

Coastal morphological stability and Climate Change

Circeo scale, Italy





Analysis of Threats and Enabling Factors for Sustainable Tourism at Pilot Scale

Coastal morphological stability and Climate Change

Circeo scale, Italy



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OVERVIEW

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REVIEW

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Abstract

The Circeo National Park has been a MAB Reserve since 1977. In 2013, its territory expanded to reach the current boundaries, which include the municipalities of Sabaudia and San Felice Circeo and a large part of Latina and Terracina.

The MAB Circeo Reserve hosts one of the few dune systems on the Pontine coastline that are still quite intact. Yet, they are affected by significant impacts, both the anthropogenic and the climate change effects.

Indeed, the medium and long-term increase of erosion risks associated with marine flooding because of climate change (such as sea level rise, extreme and increasingly frequent storm events) represent a serious threat to the coastal system. In fact, the greatest impact on tourism caused by coastal erosion is a reduction in the bathing establishments reception capacity due to the beach setback. Generally, this phenomenon may lead in the long term to a reduction in the receptive capacity of the entire coastal system and its related activities, essentially characterized by seaside and purely seasonal tourism.

On the other hand, the anthropic impact from tourism pressure appears to affect particularly the dune-beach system state (e.g., walkways caused by the passage of bathers, uncontrolled access to the beach and mechanized cleaning of the beaches).

It is therefore essential to identify strategies capable of balancing the dune functionality as well as the beach-dune system appropriate use. Indeed, the conservation and protection of biodiversity are considered fundamental principles of maritime and coastal economy.

In this perspective, the Park and the involved Municipalities have been developing different mitigation and adaptation approaches (policies, programs, projects...) to reduce the impacts of climate change on the MAB Circeo area and to balance tourism and environmental protection

I. Climate change and morphological stability

I.1. Geomorphological features and evolution trends

The Circeo National Park has been a MAB Reserve since 1977. In 2013, its territory expanded to reach the current boundaries, which include the municipalities of Sabaudia and San Felice Circeo, part of those of Latina and Terracina.

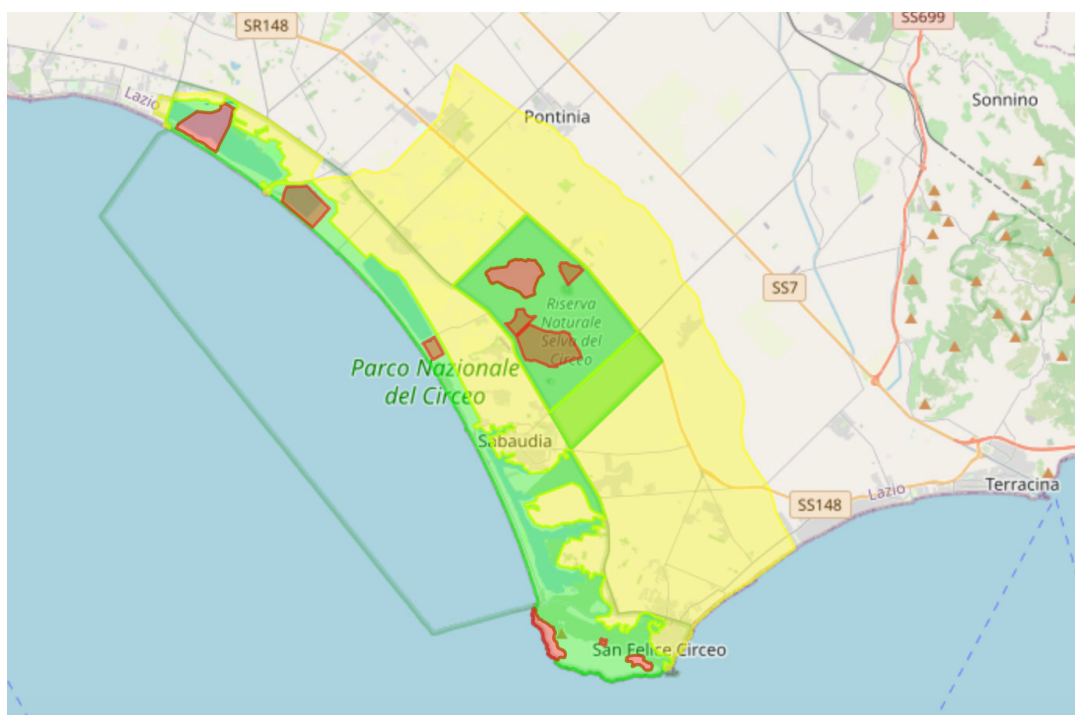


Figure 1. Boundaries of the MAB Reserve

The Circeo National Park was established in 1934 to protect not only a single species, but rather a rich mosaic of environments. Its establishment, occurred during the radical reclamation of the entire Pontine area, avoided the total deforestation of the ancient 'Selva di Terracina'. Hence, saving Sabaudia Lake, the coastal dune and the Circeo Promontory.

In 1975, the expansion decree incorporated in the park, the coastal lakes of Fogliano, Monaci and Caprolace, which together form one of the most important coastal wetlands in Italy. Since 1979, the Park has also included the wonderful and unspoiled Zannone Island.

The Circeo National Park is a territory of a diverse variety of environments, and each of them covers a specific function. The promontory is home to various birds of prey, while the dunes, which run along the entire coastline, protect the hinterland so that thousands of migratory birds can find refuge in the wetlands and the forest can be proliferated, and sheltered from the salty winds.

The Pontine Plain coastal environment, as it is currently observed, is the result of intense geological and geomorphological transformations that have occurred over time throughout central Italy. In particular, the typical shapes of the Lazio coast are closely linked to the action of the sea and therefore to wave motion, currents, and tides.



Figure 2. Pontine plain. Photo by Carlo Perotto

Wave motion is the most important parameter because waves are the main source of energy that shapes and modifies the coastline. Where the coast is formed by inconsistent rocks, the erosive effect of the sea is greater, generating low and sandy coasts. Whereas, in more rigid substrate (either calcareous or tuffaceous) emerges, the coastline is jagged, high above sea level and with immediately deep bottoms. The sea, therefore, can be considered as a very selective erosive agent and the result often depends on the physical-mechanical characteristics of the soils with which it interacts.

Therefore, different forms deriving from wave motion can be observed. In fact, waves can determine the caves formations, natural arches and erosion banks or cliffs (such as those observed in the islands of Ponza and Ventotene or in some sections of the southern coast of Lazio), as well as erosion platforms (for example along large stretches of the northern coast of Lazio).

From Torre Astura to the Circeo Promontory the coast is low, made of fine sands and incorporates a series of coastal lagoons separated from the Tyrrhenian Sea only by a continuous, but not very high, dune system. This consists of red and yellow sands of alluvial marine and wind origin, with high permeability and able to provide a certain water contribution to the lake basins behind.



Figure 3. Dune and back-dune lakes. Photo by Carlo Perotto

The Circeo Promontory is mostly made up of calcareous lithologies. This determines the overhanging morphological formation characterized by cliffs and caves, inside which interesting shapes and evident holes made by the lithodomes can be observed. Hence, testifying the sea level variations.

From the Circeo Promontory to Terracina, the morphology of the coast turns low and sandy again, with a regular profile only interrupted by the slight prominence of the delta systems of the Sisto and Portatore Rivers.

Table 1. Geomorphological profile of the coast (Guidelines for the preparation of the Plan of Ports and Coasts of the Lazio Region)

Municipality	Geomorphological profile
Latina	The coastline of the Municipality of Latina has a total length of approximately 13,231 km. The entire municipal coastal area is of a low and sandy type. It includes the mouths of the Astura River, the Acque Alte Canal and the Rio Martino Canal.
Sabaudia	The Municipality of Sabaudia coastline is totally sandy. It extends on 18,604 km, from the navigable mouth of the Rio Martino Canal (border with the Municipality of Latina) to the mouth of the Torre Paola canal (border with the Municipality of San Felice Circeo). The entire municipal coastline is included in the Circeo National Park.
San Felice Circeo	the Municipality of San Felice Circeo coastline borders with the Municipality of Sabaudia to the north and with the Municipality of Terracina to the south, and it lies on 16,353 km long. The coast is of a rocky type near the promontory, in the stretch that goes from Torre Paola to the marina at Torre Fico, and sandy from the marina to the border with Terracina.
Terracina	The Municipality of Terracina coastline, which borders with the Municipality of San Felice Circeo to the north and with the Municipality of Fondi to the south, extends on 14,134 km. The entire coast is sandy, except for the Port and for the stretch of coast in Torre Gregoriana. It includes the mouth of the Portatore River, the entrance to Porto Badino and the mouth of the navigation channel.



Figure 4. The rocky coastline of the Circeo Promontory. Photo by Carlo Perotto

Therefore, in morphological terms, the area is characterized by a ‘straight coastline’, interrupted by a ‘cliff coastline’ near the Circeo Promontory.

Table 2. Coastal morphotypes (Preparation of a preliminary environmental study related to coastal protection interventions in protected areas, for the reconstruction and protection of the coastline between Capo Portiere and Torre Paola in the Province of Latina)

Coast stretch	Morphotype description
FROM: Foce Verde TO: Circeo Promontory	Straight coastline
FROM: Circeo Promontory TO: Terracina	The land-sea contact occurs on a wide and straight sandy beach. The submarine profile has a very low slope with the presence of bars. The back beach features dune fields, coastal ponds, and possibly coastal lakes. The input from the mainland comes from low-gradient watercourses. There are mouths not projecting into the sea, possibly with pebbly wings.
Circeo Promontory	Cliff coastline
	Overhanging subaerial profile that extends into the submarine part. The land-sea contact is represented by sub-vertical walls or narrow beaches, commonly in gravel. Solid contributions come from high-gradient watercourses and from accumulations deriving from landslides and collapse of sides.

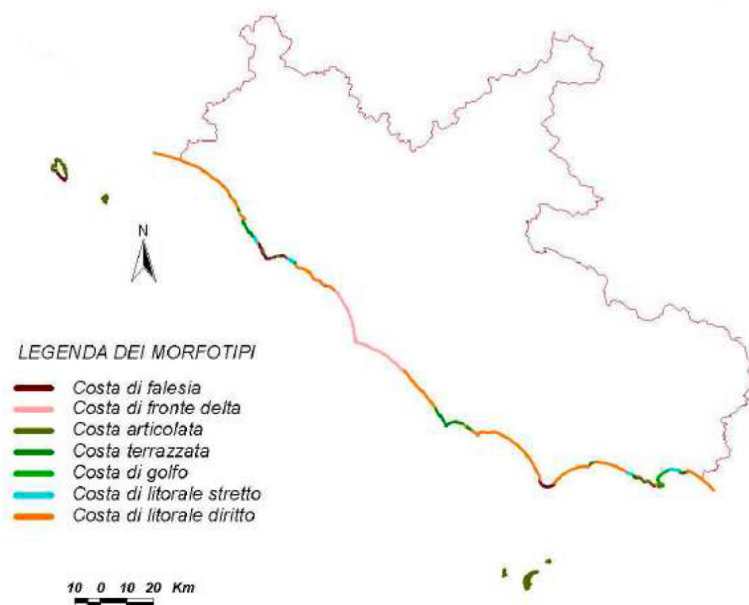


Figure 5. Classification of coastal morphotypes in Lazio (Source: Preparation of a preliminary environmental study relating to coastal protection interventions in protected areas, for the reconstruction and protection of the coastline between Capo Portiere and Torre Paola in the Province of Latina)

I.2. Natural ecosystems

Ecosystems

From Torre Astura to the Circeo Promontory the sandy coast is characterized by a highly developed dune system that once extended without interruptions. This system is made up of highly permeable sea sands and wind alluvial origin that are to provide a certain water contribution to the lake basins behind. Their origin seems to be linked to the formation of a sandy bar as a result of the sea level rise in the Versilian age, which increased over time due to the action of the wind. In the stretch of coastline between Capo Portiere and Torre Paola, the coastal dunes extend in parallel to the coastline for about 25 km, covering just over 80% of the physiographic unit. Both the altitude and the width of these dunes increase from north to south, reaching the maximum elevation and width (respectively 28 m above sea level and 250 m) near Torre Paola. Immediately behind the promontory of Monte Circeo, due to the different exposure to the prevailing winds and to the protective effect of the promontory itself, the width and elevation of the coastal dunes decrease again, reaching about 230 m in width and 24 m in height. In the 1930s, the dune system dynamics was blocked by the construction of the coastal road, built in correspondence with its longitudinal axis. This, in addition to the prevention of the dune's free morphological evolution (*i.e.*, the free advancement and retreat which would allow to limit the damage caused by the erosive action of storm surges), it has

also increased erosion due to runoff phenomena and contributed to making the entire coastal area more accessible in the summer season. From a vegetational point of view, the dunes are for the most part consolidated by specialized coastal vegetation and typical of the Mediterranean environment. Considering the different exposure to winds and solar radiation, it is possible to distinguish two different areas: the side facing the coastal lakes and the side facing the sea. The first area is characterized by more favorable climatic conditions, there is a dense, structured, and luxuriant shrub and arboreal vegetation. The situation on the opposite side is different: exposure to more constraining climatic conditions (high degree of aridity and salinity due to exposure to aerosol from the sea) allows for the development of mainly bushy xerophytic and halophytic vegetation. This can stabilize the aeolian sands through specialized root systems, thus triggering positive feedback mechanisms between the biological and sedimentological components and providing the system with both dynamic stability and resilience.

More specifically, starting from the coastline and proceeding towards the foothills, four environmental typologies can be identified in the Pontine Plain:

- Coastal and dune system.
- System of coastal lagoons and associated wetlands.
- River system and minor artificial waterways.
- Agricultural system and urban fabric.

Coastal and dune system

The coastal environment consists of crucial ecological habitat, that requires it to be safeguarded and protected, especially against the anthropogenic pressures resulting from uncontrolled tourism. The Pontine coast, which extends from the Astura River to Capo Portiere over about 13 km, is divided into two areas, with different landscape characteristics. The coastline is mainly sandy, and once it was characterized for its entire extension by thick dune strips that delimited the coastal lakes. Today, this coast stretch is covered by a dense urban fabric, generated by the construction boom of the 1960s and 1970s. The coastal dunes conservation and protection are essential since they stand as a barrier that protects the beach from erosion. Hence, controlling the retreat of the coastline. Nevertheless, uncontrolled tourism and residential areas along the coast, along with the coastal road built on the dune belt in the 1930s prevent the dynamic evolution and the self-protection mechanism of the dunes. Hence, the coastal dune can currently be considered as a threatened habitat for which adequate planning and management activities are lacking. The coastal dune stems ecological importance comes from the plant community's uniqueness that allow for its consolidation and growth. Furthermore, the coastal dune is a unique habitat also from the faunal point of view, being an important ecological corridor of the coastal environment. Typical species include the wild rabbit, the Kentish plover, the little ringed plover, the oystercatchers, the European roller, the European bee-eater and the tortoise.



Figure 6. The littoral in front of the coastal lakes is rimmed by a dunal strip along which runs the coastal road

System of coastal lagoons and associated wetlands

It consists of a series of four ‘coastal lakes’ (Paola or Sabaudia Lake, Caprolace Lake, Monaci Lake and Fogliano Lake) and by ‘wetlands’ peripheral to the lakes seasonally flooded. They form together with the meadows-pastures placed in between, a complex naturalistic and environmental system declared a ‘Wetland of International Interest’ pursuant to the Ramsar Convention (Iran 1971). Most of the 202 bird species in the Park have been observed in this environment, which is particularly suitable for stopping, wintering and nesting. Except for Sabaudia Lake, the deepest (about 11 m) and largest, the banks of the Pontine lakes are characterized by artificial embankments that largely derive from the integral reclamation of the 1930s. The coastal lakes’ physical and biological characteristics are typical of transitional environments between the emerging lands and the sea, in which sometimes continental, sometimes marine elements prevail.

River system and minor artificial waterways

As to the landscape, all surface waterways (rivers, canals, or ditches) represent an added value not only in rural systems, where they are the lifeblood of agriculture and animal husbandry, but also in urban centers, where they contribute to the conservation of animal and vegetable biocoenoses. Especially within urban environments, waterways suffer strong anthropogenic impacts that deeply affect all the components of the related biocoenoses. Effectively intervening on these threats is the way to regenerate inhabited centres and agricultural areas, restoring the important role of these humid environments in biodiversity protection. Recently, attention has grown significantly towards these important ecological corridors. In some areas, concrete actions for environmental

restoration have been planned, aimed at protecting biocoenoses, especially plant and animal species of conservation interest. It should be noted that, unfortunately, anthropic interventions of a strong impact are frequent, for example the riparian and aquatic vegetation removal, which eliminates the biodiversity of these ecosystems. From the vegetational point of view, the water bodies are characterized by species that are rather demanding in terms of hydraulic, ecological, and geomorphological characteristics of the watercourse. Where the current becomes moderate or particularly slow and the depth is shallower, the vegetation can reach the free water surface and form a cover that is sometimes considerable. The more structured and complex riparian vegetation is made up of woody species as well, with associations that settle on banks, river terraces and evolved alluvial soils, with various tree and shrub species. Despite widespread pollution, low or very bad water quality, and other impacts of anthropogenic origin, waterways are still able to host biocenoses of conservation interest, consisting of numerous species of invertebrates and vertebrates.

Agricultural system and urban fabric

Between the coastline and the foothills, the Pontine landscape is characterized nowadays by a heavily anthropized environmental matrix, consisting of a mosaic of agroecosystems and urban environments that blend into each other. The urban environment includes the Provincial capital and its hamlets, minor towns (such as Sabaudia), villages and industrial areas, and is strongly interpenetrated with the agricultural landscape. Agriculture, often intensive, is one of the main economic activities of the area. Urbanization, which began in the reclamation period and intensified during the 1960s-1970s, has led to a significant territory structural transformation. It has significantly reduced the naturalness degree and it has contributed to the gradual disappearance of the vegetation associations typical of the plains, such as the Mediterranean scrub, the Turkey oak woods, the mixed oak woods, and the meso-hygrophilous woods. This phenomenon has been recurring mainly after the disappearance or strong rarefaction of numerous animal species. The agricultural environment is also characterized by the presence of non-native plant species, introduced with the reclamation, which have shown excellent acclimatization abilities, becoming typical elements of the landscape. This is the case with the various species of Eucalyptus, planted as windbreaks, which have now acquired a historical-environmental value. The windbreak strips characterize various waterways, numerous roads, and irrigation canals and/or water outflows and fields boundaries. These strips play, like watercourses, an irreplaceable role in agricultural ecosystems, by increasing the biodiversity level and by forming effective ecological corridors, especially when they are structurally complex (because they consist of tree, shrub, and herbaceous layers).

Vegetational and Floristic Aspects

The area under study includes urban settlements, large agricultural and industrial areas, and coastal zones. Here, the environmental component is obvious: it is no coincidence that most of the territory falls within the boundaries of the Circeo National Park, identified precisely because of the area naturalistic features, incorporating the major areas of conservation interest.

The following analysis is based on the contents of the Management Plans of the SPA 'Circeo National Park' and included SCIs and aims to describe the area fauna and flora.

Dune

The state of the dune vegetation conservation is, on the whole, very critical along the entire coastline of the park. In fact, all the annual and perennial herbaceous communities are very disturbed and almost never show the typical beach vegetation zoning.

Table 3. Perennial and annual herbaceous communities within the dune (Source: Management Plans of the SPA 'Circeo National Park' and included SCIs)

Community	Habitat	Prevalent species	Distribution and considerations
Cakileto	1210	- <i>Cakile maritima</i>	Almost absent and rarely inserted within the plant communities of the consolidated dune.
<i>Elymus farcuts</i>	2110	- <i>Cutandia maritima</i> - <i>Cyperus capitatus</i>	Very fragmented distribution. The presence of <i>C. Capitatus</i> testifies the strong disturbance.
Ammofileto	2120		They are perennial communities of value, but almost absent, identified in a few strips only and very disturbed.
Crucianelleto	2210		
		- <i>Anthemis maritima</i> - <i>Cutandia maritima</i> - <i>Lotus cytisoides</i> - <i>Ononis variegata</i>	Present with high coverage rates in all vegetation strips.
		- <i>Malcolmia littorea</i>	Consistent and fertile population on the dune near Sabaudia, the species is included in the National Red Lists and the coast between Circeo and Terracina is the only Italian locality where it is present. This species is, to date, under rarefaction and prone to great risk (urbanization and tourism).
Annual Poacea: - <i>Brachipodiet</i> - <i>Malcolmietalia</i>	2240 2230	- <i>Bromus rigidus</i> - <i>Cutandia maritima</i> - <i>Phleum arenarium</i> - <i>Vulpia fasciculata</i> - <i>Silene Canescens</i>	They are distributed on the high dune, in the depressions protected from the wind. These communities are very disturbed, often due to the entry of species of the moving dunes (<i>Medicago littoralis</i> , <i>Lotus cytisoides</i> and <i>Plantago coronopus</i>) or to the contact with the perennial meadows dominated by <i>Dasypyrum villosum</i> .
<i>Juniper maquis</i>	2250		Very disturbed and compressed towards the dune top, where the road interrupts its ecological continuity. Furthermore, due to the erosion of the side facing the sea, the specimens suffer from uncovered roots.
- Pinewoods - Ash woods - Alder woods	2270 91B0		They are distributed in the back-dune, but in an extremely fragmented way and with poor and ruderal undergrowth (<i>Rubus</i> , <i>Pteridium</i> and <i>Smilax</i>).

There is a significant presence of alien species, which threaten autochthonous communities:

Table 4. Alien species in the dune environment (Source: Management Plans of the SPA ‘Circeo National Park’ and included SCIs)

Alien species	Distribution and considerations
Carpobrotus acinaciformi	It has certainly become invasive, penetrating all beach communities, with maximum invasiveness in the northern sector of the coast.
Acacia saligna	It is present with some naturalized individuals within the Juniper scrub, in the northern sector. This species, being very aggressive, needs immediate intervention.
Yucca gloriosa	It is present in the dune sector of the “Strada della Lavorazione” and has been recently spreading within the Juniper scrub.

Back-dune and lakes

Overall, the back dune depression of the Circeo National Park presents a good vegetational condition. The submerged vegetation of the Circeo lakes (Habitat 1,150) is dominated by marine phanerogams (except for Paola Lake, which is almost completely devoid of them). The presence of *Cymodocea nodosa* and *Ruppia cirrhosa* both in Caprolace and Fogliano is particularly important; Caprolace also hosts the rare *Zostera noltii*. It must be emphasized that the presence of *C. nodosa* is an indication of the good quality of superficial sediments and, therefore, of good ecological quality. This quality is, among other things, testified by the high specific diversity of algal species.

On the other hand, it is necessary to point out the presence of *Ulva* and *Chaetomorpha*, constituting a negative signal to consider, and for which it is imperative to identify causes and measures of elimination.

The Circeo back-dunal meadows-pastures (Habitat 6,420) preserve a rich and diversified flora, dominated by various species of perennial *Poaceae* and *Fabaceae* much appreciated by bred herbivores. These communities live around the lakes, on humid sandy-clayey soils, often flooded and with zero or very low salinity; near the back-dune, they are in contact with the halophilous communities.

The communities of halophilic vegetation, both annual (Habitat 1,310) and perennial (Habitats 1,410 and 1,420), are certainly the most interesting ones in the perilacustri depressions. In fact, there are several rare species, very rare or included in the National Red Lists (*Salicornia emerici*, *S. dolichostachya*, *Spergularia salina*, *Juncus subulatus* and *Puccinellia festucaeformis*), generally well preserved and expanding. The area near the ‘Strada della Lavorazione’ (a place of interaction between the salt and fresh aquifer) and the south-west shore of Fogliano Lake (a recently formed brackish area due to the breakage of an artificial lake bank) are excellent examples of environmental restoration.

Even an area in the process of becoming swampy at the Lago dei Monaci hosts halophilous vegetation in the process of recovering, as well as those around Caprolace Lake, which hosts very extensive halophilous communities, both annual and perennial (*Atriplex portulacoides*, *Limonium narbonense*). These prepare the territory for the *Salicornie*, currently absent in the Park (finding of *Puccinellia festucaeformis*).

Reed beds (Habitat 1,410) are also well developed in the Circeo back-dune. Their communities, dominated by *J. gerardi*, *J. subulatus* and *J. maritimus*, are well preserved and, in some areas, expanding.

The Pantani dell'Inferno deserves a separate mention. It is a depressed area to the east of Caprolace Lake that is hardly affected by the saltwater wedge of the aquifer, resulting in a predominance of freshwater communities. Alongside the humid meadows (Habitat 6,420), there are *Scirpus maritimus* reed beds and *Carex fens*; these communities have now become very rare due to the rarefaction of humid environments and thus deserve careful conservation, also for the fauna they host.

1.3. Impacts of climate change and anthropogenic activities on the morphological stability of the coastal area

The MAB Circeo Reserve hosts one of the fewest dune systems in the Pontine coastline that are still quite intact, but at the same time are affected by significant anthropogenic and climate change impacts.

In fact, the increase in erosion and the medium and long-term risks associated with marine flooding because of climate change (such as sea level rise, extreme and increasingly frequent storm events) have a great impact on the coastal system.

The deficit of solid transport (due to hydraulic works on river channels, dams, *etc.*), the presence of rigid coastal protection structures (which intercept the natural distribution of sediments along the coast) and the effects of climate change increase the vulnerability of the coastal strip, which is now affected by widespread erosive processes and risks of marine flooding.

It should also be noted that the degree of the coast urbanization and anthropization is a factor of preponderant importance in determining the state of erosion and degradation. For example, some critical issues are the rainwater runoff caused by the coastal road that runs across the entire length of the dune. The presence of erosion grooves deepened by the erosive wind action as well as the walkways caused by the passage of bathers and the uncontrolled access to the beach and the mechanized beaches cleaning.

The study relating to the 'Guidelines for the drafting of Ports and Coasts of the Lazio Region' plan shows that about 26 km of coastline in the Province of Latina are prone to erosion and that the most affected municipalities are Latina, Sabaudia, Fondi and Sperlonga.

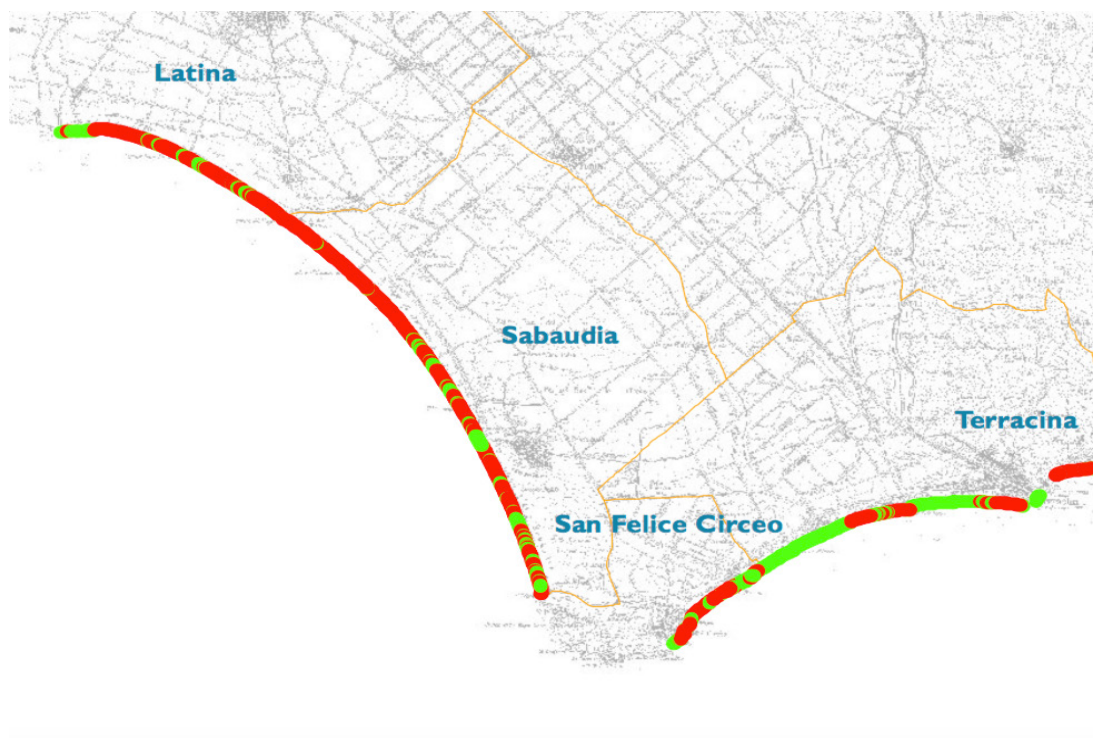


Figure 7. Comparison between the coastlines in 1943-44 and in 2010 (progress in green and retreat in red) (Guidelines for the drafting of the Plan of Ports and Coasts of the Lazio Region)

The eroding stretch starts from Torre Astura (Nettuno) and heavily involves the stretch of coast of Foce Verde to continue towards the coast of Sabaudia. The coastline between Foce Verde and Torre Paola (falling within the municipalities of Latina and Sabaudia) has been affected by significant coastal erosion for years.

More specifically, the study carried out by ISPRA indicates that overall, the balance for the coastline between Capo Portiere and Torre Paola is negative, with a sediment loss of approximately 42,000 m³/year. The most critical stretch is the one between the new mouth of Fogliano and Rio Martino, characterized by an average shoreline retreat of approximately 1 m/year.

The retreats and losses, although limited given the sizeable length of the coastline considered, are an indication of the coast's substantial stability.



Figure 8. Dune erosion

The variations observed are partly caused by the erosion affecting the rear dune belt, partly by a loss of sediments due to transverse transport, but also by the reduction of the contributions from the overflow beaches (to the north). These contributions will probably fall soon, both for these beaches' extension reductions and for the new and more efficient defense activities between Foce Verde and Capo Portiere. They limit the beach erosion and intercept solid transport from the North. A further detrimental factor could be the fluvial solid transport reduction, even if it seems unlikely that the Astura River could bring a significant contribution in terms of sediments. Another potential factor whose level of scientific investigation and analysis is still very low, is the variation of the local wave motion linked to the reduction of Posidonia meadows.

As to the stretch of coast between San Felice Circeo and Terracina, since 1970 there has been a reversal of the trend, with a significant retreat of the beach. This phenomenon has been linked to both the intense urban development of the past years and the implementation of various works into the sea, such as the Port of Circeo construction and the right-hand groin of the Badino Port extension. These artifacts have prevented the natural displacement of the sediments towards the east, creating strong erosive phenomena in the underwater areas. In the stretch between San Felice Circeo and Terracina, except for some sections, the situation is quite stable.

I.4. Impacts of climate change on tourism

The greatest impact on tourism caused by coastal erosion is a reduction in the reception capacity of the bathing establishments due to the setback of the beach (Figure 8). Generally, this phenomenon may lead in the long term to a reduction in the receptive capacity of the entire coastal system and its related activities, currently essentially characterized by seaside and purely seasonal tourism.

On the other hand, the anthropic impact from tourism pressure appears to be, as highlighted by the ISPRA study (“Anthropic impact from tourist pressure in protected areas: interference on the territory and biodiversity”), particularly affecting the state of the dune beach system in terms of biodiversity and anti-erosion capabilities.

It is therefore essential to identify strategies capable of balancing the functionality of the dune and the use of the beach-dune system.



Figure 9. The coastline between Foce canale Caterattino and Torre Paola

I.5. Mitigation and Adaptation Approaches to Address Climate Change Impacts

The climate change impact on the coastal area of the Circeo MAB Reserve is mainly related, as highlighted in the previous chapters, to coastal erosion.

In this context, the Circeo National Park hosts one of the fewest dune systems that are still quite intact but at the same time prone to significant anthropic impacts and other types of criticalities (*e.g.*, runoff of rainwater caused by the coastal road that runs along the entire length of the dune, presence of erosion grooves deepened by the erosive action of the wind, walkways caused by the passage of bathers, uncontrolled access to the beach and mechanized cleaning of the beaches).

1.5.1. Life Nature projects on coastal erosion in the Circeo National Park

Two projects have been funded through the LIFE Nature program in the area. The following table provides specifications on them.

Table 5. Information relating to LIFE Nature projects funded with the aim of safeguarding the environment of the coastal dunes of the Circeo National Park

Title	Country Region	Beneficiary	Total budget	LIFE contribution	Duration	ID code
Restoration and conservation of the habitat of the Circeo National Park	Italy, Lazio	Municipality of Sabaudia (LT)	533,333 €	400,000 €	01/10/1994-30/04/1995	LIFE94 NAT/IT/000602
Completion of the main programme for the reestablishment of the coastal dune in Parco Nazionale Circeo	Italy, Lazio	Municipality of Sabaudia (LT)	615,200 €	307,600 €	01/01/1996-31/03/1999	LIFE95 NAT/IT/000739

The first project, ‘Restoration and conservation of the habitat of the Circeo National Park’, aimed to restore and protect eight-kilometer stretch dunes from erosion by improving the infrastructures and by preserving the habitat along Municipality of Sabaudia coast. The second project, ‘Completion of the main program for the reestablishment of the coastal dune in Parco Nazionale Circeo’, aimed to complete the actions undertaken during the previous projects on two different dune sectors, through nature-based engineering works.

Thanks to these funds, over a period of about four and a half years (between 1994 and 1998) about 14 km of dunes have been involved in specific experimental interventions (both punctual and widespread) for the control of erosion and instability. During these projects:

- Structures were built to prevent the passage of bathers on the dunes, such as walkways for direct access to the beach, wooden dissuasive fences associated with windbreak screens and stakes for preventing car parking.
- Information huts were created to raise awareness on the correct use of the environment and on the origin and purpose of the restoration and protection action.
- Works were carried out for the regulation of runoff waters.
- Windbreak systems were created, of different shapes and sizes, made of different types of natural materials (cane mats, vertical fascines, porous wooden fences, checkerboard wicker barriers, *etc.*), to rebuild and protect embryonic deposits at the foot of the dune.

- Sands containment and consolidation works were carried out using wickerwork associated with coconut fiber bio-nets.
- Permeable wooden barriers were created to act as windbreaks and to attenuate wave motion.
- The asphalt layer was removed in a stretch of coastal road of about 3km, partially demolished by storm surges in the early 1980's and since then closed to traffic. This intervention allowed to restore the natural mobility of the dune, limits the runoff of rainwater and re-triggers colonization by the plant species typical of the habitat.
- Approximately 40,000 local shrub plants (*Juniperus oxycedrus* ssp., *Phyllirea latifolia*, *Rhamnus alaternus* and *Pistacia lentiscus*) coming from the forest nursery of the Circeo National Park in Sabaudia (LT) were planted on the top parts (dune crest) of the containment works. In 2006, as part of a Framework Agreement between the Lazio Region and the Circeo National Park (APQ7), the coastal dunes underwent further restoration works. Windbreak structures and a series of protected walkways were created, made of wood and coconut fiber bio-mesh. Finally, a project that has been recently approved by the Municipality of Sabaudia includes maintenance works of the walkways along the coast within the municipal area. As well as the reconstruction of the road surface thanks to the use of draining asphalt and the implementation of some of the works for the restoration of the dunes (whose location is still to be defined) mentioned in the 'Manual of Nature-based Engineering' published by the Lazio Region.

The following section is going to describe the main ongoing strategies, programs and projects relating to the mitigation of coastal erosion on a regional and local scale.

1.5.2. Program for the protection and reconstruction of the coasts

The protection program (2019-2021) of the coasts is framed by the Lazio Region in the context of an integrated medium-long term action in which both the direct effects of coastal erosion and climate change (increase in the average sea level, extreme marine weather events, *etc.*) and the indirect ones that generally reduce the resilience of beaches must be considered.

The goal is to integrate protection interventions into a logical planning that must embed sustainable development and environmental protection criteria. The plan must be based on negotiation with the interested parties, and with the administrations of coastal municipalities. They should agree on a 'planned coastline' that must be restored, where necessary, and subsequently maintained according to economic criteria as well as to efficiency, and to tourist development balancing expectations and to environmental protection. The coast erosion entails the beach large portion loss. Besides, being a real capital for seaside tourist resorts, the most effective coastal protection method should be effectively implemented to preserve and protect the area. Fortunately, generally the area's profile naturally adapts to the conditions of wave motion assuming the most

suitable layout for the dissipation of wave energy. Most of the beaches in Lazio are currently under erosion. The conservation of well-developed sandy coastlines versus the beach's erosion in general, represents a successful strategy to reduce the sea flooding risk in coastal areas. A significant part of coastal erosion can be compensated, if the conditions exist, by means of the longitudinal movement of sediments from the places of accumulation to those under erosion. The management of coastal sediments is a useful practice both to balance losses, in the case of general imbalances, and to prevent possible erosion processes, in the case of precarious balance conditions.

In this sense, it was necessary to start an organic management plan implementation at the regional level (Coastal Plan). In fact, the Regional Administration tends to equip itself with a tool for the coastal territory governance, to preserve areas with a high tourist and environmental value. This is especially important considering shared EU orientations placing specific expectations on blue growth, with reference to the Euro-Mediterranean area. The Plan will address the issues relating to the continuous and constant interaction between the coastal territory and the sea action. It will define the interventions needed for the tourist activities relaunch, the infrastructure preservation as well as for the environmental heritage. In addition, intervention should be fulfilled through compromised balances recovery and the natural processes continuity. The Plan will identify the intervention strategies, within the participatory planning broader concept, in collaboration with Administrations and stakeholders, also providing for the protection works management already implemented, according to the sustainability principles and integrated coastal zone management. The main objectives to be pursued must focus on the identification of the areas at risk of erosion, flooding, and landslides along the entire coastline, defining methodological guidelines for the correct conduction of the works.

While waiting for the organic management plan definition at the regional level, a survey of the interventions already planned and entirely financed with the regional budget was carried out. Emergency interventions and seasonal beach nourishments were also planned for the most affected areas by adverse weather. Further interventions, in addition to those that will be identified by the Coastal Plan, may be evaluated during the next budget planning.



Figure 10. Coast protection and beach nourishment in Lazio region (https://lazioeuropa.it/45_progetti_per_il_lazio-3/progetti_per_il_ripascimento_delle_spiagge_e_la_tutela_della_costa-42/)

More specifically, the following table shows the interventions regarding the area of the MAB Circeo for the period 2019-2021.

Table 6. Interventions for the period 2019-2021

Area	Budget	Municipality
Coastal protection works along the littoral from Latina to Sabaudia	€1 100 000.00	Sabaudia and Latina
Emergency interventions and beach nourishments along the entire coast	€6 000 000.00	All coastal municipalities of Lazio region

Furthermore, on 28 February 2018 the CIPE (the Italian Inter-ministerial Committee for Economic Programming) approved, with resolution no. 11, the second Addendum to the Environment Operational Plan, in charge of the Ministry for the Environment and Land and Sea Protection. The Plan is funded by the 2014-2020 Italian Development and Cohesion Fund for a total value of 782 million euro, of which 226.97 million euro allocated to the mitigation of hydrogeological risk and coastal erosion. For the Lazio Region, interventions for a total of 15,850,000.00 are planned for beach nourishment and for the reconstruction of pre-existing dunes. They are complemented by any works to fight erosion and organically rearrange the seafront, reinforced river mouths and port infrastructure where interfering, as well as to exploit marine quarries for sand extraction. The following table identifies the interventions falling within the MAB Circeo area:

Table 7. CIPE Interventions

Area	Budget	Municipality
Completion of protection works in Latina, from Foce Verde to Capo Portiere	€5 500,000.00	Latina

1.5.3. Management Plan of the Circeo National Park

One of the plan's objectives is to maintain the dune system from a geomorphological point of view, collaborating with all the competent bodies to avoid coastal erosion. It is particularly relevant in the park territory, and also in the planning of large coastal infrastructure, even if outside the park.

Guidelines and actions: as regard to coastal erosion, the Plan tackles the structural river solid transport deficit by indicating systematic soft beach nourishment interventions as the most appropriate strategy. Yet, the strategy should not stiffen the shoreline by means of rigid protection systems such as groins, breakwaters, or submerged dams. In this context, the construction of new port infrastructure must be carefully considered and supported by further the coastal dynamics investigations and of the most suitable port types. In fact, the Plan hinges on the following guidelines for sustainable seaside management relating to coastal erosion:

- Preparing an intervention proposal for those stretches of beach where coastal erosion puts consolidated activities, or the seafront road currently used at risk.
- Preparing a proposal for the environmental dune stretches recovery characterized by degradation and/or erosion, also identifying areas for which it may be appropriate to ensure more accentuated protection means. For example, through the boundary multifunctional delimitation, 'islands of naturalness' useful for the conservation of endangered species, but also of portions of dune habitat classified as 'priority habitat' by the Habitat Directive.

In addition, the Park Authority has launched a knowledge update on the state of the dune system, to define, together with the stakeholders, the appropriate utilization and management strategies within the scope of the Conservation Objectives proposed in the Plan. The scientific collaboration between ISPRA and the Circeo National Park Authority is part of the systemic action 'Anthropic impact from tourist pressure in protected areas: interferences on the territory and on biodiversity' promoted by the MATTM, to which the Circeo National Park has adhered by identifying the coastal and dune area as a target area.

The collaboration between the Circeo National Park and ISPRA aimed at characterizing the beach-dune system morphological state to support the measures to mitigate the impacts generated by the tourist use of the system. Fourteen surveys were carried out during a three years' period (2014-2017), to analyze the morphological dynamics of the 'dune-beach' transition strip along portions of the coast with different morphological structure and anthropogenic pressure. During the collaboration with the Circeo National

Park, and based on previous studies, the actions with the greatest impact on the dune's ecological functionality were identified and the related management measures were proposed, which must necessarily be undertaken in order not to further compromise its state. Within this collaboration, the stakeholder's awareness raising of the relationship between the functionality and the dune system use was also addressed, through operational meetings between the Managing Authority, Municipalities, and stakeholders. They identified the need to establish a technical working group for dune sustainable management. Nonetheless, the commitments made between the concerned parties have not been ratified yet and consequently have not reached an operational stage.

During the activities carried out, and especially during the meetings with the Municipal Administrations and with the stakeholders, the community sensitivity to the coastal erosion issue was revealed with its importance. For this reason, and on all occasions of discussion/dialogue with stakeholders, the beach-dune management system has been adequately contextualized, both within the territorial area and within the whole physical dune-beach-seabed system. Moreover, it was considered necessary (and compliant with the indications provided by the National Board on Coastal Erosion) to address the coastal erosion management in a programmatic and non-emergency context, underlining the importance of the spatial and temporal scale of the problem. The Circeo National Park erosive dynamics is therefore framed within the physiographic unit to which it belongs, that is the portion of the coast between Capo d'Anzio and Capo Circeo.

Summary of recommendations

The criticalities observed and related to the anthropic impact on the dune were analyzed through topographic measurements that are frequently repeated, and they have highlighted a strong dune foot dynamics impairment.

The dune front constructive capacity was observed exclusively in the areas characterized by lower dune system use pressure and, above all, of the dune front.

The portions of the beach commonly subjected to mechanized cleaning show the volumetric variability variation percentage of the entire beach-dune system ranging from 61% to 83%. In particular, the maximum volumetric variability values (negative) are in the area suffering from the highest tourist load.

The front dune dynamics in the 'privately used' portions of the dune are strongly compromised by the stiffening induced by the properties' fences/confinements.

Following an eco-systemic approach, the protection and management of dune systems necessarily implies two fundamental actions:

- Removal or control of disturbance and degradation mechanisms.
- Adaptation to natural dynamics in the formation and stabilization processes of sandy deposits.

These actions can be implemented in different ways, depending on the morphological structure and therefore on the uses of the dune system.

Removal/control of the disturbances due to beach cleaning

Complete prohibition of mechanical cleaning within at least 7-9 meters from the dune foot, accompanied by appropriate training and information of the cleaning staff.

Prohibition of beach cleaning practices in integral reserves.

Methods of carrying out interventions on the beaches included in General oriented Reserves:

- Beach cleaning is allowed from May to October.
- Mechanized cleaning must be carried out with towed sifting machines to optimize sand/waste separation and allow control of the maximum sieving limit, set at 20 cm.
- Bi-weekly ordinary cleaning with mechanical means and sifters.
- Daily ordinary manual cleaning operations.
- Reuse of planted material beached as agreed with the Circeo National Park Authority.
- Extraordinary cleaning interventions, including the first cleaning of the season, must be reported to the Park Authority and to the command of the Forest Service.
- Cleaning of the dune limited to the areas surrounding the regular accesses (walkways) and carried out manually.

Fragmentation of the dune

The dune habitat fragmentation in the Circeo National Park is so extensive that it requires an action plan for its control. Especially in the northern part of the Park, the phenomenon is mostly generated by uncontrolled access to the beach. The opening of new passages and walkways compromises not only the vegetational state (impacted by uncontrolled trampling), but also the sedimentary stability of the entire beach-dune system through the progressive erosion of the paths/walkways caused by the increase in wind deflation. The management of this criticality necessarily requires an integrated approach that guarantees:

- Use of walkways for all regular access to the state property and efficiency of existing ones
- Geolocation of access to the state property for beaches uses.
- Closure of the existing openings with vegetation.
- Launch of mobility management to ensure control of the access points to the beach, thereby promoting the use of shuttle/bus systems.
- Testing of parking payment systems capable of reducing the 'car-parking meter-car-access to the beach' path and therefore inhibiting the tendency to cross the dune, for example using payment systems with smartphone applications, which can also provide information on the distance of the closest access points (geolocated).
- Positioning of pedestrian crossings exclusively in correspondence with regular walkways.

Adaptation to natural dynamics

The ecosystem services efficiency provided by dune habitats in terms of protection against erosion is significantly compromised by the building of infrastructure on the dunes and especially on their front side. Sedimentary mobility is therefore a necessary requirement to guarantee the health of dune systems.

The management of the sands that settle on the seafront road should be directed towards their reintroduction in the basal portions, without however compromising the pre-existing vegetation. This procedure could take on a progressively lower cost if appropriately supported by management practices limiting the fragmentation of the dune ('exit routes' of the sand from the system) and protecting the foot of the dune (*i.e.*, the strip where the sand should settle and stabilize with the vegetation).

Finally, the management of the beach-dune system should be framed within the sedimentary dynamics of the entire beach system, including the seabed as well. The submerged portion of the beach, representing the first barrier to wave energy, is also dominated by a strong sediment mobility, which in its turn influences, quickly, the variability of beach width. Within the Circeo National Park, the southern Caterattino channel shows more of this seabed-beach-dune interaction. For these reasons, the management of erosive phenomena along these types of beaches should aim not only at maintaining the natural dynamics but also at finding solutions to prevent compromise coastal flows at the scale of the physiographic unit.

1.5.4. Memorandum of Understanding between the Lazio Region and the Municipality of Latina

The Municipality of Sabaudia, the Circeo National Park Authority, the Agro Pontino Reclamation Consortium, ARPA Lazio for the sustainable management and enhancement of the coastline between the Municipality of Latina and the Municipality of Sabaudia subject to erosion. The protocol's primary objective is to commit the signatories to the planning, design, and execution of an action plan for the restoration and protection of the beaches included in the coastal stretch. It consists of a 'unitary site' falling within the Municipalities of Latina and Sabaudia. The implementation of the plan requires the active commitment of participating concessionaires and third parties, through the signing of agreements referring to the coastal areas of their respective competence.

The parties agree to design and implement the interventions mainly using sediments that periodically cover up the water bodies connecting the sea and the coastal lakes along the entire stretch belonging to the Circeo National Park. As well as using accumulated sediments in excess near the mouths of the Mascarello and Rio Martino canals and the rigid coastal protection works already built in Foce Verde.

To counteract the erosive action exerted by the coastal solid transport directed mainly to the south, the transfer of sand will preferably take place from the excavation point to the intervention area located into north.

Relations between the parties: The Municipalities of Latina and Sabaudia are committed to identify the sites where the sediments may possibly accumulate:

- The Municipality of Latina commits to allocate a stretch of free beach as a seasonal storage of dredged sediment.
- The Municipality of Sabaudia commits to carry out ancillary works functional to the appropriate coast management.
- The Circeo National Park Authority will contribute to the restoration and conservation of coastal habitats, and through compensation measures regarding the coastal dunes
- The Agro Pontino Reclamation Consortium will carry out excavation, handling and dumping of sediments
- The Carabinieri Biodiversity Department of Fogliano, in addition to ensuring the surveillance of the dredging and sand handling operations, will carry out ordinary and extraordinary maintenance on the structures and vegetation
- ARPA Lazio will perform the sediments characterization
- The Lazio Region will characterize, classify, and dredge the sediments that are removed from the seabed around the Port of Anzio in case they cause damage to port activities.

For the protocol purposes and management, a technical working group was set up, with a representative for each of the signatories.

1.5.5. Agro Pontino Coast Contract

The EU project COASTING (*Coastal Integrated Governance for sustainable tourism*) launched in March 2019 a shared path, coordinated by the Province of Latina, towards the signature of the Agro Pontino Coast Contract, involving local authorities and actors. In particular, the medium/long-term Strategic Guidance Document of the Coast Contract identifies the following measures relating to coastal erosion (strategic axis b.2: hydrogeological risk and coastal erosion).

Table 8. The specific objective and measure of coastal erosion

Specific objective	Measure
Monitoring and mitigation of coastal erosion	conducting studies to assess the climate change impact on coastal erosion and to identify possible sustainable scenarios, both from an environmental and economic point of view, regarding the anthropic activities to be maintained or developed.
	Promoting a coordinated and sustainable management of the beaches, regarding both the bathing facilities and the cleaning and maintenance activities, as well as through the common guidelines' definition.
	Promoting the sustainable strategy definition for beach nourishment.

I.6. Blue Economy and climate change in the context of sustainable coastal tourism development

Communication COM (2021)240: Communication between the Commission, the European Parliament, the Council, the European Economic and Social Committee and the Region Committee concerning a new sustainable blue economy approach in the EU ‘Transforming the blue economy of EU for a sustainable future’. In fact, it promotes a new approach, which can better integrate the sea policy with the new European economic policy, recognizing that healthy seas are vital in achieving the transformation envisaged by the European Green Deal. The idea that environmental protection conflicts with the economy gives way to the awareness of the intrinsic links between the environment and the economy, especially in the maritime sector: the focus shifts from ‘blue growth’ to ‘sustainable blue economy’.

This paradigm shift is expressed in the EU Agenda for a sustainable blue economy, which covers a wide range of topics, including biodiversity conservation, coastal resilience to climate change and sustainable governance through maritime spatial planning and the involvement of citizens and stakeholders.

Communication COM (2021)240 defines a detailed program for sustainable blue economy, aimed to:

- Preserve biodiversity and invest in nature: protecting 30% of the EU’s sea surface will reverse biodiversity loss, increase fish stocks, contribute to climate mitigation and resilience, and generate significant financial and social benefits. The environmental impact of fishing on marine habitats will be further minimized.
- Support climate adaptation and coastal resilience: adaptation activities, such as the green infrastructure development in coastal areas and the coast protection from the risk of erosion and flooding, will help preserve biodiversity and landscapes, for the benefit of tourism and of the coastal economy.

Biodiversity conservation and protection are considered fundamental principles of maritime and coastal economy. Biodiversity is not just a prerequisite for economic activities such as fishing and tourism. Instead, biodiversity conservation and restoration provide opportunities in economic terms, as well as in terms of adaptation and mitigation of climate change. As underlined in the EU Biodiversity Strategy for 2030, extending protection to 30% of the EU’s sea surface and creating ecological corridors will reverse biodiversity loss and contribute to climate change mitigation and resilience while generating significant financial and social benefits.

A ‘blue/green’ approach to climate change adaptation is therefore promoted (as opposed to the construction of ‘gray’ infrastructure), based on natural and nature-based solutions. Indeed, the de green infrastructures development can contribute to preserving biodiversity, coastal ecosystems and landscapes, Hence, strengthening both tourism and economy sustainable development.

II. Sources of parameters data templates

Table 9. Climate change and morphological stability

Threats	Parameters	Variables	Data Type / Formula / Unit	Source
Climate change and morphological stability (erosion, vulnerability to CC, etc.)	Type of Coastline	Rocky	Unit: km	banca dati EMODnet (The European Marine Observation and Data Network), dati osservati dal 1998 al 2005
		Sandy	Unit: km	
		Cliff	Unit: km	
		Dune	Unit: km	
		Coastal marshes	Unit: km	
	Characterization of the coast (dynamics)	Erosion	Unit: km	
		Stable	Unit: km	
		Progradation	Unit: km	
	Coastal Evolution	Coastal erosion rate	Unit: mm/year	macroregioni di ISPRA
		Coastal Aggregation rate	Unit: mm/year	
	Water Temperature	Max water temperature	Unit: °C	
		Water temperature rising	Unit: °C/year	
	Sea Level Rise	Max Sea Level	Unit: cm NGT	
		Sea Level Rise evolution rate	Unit: cm/Year	
	Atmospheric Temperature	Max Atmospheric temperature	Unit: °C	
		Atmospheric temperature rise	Unit °C/Year	

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