not far from the shoreline. Moreover, the beach width is between 30 and

a few meters, decreasing towards the north, and a maximum erosion of about 100 m is observed compared to 1954. Furthermore, on the Ionian coast, there is generally a greater distance between the coast and the reliefs, so several inhabited centers have been built behind the existing dunes, as in the case of Villapiana in the Ionian coast (Figure 7). In this case, the dune system has a length of about 5 km and an area of over 700,000 m^2. The inhabited center was built almost entirely in the second half of the last century, behind the dune system, reducing it only partially within a strip of a few hundred meters where some buildings were built. The beach has a width of between 50 and 100 m and is advancing compared to 1954, with a maximum advancement of the order of 50 m.
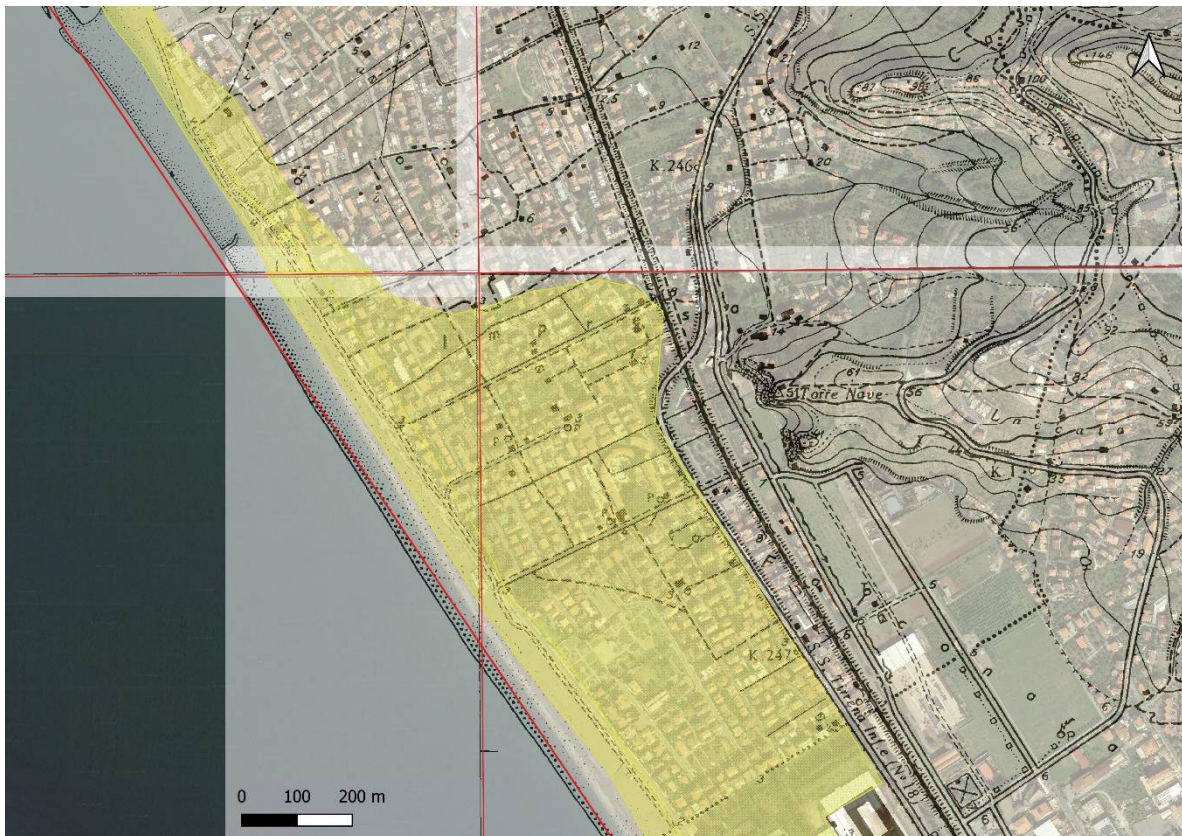

Figure 6. Guardia Piemontese: overlap between CASMEZ cartography and the most recent Google satellite image. Legend: red line = shoreline of 1954; yellow dotted area = dune systems of 1950s.

Finally, it is useful to consider the effects of climate change through an analysis of sea level rise. In Calabria, Barbaro et al. [41] analyzed this parameter based mainly on the study of Nerem et al. [86], which estimated that the average sea level has increased by 7 cm over the past 25 years, previously it was about 3 mm/year, and show that the growth rate is non-linear, but is accelerated by 0.084 mm/year. These results were obtained using data from 1993 to date, from various satellites, such as TOPEX/Poseidon, Jason-1, Jason-2, and Jason-3, and they are in accordance with the forecasts described in the fifth IPCC Report [87]. Therefore, the average value is expected to be about 10 cm, in the next 20 years, and about 80 cm in the next 100 years. Considering the beach slope values described above, in most of the examined localities this sea level rise would cause linear retreats of the shorelines of 15 m in the next 100 years. Therefore, this retreat would have a limited impact on Calabrian dune systems.

Figure 7. Villapiana: overlap between CASMEZ cartography and the most recent Google satellite image. Legend: red line = shoreline of 1954; yellow dotted area = dune systems of 1950s.

5. Conclusions

The aim of this paper was to evaluate the effects of anthropogenic pressures on the Calabrian dune systems, especially in terms of the triggering of coastal erosion processes. The analysis highlights a strong correlation between the destruction of dune systems by anthropogenic causes and the triggering of coastal erosion processes. This correlation is highlighted above all by the result that in all the municipalities where the dune systems are intact, compared to the 1950s, there are no shoreline retreats, while in all the municipalities where the dune systems have been totally destroyed by anthropogenic causes, compared to the 1950s, there are shoreline retreats.

The methodology proposed in this paper is easily applicable as it is based on open-source software, such as QGIS. Furthermore, it can be easily replicated, as it is based on freely accessible cartographic data, so it is sufficient to find similar data to carry out the same analysis in any other location.

Finally, this analysis is also of interest in the field of planning and management of coastal areas, to limit the anthropogenic impacts on coasts in the future, favoring the restoration of dune systems.

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