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COASTAL RESILIENCE POTENTIAL AS A COEFFICIENT OF THE COASTAL EROSION RISK ASSESSMENT, AND THE MANAGEMENT OF RISK AREAS VIA NATURE-BASED SOLUTIONS.

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I. ACKNOWLEDGEMENTS

II. ABSTRACT

Since climate change becomes a popular matter, people start to become more aware of its significance; they understood that this phenomenon is strongly affected by humans' activities, and that it results and was originated by a series of minor phenomena and feedback. Coastal erosion is a natural process, exacerbated by the climate change, and that is considered a natural hazard since it has started to threaten humans' safety, and their goods. As it happens to other natural hazards, such as hydraulic or wildfire, the risks of coastal erosion is mainly driven by the urban spreading and the management of the territory. Good practices, guidelines, and studies on coastal erosion assessment and management have been proposed largely in order to solve the issue; nevertheless, shorelines worldwide are still retreating, and future predictions are even worse. Solutions were proposed and tested considerably, during the last century; almost everywhere they comprised hard structures of coastal engineering that instead of solving the issue, created new instabilities, such as coastal squeezing and erosive shifting. The consequences and trends on the coasts of the world have clearly addressed us to reconvert coastal engineering to a more sustainable one, supporting the resilience of the natural environment. Resilience generally represents the capacity of natural systems, as a coast, or even a community or an individual, to cope and respond by itself to a traumatic event. Considering the loss of beaches, resilience will allow the system to use its resources by rebalancing dynamics and feedback between its components, and eventually jump back to the equilibrium it had at the initial stage before trauma's occurrence.

In this work an integrated method to compute resilience potential is defined, modeled, and introduced in both, the assessment, and the management phases of the coastal erosion risk. These evaluations comprise the use of innovative technologies, such as Geographic Information Systems to map and spatially analyze morphological, economic, and social trends. They are remarkably diverse matrices because of their nature but need to be coupled as the product of vulnerability and exposure in the risk assessment. Through an index-oriented approach, the potential of resilience was computed and integrated in the vulnerability assessment. This is crucial since risk areas must be mapped, and their usage must be regulated, independently from economic or political visions. In fact, from a normative point of view the areas exposed to natural hazards must be turned into low risk levels to improve the natural stability before their use. Nonetheless, it still represents a huge challenge since economics play a strong role in the assessment formulae, as well as in the management plans, that for these reasons very rarely result resolutive.

The study has been produced and tested on the Interreg MAREGOT Project dataset made available by the Department of Earth Sciences of University of Florence. Then, a geomorphological assessment was conducted at the Center of Geo technologies (CGT) of the University of Siena and followed by a modelling phase through diagnostic indicators of territorial changes. The latter phase was carried out at the Department of Civil Engineering of the Polytechnic University of Cartagena (Spain).

The results highlight that a resilience assessment is needed to face not just the effect of climate change, but most of all it is mandatory to plan resolutive actions that would explain the real coping capacity of coasts against extremes.

The study also pointed out the individuation of derivate risks that arose just from the humans' activities. Coastal squeezing for instance is one of the main issues created by the urbanization's dynamics; it implies the loss of habitats and spaces that should host natural processes, as well the comparing of a social justice's risk. The latter is the result of both, the high density of concessions for recreation activities on the maritime domain, and the increasing of prices and building that limit the free access and right of swimming by the most part of the society.

The index-oriented approach used to develop the present research shows the efficiency of the method that allows us to convert qualitative data into computable factors for a new, and resilience-based formula to calculate the risk of Coastal erosion.

This should be normatively modified and based on the natural coping capacity of the natural areas.

Furthermore, and probably the most important result regarding the huge normative gap that at European, and National level (in the case of Italy), still considers the risk of coastal erosion an issue that affect humans' goods.

Rather than this, through this study we reconsider, as our Nature Based Solution, the concept of risk of coastal erosion such as the risk to lose the primal resource of the beach, that very simply is the beach in itself.

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1. INTRODUCTION

1.1 GENERALITIES

Coastal erosion is one of the most peculiar natural phenomena that at the present day actively threatens urban areas and whole ecosystems worldwide. It is due to the sum of the effects directly related to climate change (such as the sea level rise-SLR- and ice caps melting), others that are considered indicators of climate change -such as the extremes (Benassai et al., 2015; IPCC, 2014; Williams et al., 2018), and further ones that are totally induced by human beings (de Jonge, 2009). Predictions on sea level rise forecast show that it will reach almost 1 m during this century, while extremes (i.e. incipient rainfalls, hurricanes, coastal surges, etc.) are constantly changing in frequency, intensity, and spatial patterns. The management of the coastal territory, and the engineering solutions adopted to defend and contrast coastal erosion, and exacerbated erosive tendencies of coastlines; these directly modified the coastal dynamics to a point where new phenomena, such as coastal squeezing and narrowing, appear (Doody, 2004; Pontee, 2013).

It is undoubted that, as a natural phenomenon, erosion/sedimentation cycles always existed (Van Rijn, 2011), but it became a management issue since human-induced factors stress the coastal systems, and reduce the space to accommodate the occurring changes (Salman et al., 2004). The scientific community provided different approaches and definitions of the problem, that basically describe the process whereby a coastal zone loses its subaerial land part (beaches, dunes, bluffs or cliffs), resulting in a net sediment imbalance and subsequent retreatment (Rangel-Buitrago et al., 2018b). Other definitions of the coastal erosion mainly differ because of the context within which they are treated, or the detail through which they are analyzed. If the first definition mentioned explains the general dynamics, the European Commission defines coastal erosion *"the encroachment of land by the sea after averaging over a period which is sufficiently long to eliminate the impacts of weather, storm events and local sediment dynamics"* (Salman et al., 2004).

It is clearer that the evaluations of the natural risks must comprise feedback released by the system's components, that in transition environments, such as the coastal ones, are varied and numerous. Here, marine, and continental processes meet, making the coasts some of the most peculiar and very sensitive environments. The coexistence between aquatic and terrestrial bio-species, the exchanges between sea and freshwaters, as well as the sedimentary inputs that feed marine currents, represent just a few examples of the delicate relationships that regulate these regimes. More features are added by humans' activities, where the coastal areas develop megacities and the biggest economies ever.

Nowadays, 41% of world's global population concentrates in coastal areas (Martínez et al., 2007); although coastal availability consists worldwide of 1.634.701 km, just 28 % is altered by anthropogenic activities (Burke et al., 2001). Hence, 457.716 km should host about 2.5 billion people (United Nations / Development Programme, 2005); however, if we consider coastal cities the ones distributed between 100 km inland, a very small part of the Earth's surface is occupied by the 15 % of the global population (Cohen and Small, 1998). Even in this case, the forecasts are not comforting. From the following Figure 1.1 the distribution of the megacities and big urban centers can be appreciated; they are still growing in surfaces and population.

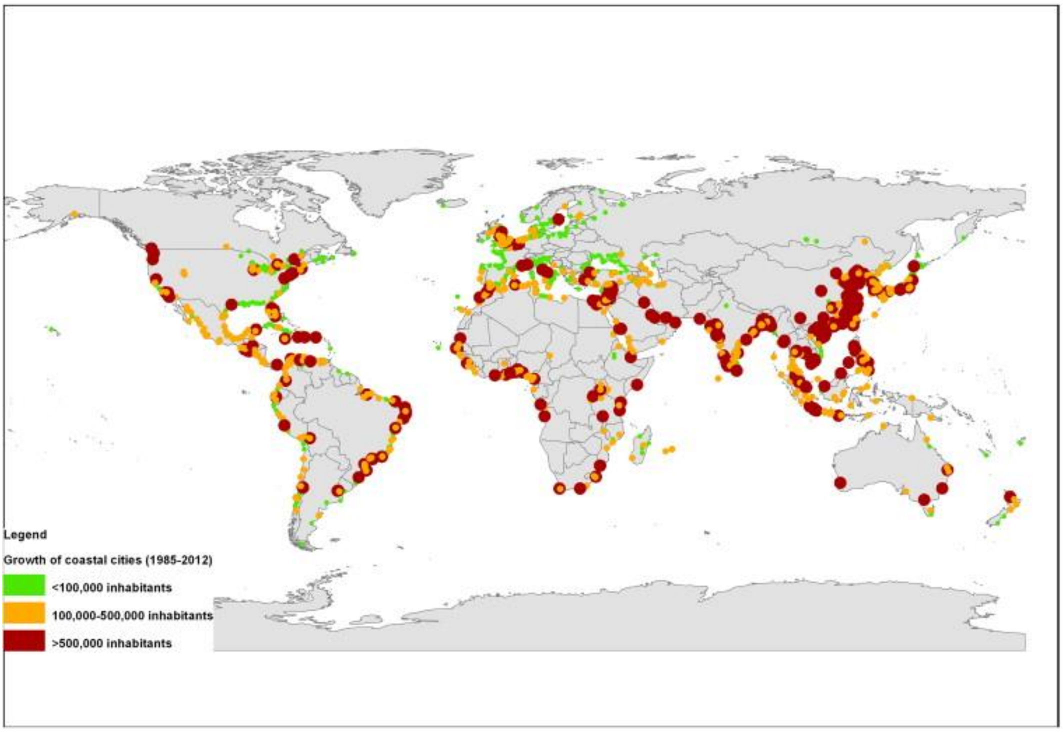


Figure 1.1 World map of Coastal Cities and Agglomerations growth between 1985 and 2012. The increase in urban population is grouped into three ranges: Cities that have grown less than 100,000 inhabitants, cities that have grown between 100,000 and 500,000 and cities that have grown more than 500,000 inhabitants.(Barragan and de Andrés, 2015).

They have populated these portions of territory mainly because of the weather regimes and countries' histories, that are the same drivers of the human's migration toward coastal areas today (Barragán and de Andrés, 2015; Brown et al., 2009; Martínez et al., 2007; Seto et al., 2011). In fact, in 2050 70% of the global population (that today is 7.2 billion) is expected to live in urban areas; this will stress and enlarge the anthropogenic spaces. Two examples are the coasts of Europe, that are still affected by incipient erosive patterns mainly due to human pressure, (EEA, 2018, 2010; Intergovernmental Panel on Climate Change, 2007), and the mainland China's coastline, that at the present time hosts 5.2 million people (approximately 31% of China's population). They already generated high levels of urban pressure on the ecosystems testified by the big land changes, that are expected to hardly increase due to both demographic spreading and sea level rise (Sajjad et al., 2018). Land changes are expected to be extensive, especially in developing countries. In these regions, also extremes and climate change's effects will be stronger than other places. At the present day in fact, only 10% of deaths from natural disasters are from developed countries, while in developing ones, from 1991 to 2000, 211 million of people were affected by them (Balk, 2009; McGranahan et al., 2007). As previously stated, the human's occupation was ruled by climate conditions, that strongly affect the physical setting of the coasts. Weather, temperatures, and water availability regimes strongly affect the vegetation coverage, and directly the sedimentary yield that should feed the beaches. Even if in this cycle other parameters are involved, the factors that affect the sedimentary stock represent the main drivers in the shoreline's variation at a global scale. A meaningful correlation was highlighted between the sandy coasts' distribution and the latitude. The relative occurrence of sandy shorelines increases in the subtropics and lower mid-latitudes (20°–40°), with maxima around 30°S and 25°N. It decreases to less than 20 % beyond the 50° parallel, in the humid tropics, where mud and mangroves are most abundant as a result of high temperatures and rainfall. (Luijendijk et al., 2018). A global overview on the occurrence of sandy shorelines could be summarized through the Figure 1.2, from Luijendijk et. al, 2018, as well as the 24% of beaches that are currently eroding.

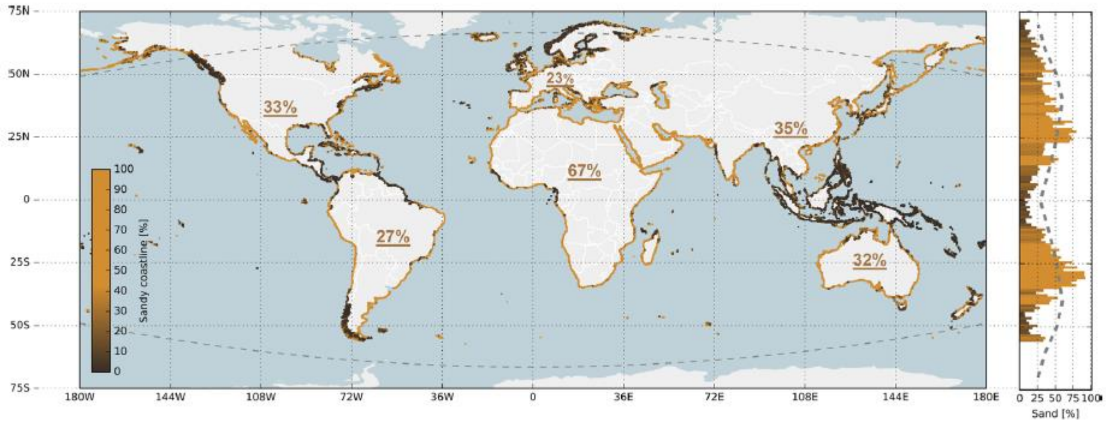


Figure 1.2. Global distribution of sandy shorelines; the colored dots along the world's shoreline represent the local percentage of sandy shorelines (yellow is sand, dark brown is non-sand). The subplot to the right presents the relative occurrence of sandy shorelines per degree latitude, where the dashed line shows the latitudinal distribution of sandy shorelines. The curved, dashed grey lines in the main plot represent the boundaries of the ice-free shorelines. The underlined percentages indicate the percentages of sandy shorelines averaged per continent (modified) (Luijendijk et al., 2018).

Thus, at a world scale today exists 33 big cities (each of these cities homes more than 8 million people), and 21 of them are located within 100 km of sandy, shoreline coasts. The correlation between sandy shorelines and human concentration appears diagnostic not just of a global process, but also because sandy beaches are the most sensitive beaches to any temporal scale. Especially in sandy beaches, a management is required after obtaining profound knowledge of all the components of the coastal system (social and ecologic), that very rarely are comparable from one place to another (Pereira et al., 2018). Differences are strong between areas concentrated in different climatic regimes, and the functions that the ecosystems issue within them depend on the countries' vocations. At the present time in fact, the environment does not provide just primary functions, but also allows us to regulate and be inspired by the natural resources (Bijlsma et al., 1995; De Groot, 1992; Vellinga et al., 1994).

User and production functions include the provision of space for humans' habitations, and socioeconomic activities, such as tourism and recreation, fisheries, agriculture, water extraction, oil and gas, commerce, and infrastructure development. These actions are the most linkable to the direct use we do, and of which we take advantage building additional structures, such as harbors, ports, bridges, roads. Additional services provided by the coasts are the inputs to the human heritage and conservancy of the landscape, that represent the class of *Information functions.* Further, and crucial classes for this study, are the *Regulation functions;* they cover a series of actions that also concern the defense of the coasts, the coastal infrastructures, as well as all the management solutions related with coastal dynamics and protection to the extremes.

They implicate costs to realize and keep some services active; this produces an economy from the coastal system that rules the functions and the relative actions. It is schematically described by Figure 1.3 (Barbier, 1994; Bijlsma et al., 1995).

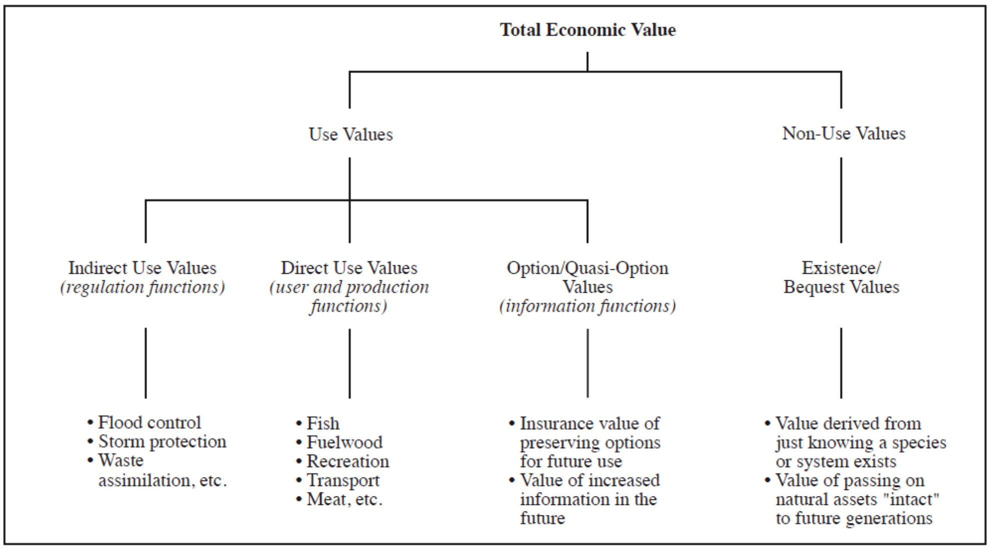


Figure 1.3. Values of coastal systems (Barbier, 1994), modified (Bijlsma et al., 1995).

While some of the functions that are developed within the coastal areas bring notable economic value to coastal countries, the maintaining and increasing building of coastal infrastructures represent important costs. At a global scale, the total value calculated for the Ecosystem Service Product (ECS) represents 77% of world global value (US$ 33 trillion dollars) worth of services annually (Figure 1.4). It is provided by coastal ecosystems of the world, including natural (terrestrial and aquatic) and human-transformed ecosystems. About 63% of the estimated value is contributed by marine systems (US$ 20.9 trillion per year), and most of this comes from coastal systems (US$ 10.6 trillion per year). Just 38% of the estimated value comes from forests (US$ 4.7 trillion per year) and wetlands (US$ 4.9 trillion per year) (Costanza et al., 1997). However, as demands on coastal resources continue to increase with expanding economic activities, coastal systems continue to face increasing pressures. The effects can be generically summarized as the degradation of natural systems (Bijlsma et al., 1995), and the socioeconomic risk for population and infrastructure exposed to erosion and flooding events (Piazza Forgiarini et al., 2019). Strategies are adopted legally, technologically, and financially by governments to adapt economic plans to the exploitable functions of the environment and its sustainability. The latter concept is deeply tied to some paradigms, due to the humans' ingenuity to try to substitute the natural resources with the economic growth. Economic accumulation in the present should compensate the future; it would be possible if technologies would provide the possibility to artificially recreate the natural resources. It is sustainable in a nature dominated by humans, where a value is attributed through the market system. This approach results deeply "unsustainable", but unfortunately represents the way the natural resources are globally thought, and through which are evaluated. In fact, in reality our technology can never reproduce the ecosystems and the species they comprise, thus the market system cannot evaluate the cost to reproduce something that could never be reproduced (Cutler et al., 2020; Landry, 2011; Vos, 2007). In fact, the natural response of the ecosystems, and the engineering solutions (technology) adopted during the last century have shown us the spreading of coastal narrowing, overexploitation of resources, and a wide depletion of the environment and its functions (Bijlsma et al., 1995; De Groot, 1992; Vellinga et al., 1994).

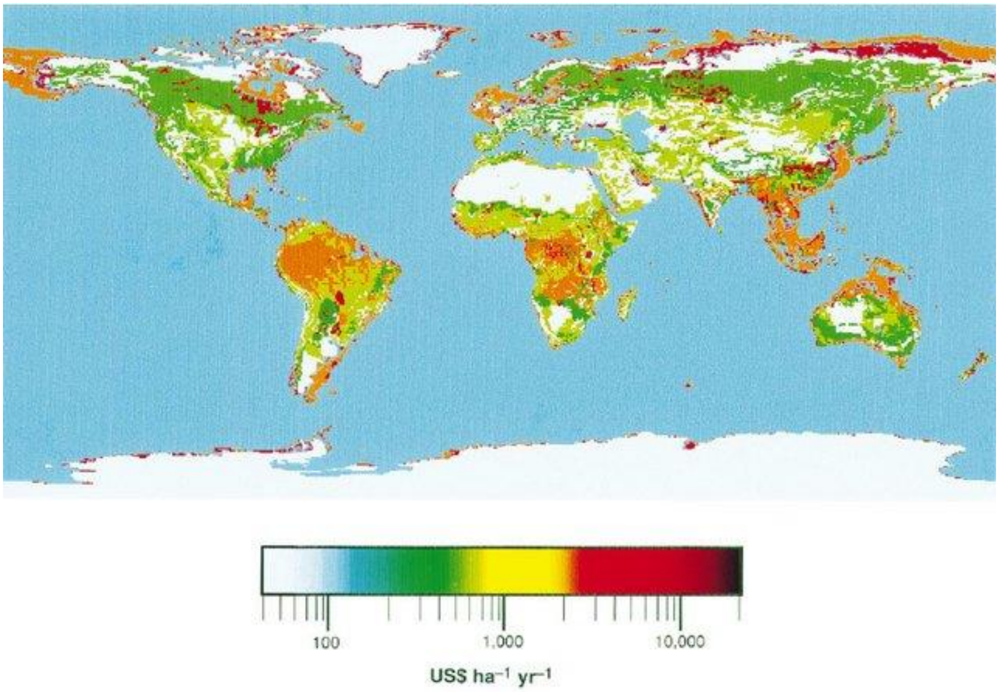


Figure 1.4. Global map of the value of ecosystem services (Costanza et al., 1997).

Cause-effect relationships between humans and environments have been explained in numerous studies, and they highlight the intricate system of feedback that characterize the coastal system also at a local scale. In figure 1.5 the functions and services that exist, and should be considered in a coastal site management, was suggested for the Mar Menor coastal lagoon -South of Spain (Perez-Ruzafa et al., 2018).

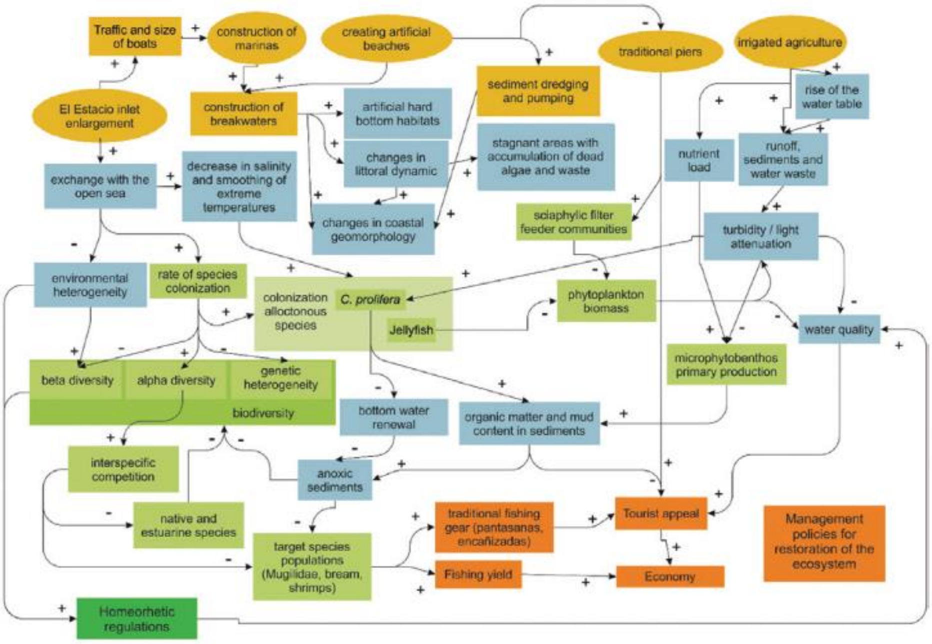


Figure 1.5. Cause-effect diagram between the main humans' activities (yellow boxes and circles on top), the environmental conditions (blue boxes), biological processes and indicators (green boxes), and socio-

economical aspects (orange boxes on the lower part of the diagram). The signs + and – indicate respectively increasing and decreasing effects (Perez-Ruzafa et al., 2018).

The assessment is clearly articulated; different skills and professionals are required for a correct evaluation. The procedures to adopt have been largely studied; protocols, guidelines, and papers defining the risk assessment consider the main characteristics of the coast, within the groups of components we mentioned previously. Generically, the risk (R) can be expressed as the probability of harmful consequences, or expected losses (deaths, injuries to property, livelihoods, disruption to economic activities or environment hazards), resulting from interaction, or the product, between vulnerability and exposure (ISO/IEC, 2009; UNISDR, 2009). The first defines the susceptibility of a coastal area to suffer damage by either inundation and/or erosion; exposure describes the socio-economic and environmental values of the elements that can potentially suffer damages (people, human activities, infrastructures and ecosystems) (IPCC, 2014). It should be highlighted that in the product between V and E, the latter is the main driver of the risk's value. For instance, once an extreme event interests uninhabited, or at least poorly urbanized areas, the risk decreases. The assessment deeply depends on the economic aspects that we already described as paradigmatic. It represents one of the main problems in the feasibility of innovative, and nature-inspired solutions; their realization is strictly limited by an anthropocentric view on the coastal erosion by the human society (Cooper and Jackson, 2019).

The main standardized approaches in the vulnerability and coastal erosion risk assessment will be analyzed. The methods used for the evaluation of natural hazards differs because of the field from which the assessment is drawn - i.e., climate change adaptation, coastal erosion hazard assessment, disaster risk management, or poverty and development (Anfuso, 2011; Anfuso and Martínez Del Pozo, 2009; Cantasano et al., 2019; Jones and Boer, 2004; Jones and Mearns, 2004; Kantamaneni et al., 2017; Weis et al., 2016). Jones and Boear have classified the assessment methodologies in two main approaches (Table 1), such as the Natural Hazard - based approach, and the Vulnerability – based approach.

- The *natural hazards-based* approach fixes a level of hazard, and then assesses how changing that hazard, according to one or more climate scenarios, changes vulnerability.
  Limits of this method are represented by the climate models that often cannot represent hazard's changes specifically in the evolutive scenarios.

- The *vulnerability-based* approach sets criteria based on the level of harm in the system being assessed, then links that to a specific frequency, magnitude and/or combination of climate events. The level of vulnerability can be decided jointly by researchers and stakeholders, chosen based on experience, or defined according to policy guidelines.

Vulnerability assessment investigates on the coastal erosion mechanisms, on the exposed socio economic values, as well as on the options to face this issue (Benassai et al., 2015; Coastal and Environmental Research Committee and Southeastern Universities Research Association, 2015; Cutter et al., 2003, 2009; De Girolamo et al., 2006; Drejza et al., 2019; Ferreira, 1999; Rangel-Buitrago et al., 2020; Ranieri et al., 2016a).

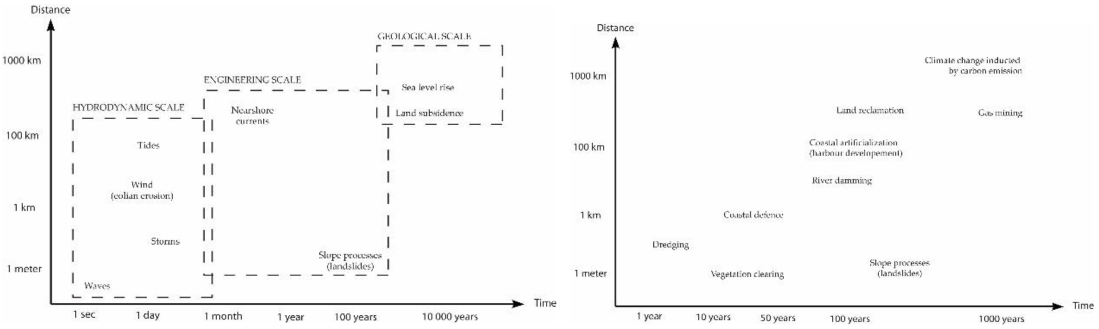
Method	Natural hazard-based approach	Vulnerability-based approach
Hazard characterization	Ranges of uncertainty described by climate scenarios and/or characterization of hazard under climate change well-calibrated	Ranges of uncertainty described by climate scenarios and/or characterization of hazard under climate change well-calibrated
Drivers of change	Main drivers known and understood	Main drivers with multiple uncertainties
Structure	Chain of consequences understood	Multiple pathways and feedbacks
Formulation of risk	Risk= P (Hazard) x Vulnerability	Risk = P (Vulnerability) e.g., critical threshold exceedance
Approach	Exploratory	Normative

Table 1 Checklist to determine the efficacy of using the natural hazard- and vulnerability-based approaches in an assessment modified from Jones and Boer, 2004; Jones and Mearns, 2004.

These represent different scenarios and fields that are linked by a coevolutionary relationship (Sterr et al., 2000). Today it is successfully investigated through the use of diagnostic indicators of territorial changes, used to integrate the different aspects that produce vulnerabilities in the coastal system (Bonetti et al., 2018; Bush et al., 1999; EEA, 2018, 2018; Garcia-Ayllon, 2018; García-Ayllón, 2017; Kumar et al., 2016; Lu et al., 2012). This allows us to individuate stressors and counteractors of the coastal erosion, as well observe how their feedback changes once the parameters change. There are no doubts, that even if vulnerability approach provides some tools through which solutions could be modelled to be economically resolutive. In the same way, there are no doubts that sustainability, as we defined previously, as well as economic values are likely to be the wrong criteria on which we base the formulae to assess risks.

Coastal resilience describes the self-organizing ability of a coast to respond in a sustainable manner to morphological, biological and/or socio-economic pressures (Klein et al., 1998). Its interest is increasing worldwide, and resilience-oriented and adaptative plans were already adopted or at least modeled (City of Santa Cruz, 2018). Toward the same direction, the Commission for Environment has published the report named "Nature-based solutions to promote climate resilience in urban areas–developing an impact evaluation framework" (Raymond, et al., 2017), to promote resilient and multidisciplinary approaches in the analysis of coastal areas. They comprise the use of technological options to investigate, and nature-based actions and normative tools to fill the gap of knowledge about the resilience potential.

It is important in the first stage of the assessments to set a proper scale of the processes to observe, from both points of view, temporal and spatial. The EUROSION Project (Salman et al., 2004) reported about the need to differentiate processes of coastal erosion in order to choose the proper management solution, since temporal and spatial scales are very different as different is their nature, even if the coastal settings will result from their sum. The categorization was done distinguishing from natural to human-induced factors of coastal erosion (Figure 1.6 a, b).



(a) (b)

Figure 1.6. (a) Time and space patterns of natural factors of coastal erosion; (b) Time and Space patterns of human induced factors of coastal erosion; modified from Salman et al., 2004.

Natural and human induced factors of coastal erosion were individuated, grouped, and their spatial extensions and temporal scales were determined. They are the same that should be during the assessment, and that also comprise an administrative level of the evaluation.
Hence, also an administrative scale must be set, that involves the various institutions that manage the coasts at different levels. Planning and mapping are part of the management process, and already offer technical tools -such as cartographic ones- exploited by governments and national entities worldwide. The administrative framework, that from a local to national or even bigger level, defines modalities of the assessments and the feasibility of the future proposals. As well the usage of the coasts is regulated by government entities, that issue permits us to occupy the territory as well economic standards to work with. In Europe the normative framework is very fragmented (European Commission, 2011; European Parliament, 2006; Lavalle et al., 2011), and will become even more once we practically restrict the analysis to a smaller level (McKenna and Cooper, 2006; Neal et al., 2018).

The present study will comprise a local scale coastal context that in the past shows an apparent balance. To investigate on it, the sedimentary stock will be analyzed since it provides space for ecosystems development, as well as for the building of services and human's benefits. For these reasons, it represents the most important component of the coastal system to preserve, in order to maintain the resilience potential of coasts (Klein et al., 1998, 1999, 2011; Bhamra et al., 2011; Coastal and Environmental Research Committee and Southeastern Universities Research Association, 2015; García-Ayllón, 2017; Raymond, et al., 2017). The sedimentary stock can be strongly affected by human induced phenomena, such as coastal squeezing, and they can even conceal natural trends during the assessment phases (Pranzini, 1989; Doody, 1992, 2004; Pontee, 2013; Anfuso et al., 2013; Bianco et al., 2020). These feedbacks directly affect the sediment availability on the active beach, and are strongly determined by inland processes, such us sedimentary discharge from rivers and channels. It also regards the benefit's distribution through the citizens, tourists, and stakeholders that are mainly concentrated in big coastal cities (Martínez et al., 2007), and that would not exercise the right of free swimming and accessibility if the space reduces. The European Union strongly supports the research and study of resilience potential to face extremes and climate change. In particular, the use of Nature Based Solutions -NBS- (Bridges et al., 2015; Eggermont et al., 2015; Nesshöver et al., 2017; Raymond, et al., 2017; Reguero et al., 2019, 2014) are supported in order to avoid the building of hard structures. They can increase and build new models of circular and resilient economy.

Even if resilience assessments were already tested (Carl Folke et al., 2002; Allen et al., 2018; García-Ayllón, 2017), at the present day they do not represent official requirements to manage and plan on coastal areas. As the engineering solutions could increase the resilience, also the evaluating methods should consider this property that can support the ecosystem and the scientific findings. Indeed, the formulae used at the present time to calculate classes of vulnerability and even risks, are mainly ruled by the economic values of the damageable goods (de Jonge et al., 2012; Gracia et al., 2018). By considering the risk to lose the natural resource involved would probably change the procedures of evaluation, as well as the categorization of risk exposed areas. Resilience potential addressed through the indices of vulnerability could be introduced in the formulae and become crucial for both, regulation, and usage phases.

The degree of resolutions of the management actions could advantage from the indices, that even if were largely produced did not solve our issues with coastal erosion.

The European Agency for Environment (EEA) systematically reports and updates about environmental indicators, such coastal erosion and land changing. They still address the coasts of Europe in a drastic retreatment, exacerbated by human pressure. Moreover, in Europe these trends are increasing also in the areas that survived the great urban sprawling of the post II World War -such as Spain and southern Italy (Hilferink and Soba, 2011). Where these processes were acting in the past, as France, today they are causing social issues, revealing that some natural hazards are not just an environmental problem; for these reasons, some of France's coasts were named the "coasts of conflict"(Meur-Férec et al., 2008).

A unique opportunity to test this research in the Region of Tuscany arose from the Interreg-Maritime Project named *"Management des Risques de l'Erosion cotière et actions de GOuvernance Transfrontalière"* (MAREGOT). It is a European program that interests the transboundary regions of Italy and France, aiming to support the cooperation between them. Within the partners' framework, the Department of Earth Sciences of the University of Florence was involved to set a monitoring plan regarding the littoral evolution of Tuscany's test sites. They were chosen depending on the criticalities individuated during the MAREGOT designing. One of these test sites comprises the littoral stripe of the San Vincenzo's municipality, in the province of Livorno (Nord East Italian Mediterranean coast). It represents an exhaustive example of urbanized Mediterranean area, where touristic harbors were conspicuously realized. They populate the coasts bounding Natural Parks and areas within all the transboundary regions. Moreover, they strongly destabilized the coastal dynamics triggering the coastal engineering efforts to the use of hard defenses, that nowadays produce coastal narrowing and squeezing.

The coastal zone of San Vincenzo has been already studied by the University of Florence, the Italian National Research Council (CNR), and the Environmental Departments of the administrative authorities, such as Regional and Provincial (Aiello et al., 1979, 1976; Bartolini et al., 1976). Although it has been considered stable by all these studies, all of them concluded that attention should be paid to the southern sedimentary cells of the Unit, where a Natural Park still preserves some dunes systems. The attention to the area arose after the building and enlarging of the touristic harbor of San Vincenzo, that ended in 2010. The site is of importance for the present study since the anthropogenic activities seem not to have disturbed it at all, even if harbor and hard defenses have been realized during the last 60 years. The results that we expect to have obtained will probably answer to some questions, such as:

- Does the resilience potential of the area support its response to coastal erosion?
- If yes; which are the natural elements of the San Vincenzo's coastal system that increases its resilience?
- Does, the management strategy adopted, increase resilience?

To answer these questions, we will perform our assessments adapting the existing ones to our case. Considering morphological, economic, and administrative characters, the Vulnerability and Risk to coastal erosion will be determined through an index-oriented approach that will comprise the resilience potential.

Data to carry on the evaluation were granted to the Centre of Geo Technologies of the University of Siena by the Department of Earth Sciences of the University of Florence. They consist of bathymetric and shorelines raw data, and sediment samples collected from 2000 to 2018 for the monitoring of the littoral during the enlarging phases of the harbor.

1.2 AIMS AND CONTENTS

Since coastal landscapes are dynamic systems controlled by multiple factors and feedback, to set a management system for the usage of coastal areas, it should first compromise the understanding of acting forces and their characters (as for example which of these factors represent some stressors of coastal erosion, and which ones are counteractors); secondly, it should work to restore the coastal environments. To this topic the European Commission (EC) issued several reports and studies including technical recommendations, best practices, and policy guidelines since 2000, when the Integrated Coastal Zone Management (ICZM) had been established. Coastal zone is defined as *a strip of land and sea of varying width depending on the nature of the environment and management needs. It seldom corresponds to existing administrative or planning units. The natural coastal systems and the areas in which human activities involve the use of coastal resources may therefore extend well beyond the limit of territorial waters, and many kilometers inlan*d (Lavalle et al., 2011).

Nowadays, an indicator-oriented approach has been largely adopted as the most exhaustive, even if perfectible method for coastal erosion assessment. It is still promoted as the direction towards the State members who should conduct the assessments, and evaluations periodically issued. The last report on the Environmental indicators (EEA, 2018) considers the coasts of Europe still affected of an increasing anthropic pressure. It was emphasized by previous documents from EC (EEA, 2010; Intergovernmental Panel on Climate Change, 2007), that also reported a lack of indicators on the matter of coastal erosion. One of the causes of this gap is the normative fragmentation of policies, as well the unconformity of the European coastline. Meanwhile, both the extremes' occurrence and the anthropic pressure are increasing worldwide in coastal areas. Even if global data shows that the pressure is higher in the main coastal cities (Martínez et al., 2007), in Europe this trend has been confirmed during the decade 1990-2000, even in developing zones, such as South of Italy and Spain (EEA, 2010). Cases that refer to regions facing the effects of the uncontrolled sprawling due to the weak policies and wrong practices. They have increased the potential of the extremes and produced stressor processes at a local and regional scale. As we introduced previously, coastal erosion and the socio economics related aspects result, at a global scale, driven by human related mass phenomena, such as human's migrations, and weather and climate regimes. Nowadays, these main drivers can be accelerated by the human beings' action in several ways, and through several processes, such as, the global warming and the consequent sea level rise. On the other hand, to a smaller scale, coastal erosion results from the combination of other natural settings, (i.e. geomorphology and sea state parameters) and anthropogenic related processes that leads with local or regional economies; both of them are hardly comparable from one place to another. In the same way as the climate changes example above, coastal erosion at a smaller scale can be seriously increased by human's actions. These are different, and they are often made inland to a watershed or hydrographic basin scale, as it happens for sand mining and deforestation (Corsini et al., 2008; Pranzini, 2018; Williams et al., 2018).

Urbans produce what are today known as *coastal squeezing* and *coastal narrowing* (Doody, 2004; Pontee, 2013). *Coastal squeeze* is commonly used to describe the loss of coastal habitats *due to the high water mark being fixed by a structure, and the low water mark migrating landward by the ecosystem, that in this way maintains its same relative position, with respect to waves and tidal forces, adapting to SLR*. Differently, the *Coastal narrowing* term is used to generally describe the reducing of the coastal zone when drivers could be different than SLR or defenses " (Pontee, 2013). The anthropogenic elements that really produce or exacerbate these reductions are *hard defenses* and coastal structures made to facilitate tourism (Phillips and Jones, 2006; Rangel-Buitrago et al., 2018c; Sanjaume and Pardo-Pascual, 2005), such as groins, seawalls and breakwaters. Their use increased during the last century and a half, especially since coastal engineering evolved realizing marinas and seafronts (Charlier et al., 2005). In respect to the case of Italy, firsts examples of coastal defenses, such as revetments, date back to the late XIX sec., while innovative designs, such as groins, breakwater, artificial islands, were largely produced during the last 150 years (Pranzini, 2018). The tendency to realize hard structures changed during the last few decades with the advancing of *soft defenses* such as the nourishments and sediment by-pass. The first nourishments documented in Italy date back to the early '70s, when some regional laws started to consider not just to protect the shore, but even to replace the lost surface, and preserve it in order to use for tourism. Today in Italy, the main cause of the coastal erosion lead with the urbanization of the coastal zone, and the wrong management of sediment's resources at a bigger scale than the morphological cell or physiographic unit (Pranzini, 2018). In general, perpendicular structures to the shorelines interrupt the longshore drift, causing the erosive focuses downdrift, and the consequent retreat. Parallel structures such as seawalls impede land-sea sediment exchanges deeply altering the beach's profile, while breakwaters reduce effective depth offshore, waves' power, and erosion. From the other side breakwaters constitute a hazard for bathers as well as causing erosion. In fact, rip currents generate between their gaps, where sediments are trapped to the offshore, as well as people.

The solutions that could be proposed to avoid the coastal squeezing, and more in general the dangerous human related feedback, have to be evaluated prior to any management plan and decision on the coastal areas, and designed in order to support counteractors of the coastal erosion, and to contrast its stressors. The environmental engineering and the coastal geomorphology should be combined to quantify these trends and to correct them through the most natural ways. These kinds of nature-oriented designs are named Nature Based Solutions (NBS); they comprise green and sustainable infrastructures as well as economical activities that support green practices, natural processes, and ecosystems. NBS should respect the environmental settings and offer a contemporary service to human communities. EU's working group called EKLIPSE works to produce policies to the implementing of NBS options, or even approaches in the designing of these infrastructures, to make the knowledge on this field quantitatively important. On this topic, a lack of indicators from their impact on the coastal dynamics is missed (Raymond, et al., 2017). Management policies should be improved to reduce this incidence on the coasts, but what is needed as of primary importance is to quantify the potential of resilience of the coasts, to know how to support it.

Although to a global scale it is impossible to adopt unique procedures for the assessment and management, at European and national levels it is mandatory. The European community shares policies and priorities with all the state members supporting resilient action plans and innovation programs to face the effect of pressure on coasts. In general, pressure consists of a certain number of actions and decisions that participates to modify the natural system to a usable environment for humans. National, regional, and local administrations usually provide cartographic supports or normative guidelines; they aim to preserve the environmental function of the coastal environment as much as possible. This should permit to respect the resilience limits of the coastal biophysical systems (Cantasano et al., 2019; De Groot, 1992; Ferreira and Laranjeira, 2000; Pereira et al., 2018; Restrepo et al., 2018). The growth of built-up areas is taken as the main metric to evaluate the pressure on coastal zones through the land cover maps. In Europe the share of built up areas in the costal zones is almost double than in the overall continental surface (European Environmental Agency, 2011). A higher built-up density may also lead to an overexploitation of natural resources (e.g. water scarcity, loss of high value soils) and an increase in pollution, thus the arising of derivate hazards.

To consider the various nature of geo and social processes, the assessment approach must describe the landscape, that is produced from their interactions with the topographic surface. Geomorphological mapping is the base to map the landscape and the relationships between geographic information, that is of importance to classify natural hazards. It allows to represent information on morphometry, hydrography, lithology, structure, age, processes, and genesis. These parameters are represented through different colors and symbols that allow priority in the representation and reduce subjective impressions. Mapping allows us to fix natural borders of geo-phenomena, to systematically correlate elements of these geo phenomena, to formalize them by measurable characteristics, as well to integrate verbal, symbolic and graphical data (Bianco et al., 2020; Dramis et al., 2011; Gustavsson et al., 2006; Lastochkin et al., 2018). On a geomorphological map a proper scale of representation can be set, and the physical properties of the sedimentary stock can be delineated.

The geomorphological assessment results from the sum of natural geomorphologic processes and human induced ones, that in the case of coastal erosion, that not only takes place at the sedimentary cell scale, but also at a hydrogeologic basin scale. Contrary, the coastal zone should include an area over and underwater; this will result in a zone where transversal exchanges should be kept in order to not lose risk on the integrity of the coastal biophysical systems through an overburden of their resilience limits (EEA, 2010; Ferreira and Laranjeira, 2000).

Different levels of assessment and vulnerabilities are generally defined; even if they are mostly conducted parallelly, some vulnerabilities were derived from the combination of others of them. The normative framework foresees tools to regulate the use of the maritime territories within the countries. We tested our assessment and management model on an Italian site; here the normative system is very articulated, and national (*Decree Law 5 October 1993, n. 400*, 1993;

Governo Italiano Presidenza del Consiglio dei Ministri, 2001), regional, provincial and local authorities are demanded to manage the territory. This makes Italy a good test, since previous authors addressed it as decisive, for the non resolutive character of the adopted decisions, the inefficiency of the normative tools, where even evolved and extended legislative systems exist, they mostly fail at a regional level (McKenna and Cooper, 2006; Neal et al., 2018).

1.3 THESIS ORGANIZATION

The thesis was structured in seven chapters that schematize the evaluation phases, findings, as well as the literature consultation, and the future research applications.

In Chapter 1, an intuitive view will be provided to focus on the coastal erosion issue. A global scale overview on this matter is provided to give a dimension of the problem from both points of views, socio-economic and environmental. Contemporary, the assessments procedures were introduced, their automatisms briefly described, together with some key concepts on the resilience of the coastal system.

In Chapter 2, the assessments of coastal risk and vulnerability are addressed considering the differences between risk, hazards, and their components. In this section of the work, a paragraph was dedicated to climate changes and sea level rise and to their effects to coastal erosion. Together with sea level rise, that constitutes a large-scale phenomenon, within the same chapter coastal squeezing and narrowing were investigated to infer on human related processes, and their feedback to the natural systems. Strategies considered within the Coastal Erosion Management (CEM), and the main processes acting in the coastal systems were largely investigated to provide enough information on the comprehension of drivers and counteractors of erosive processes. Moreover, the State of the Art comprises the concepts of resilience, together with the parameters that we are going to integrated for the resilience assessment, and the most innovative strategies in the literature that aim to propose resolutive CEMs, such as the so called Intervention Concerning the Erosion Causes (ICEC).

Chapter 3 was dedicated to introducing the research line, and the main procedures followed to carry out the vulnerability and resilience of the potential assessment. This section is then better explained in Chapter 4, where methods and a timeline are carried out while the geomorphologic and resilience assessments were explained. Relevance will be given to the Interreg-Maritime Project "Management des Risques de l'Erosion cotière et actions de GOuvernance Transfrontalière" (MAREGOT) within which the present study was developed. The site on which the study was tested will be described; sedimentological, morphological, and socio-economic trends inferred during the observations were used to perform an index-oriented approach and the production of thematic maps using a GIS suite.

In Chapter 5, a series of conclusions regarding the research's findings is provided. Graphical workflows and diagrams are used to show the main numerical results of the assessments, and to explain how they were translated in coefficients that were introduced to the proposed formula for the calculation of the resilience potential of our test sites.

Chapter 6 consists of a section within which results are discussed and critically analyzed. Here a series of findings were listed, and some potential future researches to this work are highlighted. Regarding Chapter 7, conclusions of the thesis are exposed; gaps of the research are highlighted, and possible management solutions are proposed to integrate the resilience assessment with the normative to a Local, national, and European level.

Further than the References in Section 8, we provided a list of contributions in the Section 9, that we produced during the three years of the Doctorate. Some of them were already peer reviewed as papers, and others were presented to International Congresses (oral and poster) where we actively participated. Within these events we were given opportunities to share our findings with the Scientific community, that we would like to thank for the priceless contributions they gave to our research.

Finally, in Section 10 supporting data to the thesis are provided as appendices.

2. STATE OF THE ART

In the previous section 1.1, some basic considerations on the concept of risk, and some related parameters such as vulnerability and the coastal system's components, were just briefly cited. Within this section of the thesis, these concepts will be deeper analyzed; coastal systems will be described to determine the physical matrices involved in coastal processes. Furthermore, the methods used to determine these parameters will be described within the Coastal Erosion Management's phases, highlighting valuable alternatives and the most innovative scientific findings, where possible. Stages of the Coastal Erosion Management (CEM) are the Coastal Erosion Assessment (CEA), the Coastal Erosion Risk Assessment (CERA), and the individuation of management strategies, such as the Intervention Concerning the Erosion Causes (ICEC). They are temporally consequent and require a preexistent base of data through which we analyze the territory's setting; this approach arose after several attempts to face coastal erosion through hard structures (de Jonge, 2009; Pranzini, 2018). Indeed, a priori operation to every CEM's stage at the present time consists of the mapping of those coastal areas which are at risk of erosion (Rangel-Buitrago et al., 2020). Nowadays, the territorial planning in respect to risks, or even to the aesthetic of the landscape are technologically advanced fields. Innovative technologies are increasingly applied to the study of terrestrial processes; they consist of observation instruments such as satellite images and Geographic Information Systems (GIS). These tools are used to map, to analyze and even define physical parameters. Some example are the X-Band wave radar to determine bathymetry and sea state parameters, wide set of sonars and geophysical instruments to the modelling of geological settings, etc.. (Anfuso and Martínez Del Pozo, 2009; Bishop et al., 2012; Garcia-Ayllon, 2018; Kumar et al., 2016; Lu et al., 2012; Mullick et al., 2019; Narra et al., 2019; Punzo et al., 2016; Rączkowska and Zwoliński, 2015; Rumson et al., 2019b, 2019a; Seto et al., 2011) .They permit the exploration of hardly reachable places, and overall enables us to observe them, and their physical characters, at different timeframes and with different scales. In fact, maps can display the extension of the processes and their feedback to the system, as well as showing the possible risk scenarios, resulting as a primary tool to evaluate and communicate it to other professionals and stakeholders in the clearest way (Rangel-Buitrago et al., 2020; Veersalu et al., 2011). This approach leads to perform every stage since the first assessments, to the solution's planning and monitoring.

2.1 Basic concepts on mapping, and the Coastal system.

The mapping procedure must be resolutive of the temporal and spatial scale of the processes observed, it also must take advantage of both, geomorphological, and administrative boundaries. The most common example of useful maps to the coastal field range from ecology to geomorphology, economy, social justice (Anfuso et al., 2013; Barragán and de Andrés, 2015; Cooper and McKenna, 2008; Ferrari et al., 2019; Spalding et al., 2017). Within them, geomorphological maps have already been indicated as the more useful supporting map to the risk assessment and land use planning, even if they are not enough and properly used by stakeholders (Dramis et al., 2011; Lastochkin et al., 2018). Geomorphology results from the interaction of these activities with the topography, and provides some boundaries between processes and resulting shapes, even if clear-cut boundaries in nature at many scales may not actually occur (Bishop et al., 2012). In particular, coastal geomorphology has to describe the shaping of coastal landforms, the processes acting, as well as the resulting changes (Bird, 2008). Thus, geomorphologic maps should provide this crucial information for management; for instance, the rate of the processes, process–form relationships related to the geomorphic systems, various geo-phenomena directly or indirectly related to the topography as well as human-related feedback (Dramis et al., 2011; Bianco et al., 2020). Thematic layers are made using symbols, colors and letters prioritizing respect to others. They are categorized to show the level of importance of the features represented on the map. With these items, attributes of the territory can be introduced in the map as well as in the related geodatabases, such as hydrography, lithology, genetic of the processes, etc. Through them, especially after the spreading of GIS usage, acting processes, physical matrices involved, and even quantitative -qualitative information on the phenomena can be extracted (Gustavsson et al., 2006).

Thanks to these peculiarities, the geomorphological mapping approach is likely to be the most appropriate and dynamic method to obtain a complete overview on the landscape's components, and the best one to dimension sustainable management strategies for the territory. In this approach, *the Earth surface is viewed as a three-dimensional physical surface separating the lithosphere from its outer spheres, and at the same time as a two-dimensional geometrical surface presented on maps* (Lastochkin et al., 2018).

Geomorphological maps can be distinguished depending on scales, as recommended by the International Geographical Union (Table 2). Generally, large-scale geomorphological maps are between 1:10,000 and 1:50,000, or between 1:5000 and 1:10,000, just occasionally up to 1:100,000 (Cooke and Doornkamp, 1990; Gustavsson et al., 2006). Scales have to be properly dimensioned since they indicate the degree of generalization, synoptic, and the sizes of features represented in the map (Finkl, 2004).

Map Scale	Type of Map	Scale Range
Large-scale maps	Plans	1:10,000 and larger
	Basic maps	1:10,000 - 1:25,000
	Detailed maps	1:25,000 – 1:100,000
Medium – scale maps	Synoptic maps	1:100,000 – 1:1,000,000
Small – scale maps	Maps of countries	1:1,000,000 – 1:5,000,000
	Maps of continents	1:5,000,000 – 1:30,000,000
	Maps of the World	1:30,000,000 – and smaller

Table 2 Classification of geomorphological maps, for the Geomorphological Map of Europe, by the International Geographical Union, Commission on Geomorphological Survey and Mapping (Finkl, 2004).

Coastal areas are zones of varying width that include the *Coast*, the *Shore* and the *Nearshore zone*, out at least to the line where waves break, and extending inland to the limit of penetration of marine influences (Bird, 2008; Short, 2012). A longitudinal zonation of an ideal coastal area (from the hinterland seaward) describes multiple zones recognizable through peculiar geomorphologic and even ecologic features, that are driven by the interaction sea-land (Figure 2.1).

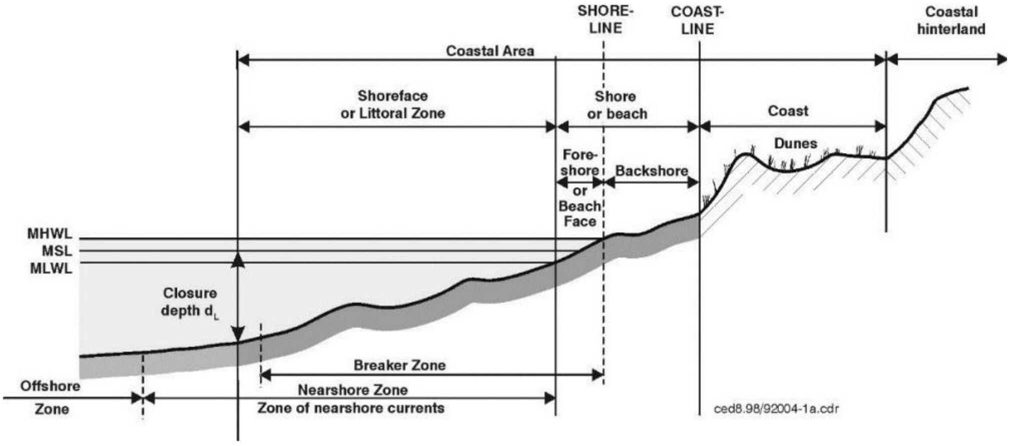


Figure 2.1. Ideal zonation of the coastal zone, after Shore Protection Manual (Coastal Engineering Research Center, 1984). MLWL= Mean Low Water Level; MSL= Mean Sea Level, MHWL= Mean High-Water Level

Indeed, hydrosphere, lithosphere and atmosphere on coastal zones establish a very sensible equilibrium dictated by multiple parameters such as waves' action, pressures, ecologic communities of flora, fauna, and sediment. The landward coastal areas are bordered by the *Hinterlands*, that in unaltered contexts are formed by dunes, lagoons, swamps, and salt marshes - in sandy coasts-, or even the crest of a cliff in rocky coasts. Usually, hinterlands should not be influenced by coastal processes. *Coast* in *sensu strictu* extents from the seaward limit of the coastal hinterland to the *Coastline* (Figure 2.1). The latter is defined as the edge of the land at the limit of normal high spring tides; it is marked by the dunes in sandy coasts, while for cliffy coasts it is generally marked by the cliff's foot at high spring tide level. Thus, coastline highlights an important limit since the zones that follow -seaward- are more exposed to sea's action. Coastline confines the coast with the *Shore*, commonly known as *Beach*. It is composed of unconsolidated material, and is further divided as *Backshore*, that extends seaward to the normal high tide limit, and *Foreshore* or *Beach face*, that is exposed during low tide periods and submerged at high tide. The limit between the two zones is marked by the *Shoreline*, as the water's edge migrates to and from as the tide rises and falls. The position of the shoreline results from the upward and landward movement of the surf zone and the reshaping of the beach profile consequently to the sea level rise. This is known as the Bruun's rule; when rising phases take place, an erosional transgression acts through a net landward movement of the shoreline (Brunn, 1962).

However, the backshore is normally dried, except during high tides and storms, while foreshore is normally wet and dry due to the varying tide and wave run-up (Mangor et al., 2017). Indeed, foreshore lays between the shoreline and the Mean Low Water Level (MLWL), can be distinguished for the presence of one or more *Berms*. Some of them are horizontal, parallel shore deposits made of beach' sediment that is accumulated by the waves during their uprush on the foreshore. Berms can be found also on the backshore when severe events occur, marking the swash limit at any time.

The foreshore is also considered part of the *Breaker or Surf zone*, such as the area that extends seaward from the shoreline, and that is exposed to waves' breaking. It belongs to a bigger portion named *Nearshore or Littoral zone*, that consists of the zone within which littoral processes of sediment's transport takes place (Bird, 2008; Finkl, 2004; Short, 2012). The outer limit of the littoral zone is known as *Depth of Closure* (DoC); it can be calculated, for a given time interval, as the seaward depth after which, there is no significant change in bottom elevation, and no significant net sediment transport between the nearshore and the offshore. The time frame relates to renourishment intervals or design life of a project, since DoC were mainly determined for engineeristic purposes (Krauss et al., 1998). Previous definitions were made characterizing DoC by significant waves occurring 12 hours in a given year (Hallermeier, 1980, 1983). Following Hellermeier 1980, DoC can be calculated as

$$d_l = 2.28\, H_{s,12h/y} - 68.5 \frac{H_{s,12h/y}^2}{g\, T_s^2} \qquad [1]$$

where, dl is the closure depth relative to Mean Low Water Level;

$H_{s,12h/y}$ is the nearshore significant weight height exceede 12 hours per year;

T_s is the corresponding significant wave period;

g is the acceleration of gravity

Through DoC, the authors defined a zonation of the beach basing on the waves' physical attributes and the diameter of the sediments composing the shore. In particular, in Hallermeier 1983 two DoCs were calculated as *Inner* and *Outer*. The first one is the DoC that limits seaward the *littoral zone*, and that can be calculated as previously shown; the outer DoC individuates the seaward limit of the *shoal zone*. The latter can be determined following Hellermeier 1983, as:

$$dlout = 0.018 Hm Tm \sqrt{\frac{g}{d50(s-1)}} \qquad [2]$$

where Hm and Tm are respectively, the median wave height, and the period,;

d_{50} is the median sediment diameter;

s is the ratio of specific gravity of sand to that of fluid (about 2.65).

The d_{50} factor corresponds to the Median diameter of the sediments determined through granulometric analysys. The distribution of grain size classes can be approximated to a log-normal distribution that provide a description of the sediments on the bed through the value of the median diameter (d_{50}) and the geometric standard deviation, such as $\sqrt{d_{84}/d_{16}}$ (Figure 2.2).

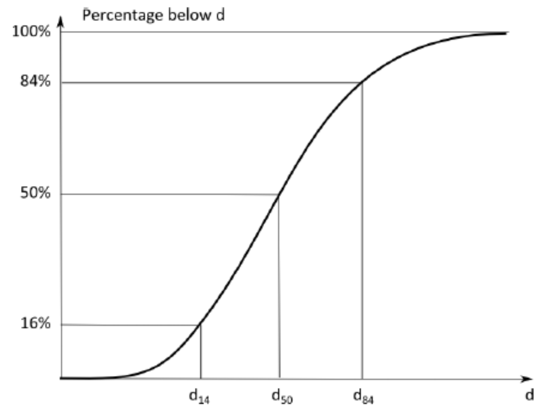


Figure 2.2 Log-normal distribution of sediment sizes (Mangor et al., 2017).

A wave is considered as the sea surface displacement through an oscillatory motion, within time and space domains. The oscillation is measured as the profile of the surface elevation between two successive downward or upward zero-crossings of the elevation of the sea surface (Buckley et al., 1984; Goda, 1986; Holthuijsen, 2007).

These kinds of waves are ruled by gravity, that is considered constant even if we are here excluding other phenomenae that would be of more interest in a large scale oceanographic contribution, such as the Coriolis force, the attraction due to Moon and the Sun, etc.. Classical methods to study waves are based on the Stokes' Law and Airy' equations, that's why the waves we will analyze in this section are called Airy/Stoke's waves. They allow us to model waves as sinusoids even if viscosity and turbulence are considered negligible, and the wave's height is smaller than its length (Figure 2.3). Airy's theory provides the value of the instantaneous water height $\eta(x,t)$, and other fluid dynamics variables as time (t) and space (x) functions, as:

$$\eta = \frac{H}{2} \cos (kx - \sigma t + \psi) \qquad [3]$$

where, $\sigma = 2\pi/T$ is the angular velocity (T is named period of a wave)

$k = 2\pi/L$ is the wave number (L is termed wavelength of a wave)

ψ = is the phase

Statistical operators that mathematically define a wave are *Wave Height, Wavelength* and *Period*. Theoretically a wave can infinitely propagate, and when it is modelled it is associated to a record of waves. The wave height is the difference in height between peaks and troughs, and we will talk about *Significative Wave Height* (*Hs*), such as the mean of the highest one-third of waves in the wave record. Similarly, the period that generically is the time interval between the start and the end of the wave, is determined as *Significant Period (Ts)* or the mean of the *highest* one-third of waves. The Wavelength (*L*) represents the distance between two crests, thus the velocity with which the waves propagate results from the ratio between L and T, known as *Celerity*.

$$C = L/T \qquad [4]$$

Period does not depend on the water depth, whereas celerity and wavelength decrease as depth decreases (Holthuijsen, 2007; Sverdrup and Munk, 1946).

Within this description of the waves' propagation (Airy's theory), we assume that the particles transported by a wave follow closed orbits (Figure 2.3), as well as the fact that waves do not transport mass.

Actually, these orbits are not closed, and there is a flux with same direction of the waves' propagation (Dean and Dalrymple, 1991).

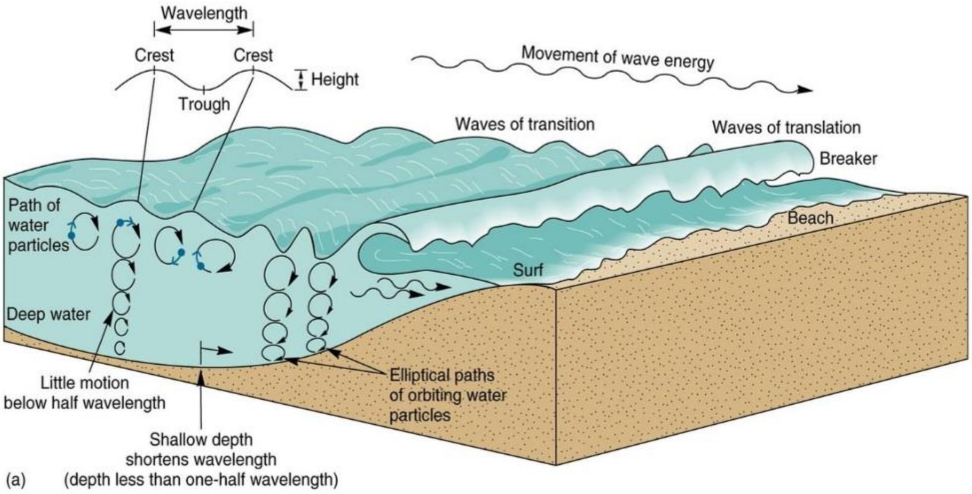


Figure 2.3. Waves' motion toward the shore and physical attributes (imagine source: www.thegeographeronline.net/coasts.html).

Waves transport to coasts half of the necessary energy to power hydrodynamics (Short, 2012) as potential energy; this energy is then released as kinetic energy once waves break.

This wave is also termed *linear,* since the equation that describes how in a field of waves, with different frequencies, they are "dispersed" (separated) depending on their celerity.

The equation, named *Dispersion Relationship,* is valid only for small amplitude waves for which it is linear (Dean and Dalrymple, 1991); it changes for deep and shallow waters, since within the latter the water depth is smaller than the wave number (k), and the velocity depends just on the depth. Thus, in shallow water the dispersion relationship can be written as:

$$\sigma^2 = gk \tanh = gk^2 h \quad \Rightarrow \quad \frac{\sigma^2}{k^2} = C^2 = gh \qquad [5]$$

where, k is the wave number equal to $2\pi/L$;

h is the depth.

From the previous relationship, Celerity can be determined as:

$$C = \sqrt{gh} \qquad [6]$$

We should pay attention to the fact that wave's motion in deep waters is basically generated by winds; so, waves' dimensions depend on the wind's velocity, duration, and *fetch* length. The latter represents the longitudinal extension of the sea's portion covered by the waves for a known period generating waves' motion -it is assumed that this direction will remain constant. This measure gives interesting information on the wave motion intensity that can be assumed to a certain site; for instance, the highest wavelengths corresponds to the longest fetches, even if the winds intensity is the same from other directions.

Hence, the stronger the wind is, the longer it blows, the larger the waves are. In the cases of closed seas, a *geographical fetch* (Fg) is considered as the distance between 2 opposite coasts. This is not the case of the Mediterranean, for which ae maximum distance of 500 Km can be assumed (Cavaleri, 2005).

To use undirected methods (based on wind's regimes observations) for the modeling of sea state parameters the *effective fetch* (Fe) is used. It considers the effect of fetch's width and the directional dispersion of wave's energy during its propagation (Saville, 1962). Through the Saville's formula, from the geographic fetch the effective one can be determined such as:

$$F_{e,\,w} = \frac{\sum_{\phi_i=\phi w-\theta}^{\phi w+\theta} F_i cos^{n+1}(\Phi_i - \Phi_w)}{\sum_{\phi_i=\phi w-\theta}^{\phi w+\theta} cos^{n}\,(\Phi_i - \Phi_w)} \qquad [7]$$

where, $F_{e,w}$ is the length of the effective fetch for a direction φ_w;

F_i is the length of the geografic for the direction i-esima φ_i;

φ_w is the average direction (referred to cartgraphic North) from where winds are originated;

$\varphi_w - \theta < \varphi_i < \varphi_w + \theta$ is the direction i-esima (referred to cartgraphic North) inherent to a sector with 2θ considered around the direction φ_w (the Saville's method uses a value of 45°);

n is the exponential term defined after the law of directional distribution of waves' spectrum that characterize the site (equal to 2 or 3 for the Mediterranean area).

These kinds of waves have a characteristically small wavelength when they are formed by winds' action. Once they are distant enough from the forming of winds, and they do not feel their effects anymore, they move toward the coast modifying their wavelengths and period (Figure 2.4) and assume the characteristics of a long period waves, known as *swell.*

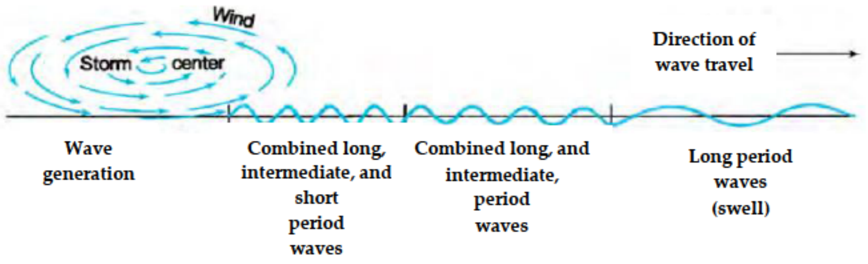


Figure 2.4 Waves propagation and periods; image modified from www.people.ucsc.edu.

Changes on the transverse profiles of the seabed in coastal waters is determined by the waves' characteristics, by the swell waves' persistence, or by the occurring of *seas* or wind waves, that, conversely, have a short period.

During breaking, waves change their shapes and physical characteristics. Once they feel the seabed (Figure 2.3) the orbits become ellipticals, while wavelength and period decrease together with speed. It is important here to understand the differences between swell and seas, and most of all on the effects they have on the beaches' profiles. Swells hit the shore with a long frequency up-rush; between two waves the timespan is long enough to let the beach drain and be permeate again by the consecutive wave. Under these conditions the backwash has reduced speed and consequently the sediment transported in suspension on the shore will sediment. Usually these waves cause an increasing of the beach, with dimensions dependent on the sediment quantity transported by the waves. Continuous swells' action generally steeps the offshore zone where swells take charge of the sediments and compacts the increased beach.

Conversely, seas are very disorganized and with a high frequency. They spill big quantities of water on the beach within a small timespan; under these conditions the beach will be suddenly saturated, the backwash will take in charge of the sediments from the beach, and the big amount of water will wash it seaward. Thus, sediments will be suspended until the water velocity decreases letting it to sediment. A series of bars will be formed out of the closure depth, and an erosion of the submerged beach -breaker zone - will result consequently.

The biggest variations of the beach's profile are seasonal (winter-summer) and takes place from the dunes to the closure depth. (Figure 2.5). Respectively, during the winter -when seas prevail - the beach will show a *bars profile*; during the summer, the swells will increase the beach extension seaward, by drawing a berm profile (Bascom, 1964; Shepard and Inman, 1950; Wright and Thom, 2016). These seasonal variations are crucial for instance to design coastal structures to evaluate safety distance.

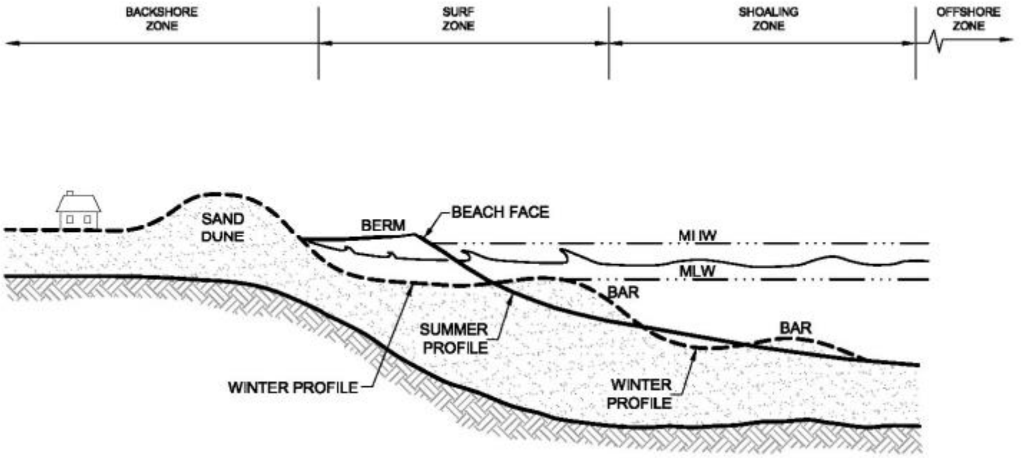


Figure 2.5 Summer and Winter profiles of a typical Pacific Coast, modified from Bascom, 1964. Image source www.fema.gov.

Nowadays, the determination of the sea state from the wind is still carried out even if datasets, obtained by buoys' measurements, to be statistically usable must register a sufficient time span of at least 30 years. A different approach consists in modelling the wave spectrum. It considers a measure record, that is reproduced as the sum of many harmonic wave components. This method allows the description of the sea surface as a stochastic process. The flux of energy carried to the shore can be calculated per each unit of the wave, together with waves' parameters. This energy feeds *Coastal dynamics* causing *longshore* and *cross-shore* sediment transport. The first one arises from longshore currents acting in the littoral zone and triggered by waves; cross-shore from the other side is mainly influenced by approaching waves and water elevations (Kassas, 2004).

These processes of sediment transport and a set-up of the mean water level starts once waves enter the surf zone, and later break. Waves' motion is strongly affected by both, submarine topography and shoreline's stabilization structures.

The variations in wavelengh and waveheight that occurs when a wave interacts with a changing submerged topography during its propagation toward the coast is known as *Shoaling*. Indeed, when the isobathes tend to be rectilinear and parallel, and the waves' motion is orthogonal to the coastline, they will keep a bidimensional shape, and they will be defined as *long-crested*. Shoaling phenomenon highlights that wave's parameters vary due to the depth variations. It develops through the conservation of the average flux of energy per width unit of the wave's crest, from an infinitive depth to a generic depth (Figure 2.6).

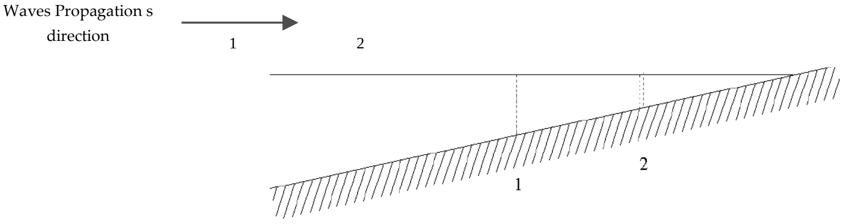


Figure 2.6 Simplified explanation of Shoaling; image source from Prof. Pugliese Carratelli.

In Figure 2.6 we can imagine that a wave propagates from deep to shallow waters, where the seabed becomes steep; even if waveheight variates, period does not. If we consider a volume imposed by the two vertical planes perpendicular to the direction of wave's propagation, in the absence of dissipation, the average energy flux in the time unit (average power = *pressure* x *area*x *velocity*) that crosses the section 1-1, might be equal to the one that passes through the section 2-2. Basically, seabed causes the reduction of the wavelength, the change of waves' crests direction, and the dissipation of energy through the friction on the seabed, and the breaking.

To easyly explain the wave's tranformation phenomena during propagation, the sin wave (harmonic wave) is defined through its *amplitude* (a = H/2), the *radian frequency* ω = 2π/T, and the *wave number* k = 2π/L. (Dean and Dalrymple, 1991; Holthuijsen, 2007; Kassas, 2004).

A harmonic wave's propagation (in fuction of time t, and space x) can be expressed in terms of wavelenght, height and period as:

$$\eta\ (x, t) = H/2\ sin\ (2\pi/T\ t - 2\pi/L\ x) \qquad [8]$$

Following the same authors, the propagation expressed in terms of amplitude (Figure 2.7) results even more comprehensive in order to explain transformation phenomenae during propagation, as:

$$\eta\ (x, t) = a\ sin\ (\omega t - kx) \qquad [9]$$

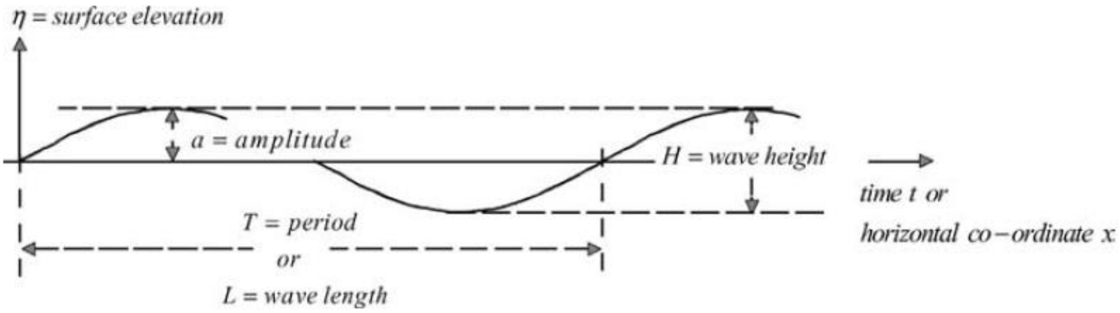


Figure 2.7 Sine wave from Holthuijsen, 2007.

Sine and cosine differ in the phase of 90°; the *phase* of a periodic function represents the timespan elapsed between the two moments of the motion, and is given as an angular measure.
It represents the angle, that vary in time, associated to the harmonic motion, or the propagation of the Airy/Stokes' wave.

The speed through which the phase propagates is termed *phase velocity*, that can be imagined as the speed of the wave's crest. Once the phase velocity changes a *Refraction* occurs.
In particular, when the depth decreases, the resulting wave's train will decrease its celerity on the fronts side, while the ones in the back positions of the wave's front will preserve the initial celerity. It will cause the orienteering of the wave's fronts that will align to the isobathes, and wave heights modifications as consequence of energy's flux conservancy. This is a phenomenon that depends only on the depth, that in shallow waters decreases (Coastal Engineering Research Center, 1984; Dean and Dalrymple, 1991). The concept of shallow waters here is relative, since it is based on the ratio between wavelength and depth. For instance a *tsunami* has a wavelength greater than 20 Km, hence a 1 Km depth in this case can be considered shallow.
The crucial difference between deep and shallow waters is that in the first case the depth is greater than the half wavelength (d>L/2), while in shallow waters depth is smaller (d<L/2).
Refracted waves' direction can be calculated through the Snel's law, if we consider parallel depth contours, as

$$\frac{d}{dn}\left(\frac{\sin\theta}{c}\right) = 0 \quad \Rightarrow \quad \frac{\sin\theta}{c} = constant \qquad [10]$$

where the angle of propagation θ is taken between the ray and the normal to the depth contour as shown in Figure 2.8, from Holthuijsen, 2007.

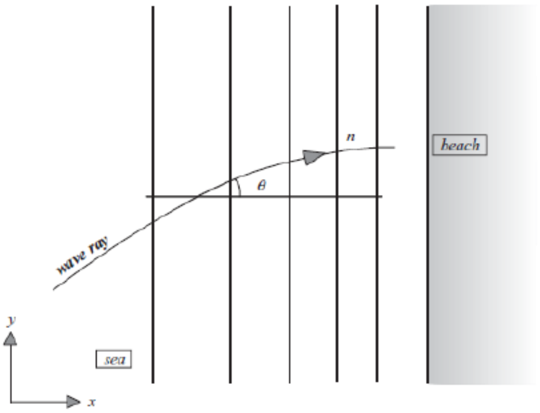


Figure 2.8 Schematic representation of Snel's law, and ideal representation of the angle θ, from Holthuijsen, 2007.

In the next figure (Figure 2.9) a bay with regular and almost linear isobathes is considered in the sub-plot A; waves' refraction is shown in the sub-plot B, where the waves are re-oriented and their energy displaced in all directions during the motion toward the coast. The spacing between waves crests axis indicates the energetic distribution, that in this case is omogenous in all the sectors.

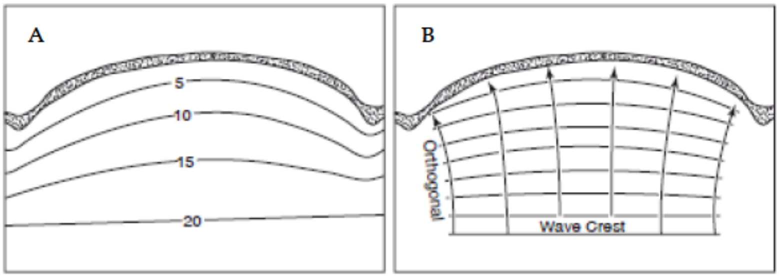


Figure 2.9 Refraction of waves in a bay, modified from Bird, 2008; (A) isobaths in a bay; (B) energy distribution in a bay during refraction, where the waves' crests are drawn as orthogonal to the coastline, through black arrows.

When waves move over through (Figure 2.10), the crests' axis converge, and orientate ortogonally to the promontories. Differently from the case in Figure 2.9, the waves' crests are more distant in the center of the sketch map while converging in the lateral portions. The energy is dissipated better in front of the bay, where the refraction index decreases (0.5) and a curved beach being formed. This fact explains the forming of the behaviour of larger wave heights, as well as the reason why headlands tend to be dismantled (APAT, 2007; Bird, 2008; Finkl, 2004; Paganelli et al., 2014; Pranzini, 2004; Van Rijn, 2011).

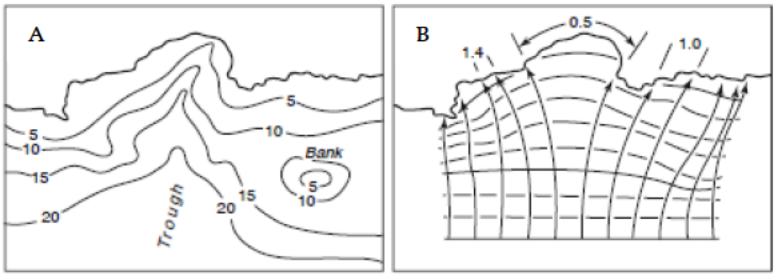


Figure 2.10 Refraction of waves over a through, modified from Bird, 2008; (A) isobaths show different slopes and evolution; (B) energy distribution during refraction, where the numbers indicate the refraction index.

Further wave's transformation phenomenae during propagation are *Diffraction and Reflection.* They are of particular interest where coastal structures are present, either on the shoreline or in the nearshore zone (Bird, 2008). Indeed, these two

Reflection is a common wave's transformation that occur to high coasts or in front of vertical coastal structures, such as seawalls. From a planimetric point of view, the sine wave of Airy follows the rules of the optical geometry. Hence, the reflection angle (θr) of the propagation vector is equal to the incidence angle (θi) as is briefly shown in the Figure 2.11.

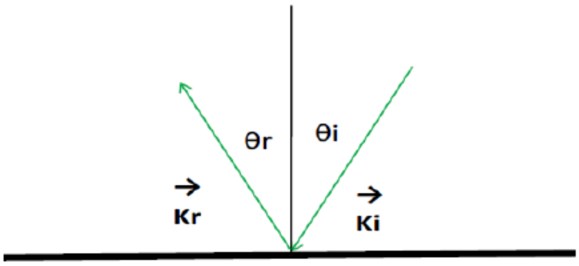


Figure 2.11 Reflection angles and coefficient

But reflection is not total since the wave height of the reflected wave (Hr) is always smaller than the incident one (Hi); from these assumptions we can define a *Reflection coefficient Kr*, as:

$$Hr = Hi\ x\ Kr \qquad [11]$$

For instance, a totally reflective structure, such as a vertical wall, theoretically has $Kr = 1$, while a beach with a small slope has a Kr almost equal to zero, since it strongly dissipates energy.

The descriptions we did previously are acceptable if we think that the variations of the seabed and the wave neighbors are gradual. But, once these conditions drastically change in the vicinity of the waves (the distance unit is the wavelength), the description of the wave's transformation cannot be done using the concepts of ray's propagation as we did above.
Diffraction is the effect for which waves are modified by an obstacle, and results as the energy spreading by waves in sheltered areas. In this case there is not a precise direction of propagation, thus, waveheight does not evolve gradually along a wave's ray, and the phenomenon is totally bidimensional. In fact, if waves would keep moving along a ray, in the downdrift zone of a groyne a complete calm zone would be produced, while in the neighboring areas waves would not

change shape nor height. It is a crucial parameter to define during the designing of harbors and basins, and is calculated through the *wave's function*, that represents a "local waveheight"in each point (x,y). It is an elliptic equation where the neighbors conditions are represented by the sea state parameters in the area and water height can be written as:

$$\eta = a.\ f(x,y)\ \cos\ (kx - \sigma\ + \psi) \qquad [12]$$

where, $f(x,y)$ is the wave function that describes the variation on the horizontal plan of η, in respect to the calm sea level;
a is the amplitude (for instance H/2),
kx is the wave number
σ is the frequency
ψ is the phase

After a waves' transformation that occurs during the propagation, waves break on the beaches; interacting with the sedimentary matrices on the seabed where they transform sedimentary deposits in stable morphologies with the hydrodynamic conditions they dictate.
As we understood, approaching shallow waters the waves decrease their velocity, period, and length, but conversely their heights and steepness increase. The waves' shape change, and crests become narrow and sharp, while troughs become flat and wide. This phenomenon continues until even elliptical orbital within waves, described with the Figure 2.3, cannot complete their motion. Velocities' particles near the crests becomes higher than wave celerity, and energy is dissipated through turbulence on the wave surface first, and later by breaking (Battjes, 1974; Bird, 2008; Galvin, 1968). Hence, the surf zone first and then the shore will be attacked by a *swash or uprush* of water that after dissipates its final energy will return to flow seaward in a *backwash.*
The breaking dynamics and type change depending on the wave's parameters, as well as on the nearshore gradient. Four types of breaking have been defined, such as *Spilling, Plunging, Collapsing* and *Surging* (Figure 2.13). Through the aforementioned parameters of the *surf similarity parameter* ξ_0, also known as *Iribarren number,* can be calculated to classify wave breaking (Iribarren Cavanilles and Casto Nogales, 1949; Battjes, 1974; Peregrine, 1983; USACE, 2003), as:

$$\xi_0 = \frac{\tan\alpha}{\sqrt{\frac{H}{L_0}}} \qquad [13]$$

where α is the slope angle (or nearshore gradient (Bird, 2008))
H is the wave height
L_0 is the deep-water wavelength.

In the Figure 2.12 the four types of breaking are described following the Iribarren number.
In particular, *Spilling breakers* present a $\xi_0 < 0.5$, and are peculiar of short and high waves that propagate over a flat shoreface. As shown in the expel of Figure 2.12 waves have foamy crests due to the air bubbles that are incorporated during the crests spilling. A further peculiarity of

these waves is the shape that they preserve during the breaking, that is just affected by the wave height reduction (USACE, 2003; Bird, 2008; Davidson-Arnott and G.D, 2010).

Plunging breakers have ξ_0 comprised between 0.5 and 2.5, that is usually attributed to moderately sloping shoreface and moderate waves. Similar to spilling, they incorporate air producing foamy crests, but conversely, the crests rapidly assume a water jet shape that literally twists forward, plunging into the wave body and generating big splash and vortices. The consequence is a drastic energy loss of the wave after splash, that even if it is not so erosive, it still produces a strong backwash (Bird, 2008; Davidson-Arnott and G.D, 2010; Mangor et al., 2017; Peregrine, 1983).

Collapsing breakers are not usually well considered since they represent a transition type between plunging and surging. ξ_0 is comprised between 2.5 and 3.7 that can be usually met where low steep waves break on a steep slope. Collapsing breakers subside as they move toward the shore and are still debated within the scientific community since they are a "describable" transformation between two extremes. They appear vertical, having peaked crests that show a similar tendency to plunge, but finally they dissipate energy reaching the shore as thin water layers (Sunamura and Okazaki, 1996).

In fact, the other extreme is represented by *Surging breakers* that have a $\xi_0 > 3.7$, that characterizes a smooth wave's shape without a defined crest. Usually, low steepness and swell break onto steep slopes. Even in this case, foamy crests will be produced by air bubbles incorporated during the crests' agitation. However, the wave will spend a huge amount of energy to "climb" the shoreface that in these cases could be constituted by hard bottoms, steep slopes, or even be a very reflective shoreline that dissipates energy (Mangor et al., 2017; USACE, 2003).

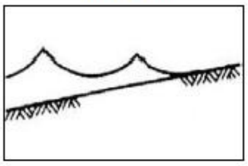
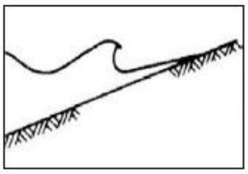
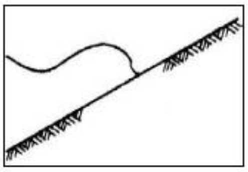
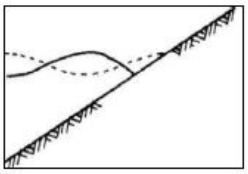
Type	Diagram	Example	Description
Spilling $\xi_0 < 0.5$			-Wave crest becomes unstable and spills down while introducing air bubbles inside. -Characteristic foamy water. -High-steepness waves over mild slopes.
Plunging $0.5 < \xi_0 < 2.5$			-Wave shoreward face becomes first vertical, curls over and finally plunges into the water ahead. -Air can be trapped inside the curl. -Medium steepness waves over intermediate slopes.
Collapsing $2.5 < \xi_0 < 3.7$			-Wave crest becomes vertical, until the base collapses arriving to the shoreline as a thin water layer. -Low steepness waves over steep slopes.
Surging $\xi_0 > 3.7$			-Wave crest remains unbroken, and the wave arrives to the shoreline with small shape changes. -Low steepness waves over very steep slopes.

Figure 2.12 Wave breaking type after Hedges, 2003 (Roca Barceló, 2014).

These concepts are usefull since we need to know the waves' tranformation and the energy dissipation on the shore; even on the eventual defense structures, that nowadays occupy shorelines wordwide, the waves' effects consider the same wave's transormation and physical modelling.

In general, for the purpose of our study, it is important to know that surging, spilling and collapsing breakers produce strong onshore flows, commonly named *wave swash* or *uprush,* followed by *backwash or downrush*. For these three cases of breakers these dynamic results in feeder currents that apport sediment to the shore. In atural conditions this is a good prospective for increasing shorelines. On the other hand, plunging breakers' behaviour is completely opposite, since a short swash and a stronger backwash result in cross shore transport seaward.

A further hydrodynamic process in the surf zone is the *wave set-up,* or the mean water level elevation caused by wave height reduction. It can be cosidered as 20 % of offshore *Hs,* an is of crucial importance since its gradient has to be known to obtain the circulation of waves in sheltered areas such as harbors (Mangor et al., 2017).

Types of breakers are of course calculable and already observed types of transformation that depend of several factors; according with Bird 2008 they can be summarized as:

- Local winds
- Changes in nearshore water depth accompanying the rise and fall of tides or other short term sea level changes
- Currents
- The gradient and topography of the sea floor.
- The configuration of the coastline

These factors determine the *morphodynamic state of the beach,* used to describe the regimes of variations in the relative dominance of near bottom surrents' motions (Wright and Short, 1984). Six states have been recognized (Figure 2.13) after Wright and Short, 1984 by other authors such as Anfuso 2001, and Aagaard et al., 2013. They aimed to investigate respectively, on the behaviour of surf zones after artificial nourishment, and on the processes transporting sediment rates and driving beach morphology from one state to another.

Morphodynamic states are Reflective, Dissipative and Intermediate, with the latter that is composed of 4 types (Anfuso et al., 2001; Wright and Short, 1984). The first two states are extremes, while Intermediate are mixed states between these two.

A state comprehends the depositional forms, and wind waves' energy that is transferred to the surf zones, or hydrodynamics. This process changes the fluid motion's properties, creating dissipative and reflective regimes, and different morphologies. Wright and Short defined four modes of motion that if combined with the morphologies and processes allows us to define the six states:

1. *oscillatory flows* is dominated by waves, thus sediment motion consists of agitating oscillations, and the frequency band that characterize this mode is the same as the deep-water incident waves.

2. *quasi-oscillatory flows* where the wave' regime is composed of standing waves and edge waves. Their frequencies are lower than incident wave frequency, and they can be furher distinguished in *subharmonic edge waves* -with a period that is twice the incident ones- *long-period infragravity* with periods on the order of 1 to 3 min, and *higher frequency infragravity* motions at periods of 30--50 s.
3. *net circulations* generated by wave energy dissipation, that mainly produce longshore currents, rip currents and rip "feeder" currents.
4. *non-wave generated currents*, as tidal currents and currents generated by local wind shear

The models described the drive of sediment transport (steady currents), the onshore transport (oscillatory flows and infragravity wave frequencies), as well as the cross-shore. Balance between oscillatory and steady currents is crucial since they determine whether a beach is eroding, or accreting (Aagaard et al., 2013).
Dissipative and Reflective are considered respectively flat, shallow beaches with relatively large subaqueous sand storage, and steep beaches with small subaqueous sand storage.
In both cases the changes in the morphologies are weak since they present a small transport rate and cross-shore. To distinguish Morphodynamics states, the Surf-Scaling Parameter can be calculated by the Equation 14 (Guza and Inman, 1975):

$$\Omega = a_b\,\omega/(g\tan^2\beta) \qquad [14]$$

where a_b is breaker amplitude,
ω is incident wave radian frequency (2π/T; T = period),
g is acceleration of gravity and
β is beach/surf zone gradient.

Basically, *Reflective states* have Ω between 1 (complete reflection) and 2.5. With these values, waves surge or collapse directly on the shoreface through runup. The net sediment transport is very weak, and these beaches present a narrow surf zone, or even it does not exist at all, as well as bars. These beaches are usually made of coarse material especially at the step where the wave plunges; the higher the wave heights, the higher the slope is. They are considered representative of summer profile shapes, with peculiar morphologies such as the cuspate swash zone, and a high crested berm during low energy regimes (Wright and Short, 1984).

Dissipative states occur when $\Omega > 2.5$; energy is dissipated through plunging waves, that transform in a spilling breaking once $\Omega > 20$. In these beaches incident wave energy increases with increasing Ω, and the surf zone assumes a wide shape with gentle slope. Transport occurs mainly offshore, while seaward it can be dominant with just a local increasing of the wave's height.
Low gradients are peculiar, since these surf zones are mainly made of fine sands, and present multibar systems (Aagaard et al., 2013; Aagaard and Masselink, 1999).

Intermediate states are characterized from a very variate Surf-Scaling Parameter along the profiles. States are distinguished as *longshore bar-trough state (LBT), rhythmic bar and beach state (RBT), transverse bar and rip (TBR), ridge runnel low tide terrace (LTT).*

In general, Intermediate states are composed of large cross-shore transport gradients, and alongshore ones. Shapes of the deposits here vary drastically because of this dynamic status; it is testified by the high rates of sediment transport made by subharmonic and infragravity standing waves, that also causes rips and feeder currents.

Cross-shore transport is an important parameter to know, especially in urban contexts; coastal defenses and management strategies that can change the contours elements on the dry and emerged beaches. Even if morphologies, and littoral currents are modified through coastal designs, the sea states and wave's characteristics will be naturally generated, thus they will set with the new physical conditions "looking" for a new equilibrium. In Figure 2.13 Aagaard et al. summarized the main states, stressing on the sediment transport rates and direction, together with the agitation level of the seabed, giving an idea of the morphodynamics in the main states.

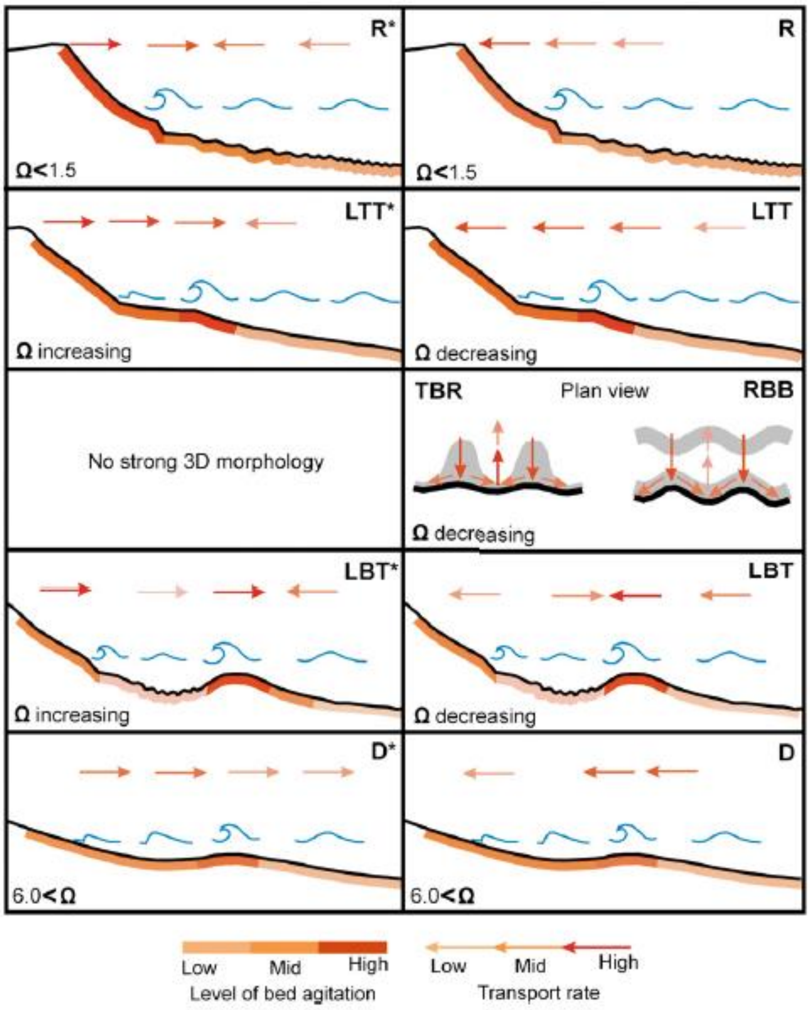


Figure 2.13 Beach state model from Aagaard et al., 2013; Ω is the Surf-Scaling Parameter, while sediment stirring and net sediment transport are respectively explain by the color intensity bar, and the color intensity arrows. The states are representative of Reflective ones (R, R*), Dissipative (D,D*) and Intermediate low-tide

terrace (LTT and LTT*), transverse-bar and rip (TBR), rhythmic-bar and beach (RBB), longshore-bar and through (LBT and LBT*).

An example is given in Figure 2.14, where peculiar structures of beaches's deposits are described for a barrier island case. Stratifications and sedimentological features are the results of characteristic morphodynamics. For instance, the *Breaker zone* is comprised in the littoral one; within it longshore currents form a system of bars generally made of coarser material. Bars are confined seaward and landward by two slopes that respectively enter the *Shoaling* and *Surf* zones. These further zones can be individuated on the basis of the waves' dynamics and their grade of interaction with the seabed. In the following figure youcan observe how the stratifications respect the direction of flux, that is bivariate on the beachface from registering the two wave directions (ascending flux to the shore and dropping one seaward).

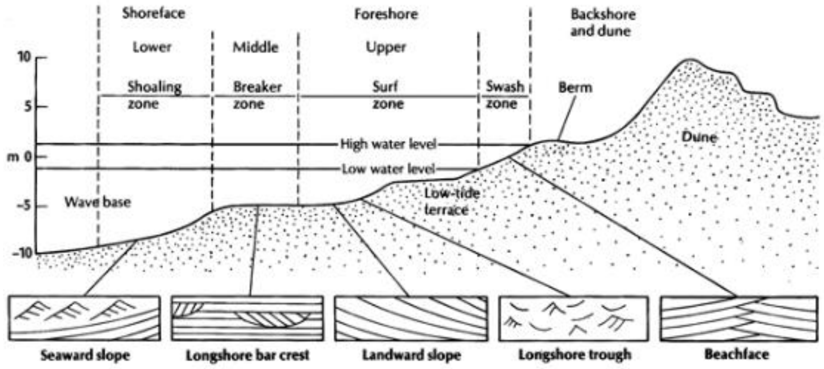


Figure 2.14 Schematic beach's profile showing the main components of the seaward facing barrier island (Prothero, 1990).

The morphodynamics states approach, that we explained in pills, was proposed during the '80s as a method to also understand the ecological aspects related to morphodynamics (McLachlan and Erasmus, 1983). Nowadays, it represents a better-known proceeding used to categorize morphodynamics states integrating also ecological features, related issues, and some management considerations (Table 3). Considering breaker wave height and mean spring tide range, three beach types were classified, such as wave dominated (WD), tide modified (TM) and tide dominated (TD); later seven morphodynamics states were inferred (McLachlan et al., 2018).

Type-state & environment	Morphology	Dynamics	Ecology	Management
WD Reflective Sea & swell Usually microtidal (Not developed where sand is exceptionally fine; coarse sand & cobble beaches can remain reflective even under large waves)	Medium-coarse sand, steep beach face usually with cusps &/or berm No reduced layers Possible wide landward sloping backshore Limited, stable (well vegetated) foredune	Waves surge up beach face No surf zones Swash zone turbulent with strong uprush & backwash matching wave period	Impoverished macrofauna but rich interstitial fauna because of filtration of large volumes of sea water by wave action Stable backshore suitable for supralittoral fauna; as well for turtle nesting	Steep beach gradient, surging waves & deep water immediately seaward. Stable backshore may house nesting birds and turtles. Suitable for backshore recreation on berm as dunes stable. The beach surge/break is strong under larger waves
	Rhythmic longshore with alternating bars			

WD Intermediate Sea & swell Usually microtidal (Unlikely to develop where tides >3 m)	& rips & changing beach face slope Sand variable but usually fine-medium No reduced layers Usually well-developed foredunes & may have transgressive dunes	Moderate to heavy plunging wave action on bar; surf zone always present Swash zone wider with longer period swash, longer uprush & backwash, & less turbulence.	Variable macrofauna in surf zone & beach, rich interstitial fauna Moderate volumes of water filtered, driven by waves & to some extent tides	Rip currents & deep channels, cause of many beach rescues & drowning. Highly dynamic and continuously changing morphology. Suitable for backshore recreation but dunes may be sensitive.
WD Dissipative Sea & swell Usually microtidal	Fine sand May be reduced layers in deeper sediment Flat beach with narrow backshore & potentially extensive dune	Heavy wave action (sea & swell with multiple lines of spilling breakers) Wide surf zone (100 s m). Wave bores (rather than wave swash) move up & down the swash zone, with long swash periods (~30-40 s)	Surf diatoms present Rich macrofauna in surf & beach; moderate interstitial fauna. Low filtered volumes, primarily driven by tides, but wave pumping significant, especially in the surf zone	High energy beach with pronounced set-up & set-down can be hazardous. Large swashes & bores during storms will erode dunes. May support clam (& other) fisheries. Not suitable for backshore recreation or swimming .
TM reflective Sea & swell; usually mesotidal, not macrotidal	Coarser sand, steep HT beach face, with sharp break at base extending to wide intertidal low tide terrace. Reduced layers possible on lower shore	Surging waves & turbulent swash on HT beach; spilling breakers across continuous low tide terrace	Stable back shore Variable but likely poor macrofauna. Filtration of fair volumes on upper shore, so rich interstitial fauna there.	Suitable for backshore recreation & swimming under normal low waves
TM intermediate Sea & swell Tides >2 m (Long periods of inactivity between storms in sea environments)	Steeper HT beach with coarser sand, abrupt break to low gradient wide intertidal usually of finer sand. Reduced layers possible on lower shore. Bars, troughs & rips in LT surf zone	Surging waves on steeper upper beach during HT, spilling waves across, wide intertidal zone during mid-low tide Moderate to long swash periods Intermediate LT surf zone	May have surf diatoms; Rich macrofauna & variable interstitial fauna Low filtered volumes driven by tides & waves, also subtidal pumping	Rip currents in LT surf distant from HT beach & potentially hazardous. Suitable for recreation, both on backshore & intertidal, with rip currents & variable topography an issue in the LT surf zone.
TM ultradissipative Sea & swell Usually occurs under large tides (at least mesotidal)	Steeper HT beach with medium sand, lower shore usually of fine sand. Narrower HT beach grading to wide (100 s m) low gradient intertidal may be featureless or contains low ridges & runnels Reduced layers may be present but well below surface	Continuous wave action (swell more likely than sea) with spilling breakers across a wide low-gradient surf zone with multiple breakers Long swash periods Wide beach & dissipative surf zone	Biologically rich with surf diatoms, rich macrofauna & variable interstitial fauna. Low filtered volumes driven mainly by tides across the intertidal & by wave pumping subtidally	Productive & may support fisheries. Generally suitable for recreation, both on backshore & intertidal under normal conditions, with potential for rips in surf zone
TD flats Sea only		Low spilling breakers during limited periods of	Rich macrofauna; interstitial fauna	Poorly developed HT beach above very wide tidal flats,

Limited wave action between long periods of calms Large tides (at least mesotidal) Extremely low waves («0.5 m)	HT beach narrow & of coarser material with sharp break at base Inactive except during brief periods of wave action Very wide (100 s m) sand/mud flats Reduced layers near surface	wave action. Very small swash zone Range from higher energy ridged sand flats to mud flats (true tidal flats are similar but with no beach)	restricted to surface layers Subtidal seagrass meadows may be present on lower shore	which may have tidal drainage channels or be muddy, both of which are hazardous. Generally, not suitable for recreation. People can be trapped on tidal ridges by rising tide & cut-off from shore

Table 3 Characteristics of the seven types-states of sandy beaches identified by McLachlan et al., 2018.

Every state in this way would clarify the ecologic implications enough with the morphodynamics and with the expected management and environmental issues that managers should take care of. It can be observed in the last column of the Table 3 that different sources of impacts can arise from an initial or even deep integration on the ecologic features.

In our study, as we already said, different matrices should be computed to have a complete overview on a so complex matter of study. The morphodynamic characterization of beaches as proposed by MacLachlan links different stages of assessments, and permits us to qunatify potential impact considering ecology, waves and sediment transport interesting beaches' sedimentary stocks.

The sedimentary stock provides space for ecosystems development, as well for the building of services and human's benefits. For these reasons, it represents the most important component of the coastal system to preserve in order to support coastal dynamics exploitation, as well as maintaining the resilience potential of coasts (Bhamra et al., 2011; Coastal and Environmental Research Committee and Southeastern Universities Research Association, 2015; García-Ayllón, 2017; Klein et al., 2011, 1999, 1998; Raymond, et al., 2017). Through the Brunn's rule the sedimentary stock, or space needed to accommodate nearshore processes is calculated as the area of the nearshore zone times the annual rate of relative sea level rise (Brunn, 1962).

Basically, sedimentary sources are rivers that discharge material through deltaic systems, while high coasts' beaches are nourished directly by the desmantling of the cliffs (Finkl, 2004; Short, 2012). As we saw before, once the sediment enters within the coastal system it will be envolved in the coastal dynamics. Sedimentary processes will be originated with magnitudes and sedimentary products gouverned by the hydrodynamics of the site (waves energy, longshore and cross- shore courrents), and the dimension of the sediments.

In the Coastal Geomorphology, a coast is usually sectorized through basic units with same coastal dynamics, that are named *littoral cells* (Aiello et al., 1976; Bray et al., 1995; Anfuso et al., 2013; Anfuso, 2011; Pranzini, 2018), as represented in Figure 2.15 B.

They can be distinguished between *morphological* and *littoral cells* (Bray et al., 1995; Carter, 2013). The first group comprises portions of the coast limited laterally by fixed and stable limits to a large temporal scale; even if these limits change their position in association with wave's regime that are considered fixed, as happens to natural and human made structures (for instance rocky cliffs and harbors). In the case of littoral cells, the lateral limits change their position in time because of divergence and convergence processes caused by submerged features and approaching waves.

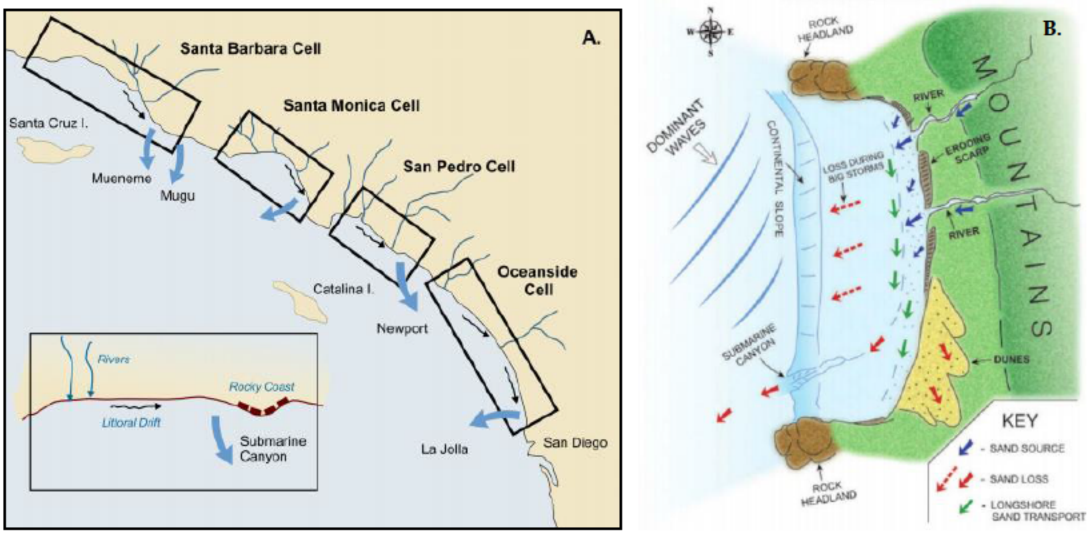


Figure 2.15 (A) Example of categorization into littoral drift cells on the California Coast (Bowen and Inman, 1966; Komar and Inman, 1970); (B) Simplified schematic sketch map of a littoral cell (Douglas, 2016).

Limits can be *divergent* if the drift of the longshore currents have two opposite components, while they are named *convergen*t when littoral drift converges (Figure 2.16). A further class comprises the *pulse* limits, that are peculiar of accumulation to one side of the limit, and erosion to the other side; *absolute* limits act as barrier to sediments, *permeable* ones allow it to pass (Anfuso, 2011; Lowry and Carter, 1982). The same authors suggest to further divide cells in sub-cells that can be made by human made structures interfering with natural sediment transport within major cells (Bray et al., 1995), even if human made structures can also form major ones (Anfuso and Martínez Del Pozo, 2009). Through the analysis of the limits' feedback, hard structures such as the harbors resulted very invasive of the longshore regimes since they control the sedimentologic migration of the sediments. Structures, as well as waves and bathymetric conditions affect the drift of longshore currents; their component becomes unidirectional, and only fine sediment can be transported, since structures intercepting the shoreline interrupt the supply of coarse sediment to the areas downdrift (Bray, 1997; Runyan and Griggs, 2003).

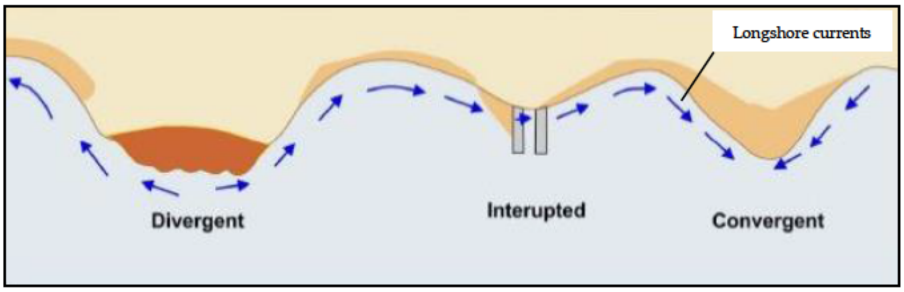


Figure 2.16 Types of limits, after Bowen and Inman, 1966; Komar and Inman, 1970.

Submarine canyons have a key role since they also represent some abrupt morphological limits that avoid the bypassing of sediment to the next cells downdrift, and a phenomena of an irreversible nature, since sediments that are trapped in canyons will never go back to the original system (Van Rijn, 2011). This introduces the concept of *Physiographic Unit* (PU), or *sediment cell*, as a portion of the coast in which the displacement of sedimentary materials is confined within its boundaries (Bruschi et al., 2008; Corsini et al., 2008). Even when the coastal zone is characterized by uniform geological features, natural or artificial limits, a PU is considered as a closed area with a cycle of sedimentation that includes sources, transport and sinks of a balanced sedimentary budget (Figure 2.17).

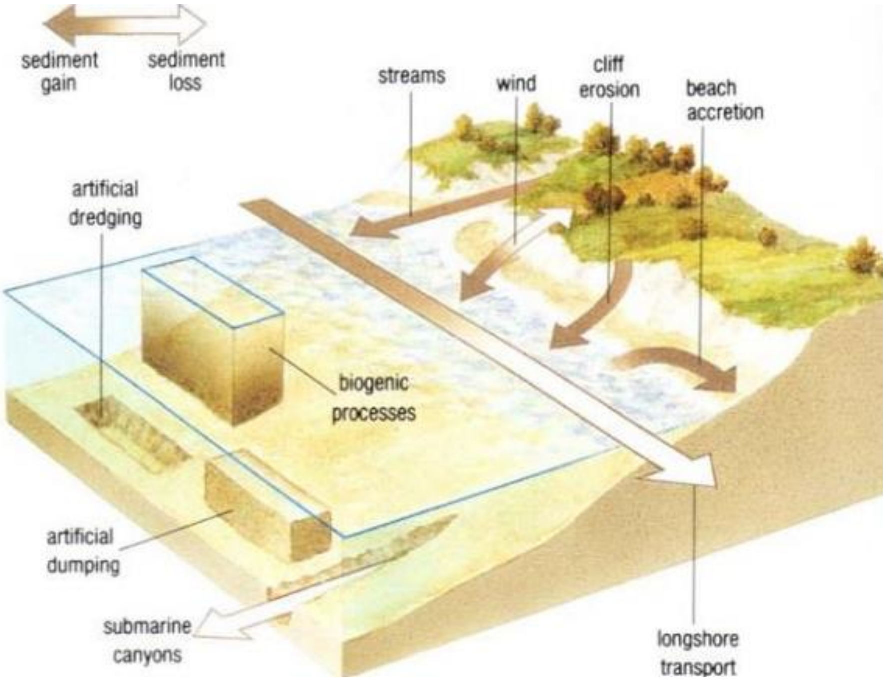


Figure 2.17 Main processes and sedimentary exchanges within a littoral cell (The Open University, 1999).

Canyons often delimitate PUs' extensions, representing hard faceable issues for sedimentary stock management. In fact, they attract sediments to greater depths, out of the longshore currents' actions, as well as avoiding cross-shore exchanges to the nearshore. Moreover, limits of a PU cannot be considered stable over time since they result from the interaction between structures, natural events and coastal dynamics; these features are extremely variable (Bruschi et al., 2008). Within an ideal PU, the sedimentary material is mainly distributed by rivers and littoral courrents, even if other mediums, such as wind, biogenic and anthropic processes involve it. Wind in fact classes eolian sands to build dunes, and even to remove these sands out of the coastal borders. Similarly, biogenic processes and anthropogenic modify and re use it in several ways.

The link between resilience potential and sedimentary stock is the aspect that we have taken as primary key in the assessment phases, as well as in the management solution proposed. Within the present work, quantitative and qualitative information were extracted from both, the field observations, and digital supports, such as official cartography and satellite images. Even the technique to quantify changes was chosen after testing and comparisons of scientific and normative guidelines. An integrated methodology is presented to face the different stages of CEM, and to finally quantify the potential of resilience of beaches and the risk derived.

At the present day, modelling risk becomes a very articulated operation. Natural hazards, in general, give us a new perspective to the natural resources' depletion. Unfortunately, the risk and its component are affected by the singular perception of each individual, since an anthropocentric perspective rules the degree of these parameters.

In the next few paragraphs, risk, hazard and disaster were defined since their use is very popular and also subjective (Burton et al., 1968; White, 1974); very often they are intended as synonymous, just as much often they are used to express different concepts.

In order to do this, we need to introduce the *event.* It is described as a perturbation in a geophysical system displaying relatively high variance from the mean (White, 1974). If events are rarer than the 10th or 90th percentile within their statistical reference distribution at a particular place, they are called *Extreme Climate Event*s (IPCC, 2001). When they occur in regions occupied by humans, requiring some degree of response by them to reduce their negative impacts, they originate the *Hazard* (Burton et al., 1968).

2.2 Hazard, Risk and Disasters

Hazard can be associated to natural and anthropogenic factors, that may cause health impacts, loss of life, damage of property, socio-economic and environmental resources (Cutter et al., 2009; ISO/IEC, 2009; Smith, 1996; UNISDR, 2009). *Natural hazards* describe climate events with the potential to cause harm (Burton et al., 2004). Examples are geological, meteorological or hydrological hazards, that are "*described quantitatively by the likely frequency of occurrence of different intensities for different areas, as determined from historical data or scientific analysis*" (UNISDR, 2009). Some of them result from the sum of contributors to some of these processes, such as that of geological source. (i.e. earthquakes) that manifest as a coastal water-related hazard (i.e. tsunami) (UNISDR, 2009; Sleiko, 1993; Glade, 2003; Petrosino et al., 2004; Grezio et al., 2012). Physical parameters that characterize them were defined in Burton et. al 1968, such as:

- *Magnitude*, or the level through which events can be considered as extreme
- *Frequency, as* the number of occurrences of an event with a given magnitude
- *Duration, as* the length of time over which a hazardous event persists
- *Areal Extent*, or the space covered by the events
- *Speed of Onset*, as the length of time between the first appearance of an event and its peak
- *Spatial Dispersion,* as the pattern of distribution over the space in which its impacts can occur
- *Temporal spacing* as the sequencing of events, ranging along a continuum from random to periodic

Hazards can be further categorized into *Sudden onset hazards* and *Chronic hazard* (Cutter et al., 2009). The differences are the timescale of occurrence and the immediate/long term impact they produce; sudden onset hazards range for short time -from hours to weeks- as it happens for flooding and hurricanes, while chronic hazards are very slow onset events, such as drought or sea level rise .

UNISDR, 2009 also highlighted that most of the hazardous events today are increasing in frequency, and on many occasions, they occur in areas where environmental resources are overexploited and degraded. This is the example of landslides, flooding, and even coastal processes, that produce a *Socio-natural hazard.* Since they arise from geophysical and hydrometeorological events, they could be modelled and understood, but differently from natural hazards, the socio-natural ones can be reduced and avoided through wise management of land and environmental resources.

Coastal erosion can be caused by hydrometeorological hazards when it is due to natural events - such as, hydrological, oceanographic, coastal storm surges, etc.- but it is affected by human's actions, especially on a regional and local scale.

Once events become so disruptive to the functioning of a community or a society involving widespread human, material, economic or environmental losses and impacts which exceeds the ability of the affected community or society to cope using its own resources, they are defined *Disasters.* They result from the combination of the *Exposure* to a hazard, the conditions of *Vulnerability* that are present, and the insufficient capacity or measures to reduce or cope with the potential negative consequences. As well as hazards, their impacts may include loss of life, injury, mental and social well-being, damage to property, destruction of assets, loss of services, social and economic disruption and environmental degradation (UNISDR, 2009). They represent large scale events that overwhelm the local capacity to effectively respond to and recover from an event (National Research Council, 2006).

Both, disasters and hazards are caused by the interaction between society and a second matrix, such as natural systems, technologies, or within society itself (Cutter et al., 2009). People and their goods, that could be potentially hit by harmful events, are generically defined as exposed, and the *Exposure* gives us the quantitative risks associated with that hazard in the area of interest, if combined with the *Vulnerability*(UNISDR, 2009). The latter expresses the degree to which a system is susceptible to, or unable to cope with adverse effects of climate change, including climate variability and extremes (IPCC, 2001). A more complete definition on the Vulnerability's concept was provided by Cutter et al., 2009, as the susceptibility of a given population, system, or place to harm from exposure to the hazard and directly affects the ability to prepare for, respond to, and recover from hazards and disasters.

Consequently to these concepts, for the same authors the *Risk* may represent the likelihood of incurring harm, as well the probability that some type of injury or loss would result from the hazard event, or easily, the combination between vulnerability and exposure (Burton et al., 2004; Cutter et al., 2009; ISO/IEC, 2009; UNISDR, 2009). It is related to a future probability that a hazard would cause loss, while disasters are consequent to any events that caused uncontrolled damages that humans and the environment did not support. (Meur-Férec et al., 2008).

Within the risk context, consequences are intended as the potential loss of a resource by an event in a period of time, and under some harmful conditions. We must pay particular attention to the vulnerability to socio-natural hazards, such as coastal erosion, where vulnerability encompass the evaluation of different sources with different natures, hence different kinds of units exposed. Generically, Risk to geophysical hazards are calculated through notation proposed by UNESCO (UNESCO, 1972), such as:

$$R = H * E * V \qquad [15]$$

where H = hazard; E = exposure such as the number of people, properties and other elements that can be subject to damages and losses; V = vulnerability is the proportion of these elements that might be lost (Varnes et al., 1984; Totaro et al., 2020).

2.3 Climate Change and Coastal Erosion

Climate Change suddenly appears preponderant as a coastal erosion's driver. It refers to climatic changes that can be measured through comparisons with the means, or even the properties' variations of climatic regimes that in any case are observed for relatively long periods of time. Similar to coastal erosion it can be induced or due to natural or human made causes that perturbate and change composition of the atmosphere's and land use Even for climate change a related *vulnerability* exists since there are natural systems potentially susceptible to climate variability and extremes. It means that even a *climate related Risk* exists, and it arises from natural hazards and the susceptibility of the system considered (Burton et al., 2004; IPCC, 2001). A vulnerability conceptual model of calculation (VA) was proposed as one of the main findings of the World Coast Conference 1993, and later modified (RIKZ and IPCC, 1994; Rocha et al., 2020).
Climate change generates sea level rise (SLR) through thermal expansion and ice cap melting; nowadays these phenomena have been exacerbated by the greenhouse production globally, as well by some local effects due to anthropic activities.
The evidence on the SLR already exceeded the expectation forecasted for the present century (IPCC, 2007, 2014); these previsions agreed with a 90% confidence interval between 26 and 82 cm, but nowadays observations reveal that sea levels will increase up to 1 m by the end of this century.
Intergovernmental Panel on Climate Changes (IPCC)fixed an extended range of 0.5 to 1.4 m for 2100 compared to 1990 data decade (Cooper et al., 2008). Through these observations, the global-mean of SLR was considered as a range between 0.18 and 0.59 m by 2090–2099 (based on the 1980–1999 period). Trends are strongly affected by uncertainties due to the contribution of future emissions of greenhouse gases, future climate change, and ocean and ice sensitivity to the climate (Emery and Aubrey, 2012; IPCC, 2007). Indeed, SLR is the result of an articulated dynamism between land and oceanic processes that takes place on different scales, from local to global. The main reasons of global SLR after the II IPCC are reported in Table 4, and consider the observed data from 1910 to 1990 (Bijlsma et al., 1995, 1995; RIKZ and IPCC, 1994; Church et al., 2001).

Source	**Minimum** (mm/yr)	**Central value (mm/yr)**	**Maximum (mm/yr)**
Thermal expansion	0.3	0.5	0.7
Glaciers/ ice cap melting	0.2	0.3	0.4
Greenland 20th century effects	0.0	0.05	0.1
Antarctica 20th century effects	-0 2	-0.1	0.00
Ice sheets – adjustment since LGM	0.0	0.25	0.5
Permafrost	0.000	0.025	0.05

Sediment deposition	0.00	0.025	0.05
Terrestrial storage (not directly from climate change)	-1.1	-0.35	0.4
Total	-0 8	0.7	2.2
Estimated from observations	1.0	1.5	2.0

Table 4 Estimated rates of sea level rise components from observations and models averaged over the periods 1910 to 1990 (Bijlsma, 1997; Church et al., 2001). Note that the 20th century values for Antarctica and Greenland derive from models not observations.

Previsions after 2000 were done by Church et. al 2001; their forecasts noted about the faster SLR compared with past century's means. Sources in the previous table were analyzed, and a potential variability of 50 % of their averages was calculated by 2100. The biggest amount of uncertainty is provided by CO_2 emissions, which is the main reason of increasing average temperature and consequently responsible for ocean volume changes -*eustatic SLR* (Pfeffer et al., 2008)

After the World Coast Conference in 1993, and later by IPCC contributions and the authors we cited, accelerators of the SLR, as well as sea level fall, were expected. From Table 4 in fact, the source type *"Terrestrial storage"* is addressed as not directly dependent by climate change.

These kinds of contributions arose from the anthropic actions; the urbanization process that took place in the past, and that is still ongoing, comprises several actions. Just to give an example, the interferences within river basins and sediment extraction provide a huge gap in the sediment supply; nonetheless, the groundwater and oil spilling, and in general the depletion of the natural resources that concern the coastal management, entail the building of infrastructures and are always able to support greater fluxes of users. Moreover, the timescales of some of these dynamics are totally different (years, decades or longer); change is also related to past climate change, and these accelerators are not determined solely by climate.

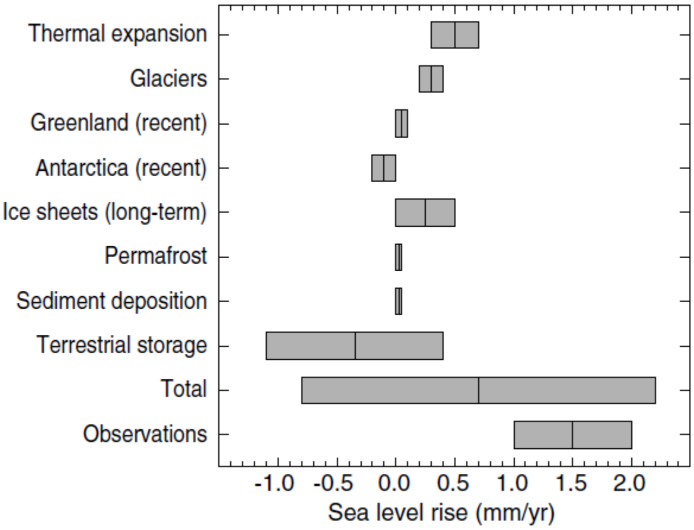


Figure 2.18 Estimated contributions from different sources to global SLR after Church et al., 2001

Differently from global climate change, *relative sea level change* measures the local contribution; considering a specific location, eustatic and steric components of the global trend are corrected. Local effects concern the net increase in the level of the ocean relative to local land movements.

They comprise vertical displacement, sediment supply, isostatic adjustments and all that effects due to sea state parameters and oceanographic variations (Church et al., 2001).
Three clear examples of the reasons why relative SLR is the parameter that we should consider (since we are analyzing coastal erosion at a regional or even local scale), were reported by Church et al. They are the Bangkok area where groundwater extraction induced sediment compaction – hence a notable subsidence and SLR increasing. A second one is Honolulu that reflects the global means, while the third example is Nezugaseki in Japan where a subduction in SLR resulted after the occurring of an earthquake in 1967.
From these authors, and mainly after the IPCC meetings, some fixed points for future SLR were defined. The most important ones assumed that the means calculated are affected by both, the up mentioned feedback, and by the bias on the mathematical models used. Furthermore, it is important to pay attention to the fact that future forecasts assume CO_2 concentration and production levels, that represent the biggest part of uncertainties, to be stabilized for the end of this century. If this happens, SLR will keep increasing even in the next century or further, but with different rates within the different regions of the globe (RIKZ and IPCC, 1994).
Several models were used for these calculations, and even if sometimes big differences were noted, general patterns, confirmed by most of the models compared are:

1. The maximum SLR is expected in the Arctic Ocean; it is probably due to the sea level compensation as a response of the pressure gradient at depth. It should be provoked by the increasing of runoff and precipitations that are able to change the density of the oceanic waters and salinity (Gregory et al., 2001; Miller and Russell, 2000).

2. The minimum SLR is expected in the circumpolar Southern Ocean, where the low thermal expansion, changes in wind patterns and transport of the heat were addressed as the main causes (Gregory et al., 2001; Hirst, 1998).

3. Further than extremes values, other regional patterns were highlighted for the north-west Atlantic; here there is a reduced rise south of the Gulf Stream and a rise to the north. They can be associated with increase in ocean temperatures and changes in ocean circulation, that will produce a 15 ± 5 cm variation if the atmospheric CO_2 will double (Bryan, 1996; Latif et al., 2000).

4. As we already said, land movements and terrestrial storage are expected to both, increase producing a SLR to 2100 (Church et al., 2001).

More recent papers focused on the Mediterranean Sea, as a closed basin that does not follow the global means since it is not influenced by open oceanic conditions, (Fenoglio-Marc, 2002; Vigo et al., 2011). In general, as aforementioned, bio geophysical aspects within these closed contexts are crucial to coastal areas. Regional or even local climate implicates severe levels of harm to the areas already affected by terrestrial storage effects. The combination of always more aggressive extremes, storm surges and land subsidence creates the perfect conditions for flooding of low-lying areas, beach erosion and saline intrusion (Cooper et al., 2008). Once these drivers are coupled with SLR they make coasts particularly prone to disasters (Benassai et al., 2015).

However, for the Mediterranean Fenoglio-Marc in 2002 they calculated an average of 2.2 mm/yr during the decade 1992-2002. Even this data is tricky, because a local scale conceals the real values. Western Mediterranean areas in fact show a change of 0.4 mm/yr, while completely opposite trends are observed between Ionian Sea (-11.9 mm/yr) and Eastern Mediterranean (+9.3 mm/yr).

The authors found that changes on the sea level in the Mediterranean basin are mainly due to seasonal thermal origin, and secondly atmospheric pressure and wind field variations.

Regarding the Italian coasts, the IPCC commission calculated that in 2100 vulnerability trends due to SLR are expected to increase in the whole national littorals, except in the regions where isostasy and tectonic flip these rates, as it happens in Calabria and Sicily (IPCC, 2007; Lambeck et al., 2004; Rahmstorf, 2007; Lambeck et al., 2011) (Figure 2.19).

In particular, the Tyrrhenian areas more exposed to SLR are concentrated to the biggest rivers' plains within the regions of Tuscany, Latium, and Campania.

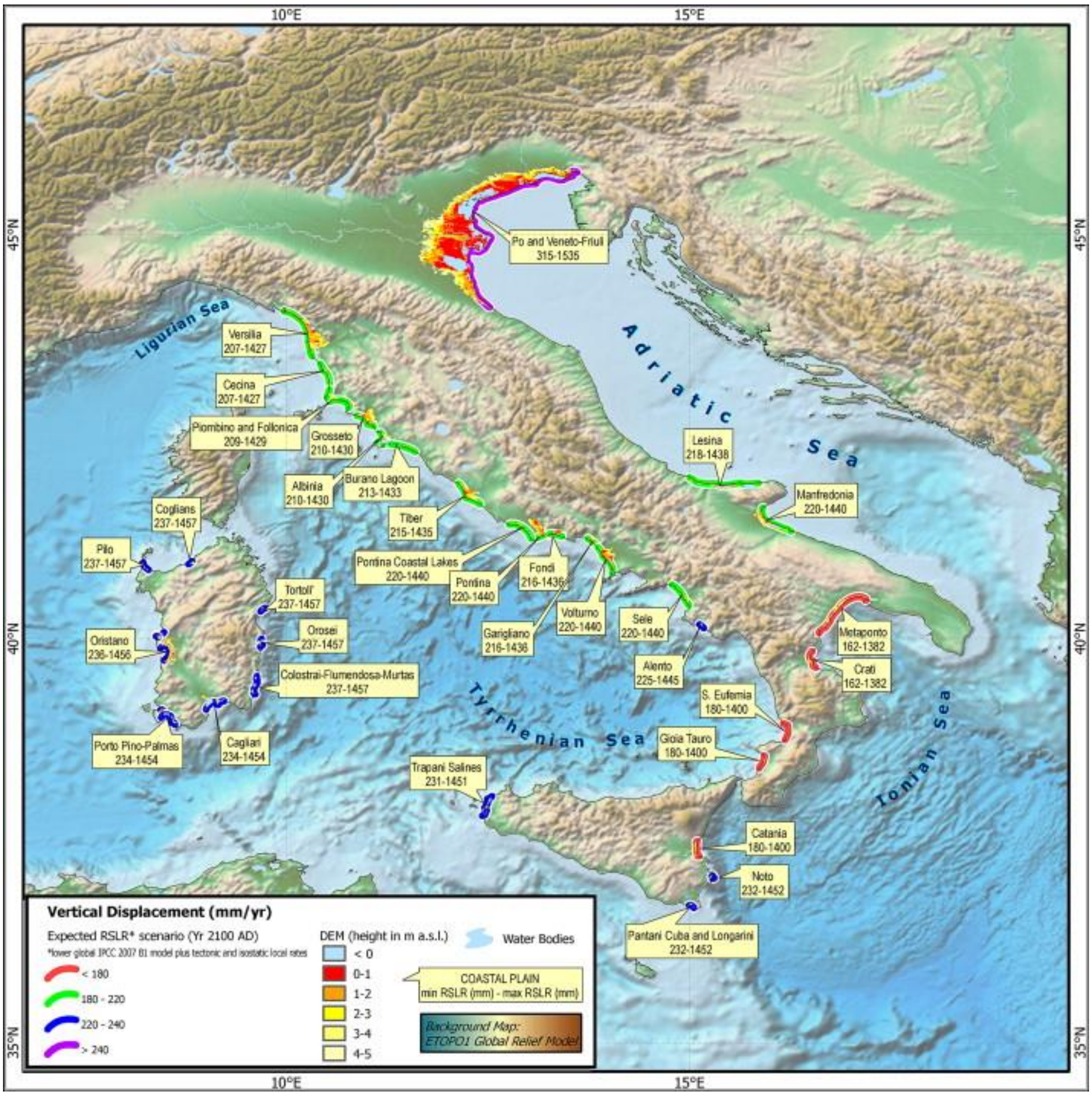


Figure 2.19 Vulnerable areas to coastal inundation due to SLR projection at 2100 (Lambeck et al., 2011).

The projections obtained from the studies aforementioned reveal that coasts of the future will be affected by natural phenomena and extremes that increase the stressing patterns affecting coasts at the present time. This aspect is crucial for managers and administrators of the littoral zones; consequently, coastal erosion will increase, and even an increasing disparity will arise from the advantage of the resources, creating a social justice issue (Benassai et al., 2015; Hinkel et al., 2015; Lambeck et al., 2004; Phillips and Jones, 2006)

The potential impacts have been investigated by McLean et al., 2001 including biophysical and re socioeconomic related ones that are summarized in Table 5.
The same authors indicated *Adaptation* as the right strategy that stakeholders and users should promote to limit the increasing of risk levels to the end of the century, as well the economic expenses to face and restore the areas exposed.

Biophysical impacts	**Socioeconomic impacts**
Coastal erosion	Loss of properties and habitats
Inhibition of primary production processes	Flood risk and loss of life
Coastal inundation	Damage to coastal protection and infrastructures
Storm-surge flooding	Increased disease risk
Landward intrusion of seawater	Loss of renewable resources
Changes in surface and groundwater quality	Loss of tourism and recreation functions
Changes in pathogens distributions	Loss of cultural resources and values
Reduced sea ice cover	Impacts on agriculture and aquaculture

Table 5 Potential impacts to coastal areas caused by climatic change, modified after McLean et al., 2001.

2.3.1 Coastal Erosion Management

CEM can be defined as an interactive, dynamic and multidisciplinary approach made to prevent, mitigate, and avoid any ecological, social and economic losses derived from the coastal erosion process (Bush et al., 1996; Cooper and Pilkey, 2012; Gracia et al., 2018; Rangel-Buitrago and Neal, 2019; Williams et al., 2018). Together with technical and scientific tools, institutions at different levels systematically made CEM related actions, that today are strongly supported by communication campaigns. During the last 60 years, the modern society started to promote public actions to defend the planet and to act sustainably. Examples are "green" associations such as, Legambiente in Italy, Ecologistas en Acción in Spain, or Nature Conservancy in the U.S.A., of which the oldest were founded during the 50s'. After 60 years of activity they are still debating on defending the natural environments from depletion, fighting for more sustainable approaches to safeguard environments and ecosystems. Today these kinds of movements are increasing and can involve bigger parts of the society even more, making it more aware also on the natural risks. This process generated important experiences; the last one, supported by Greta Thumberg, is named Fridays for Future, and in about one year has created a climate strike movement of 3.6 billion of people. They had a big impact also on the institutions, that have started to increase the consideration of the social parts in the global investment industry, as well as regarding human rights related to climate's decision (Kühne, 2019; La Manna, 2020). Coastal erosion represents a socio-economic risk because it implies effects to several strategic industrial fields; this is the reason why to plan a successful CEM, stakeholders, scientific and communities must participate (Gracia et al., 2018).

CEM differs from the Disaster Risk Management mainly because the latter is a process that uses administrative directives, organizations, and operational skills and capacities to implement strategies, policies and improve coping capacities in order to lessen the adverse impacts of hazards and the possibility of disaster (UNISDR, 2009).

CEM today are mandatory because of the increasing human pressure on coasts and the great incomes that derive (IPCC CZMS, 1990; Barragán and de Andrés, 2015; Gracia et al., 2018, 2018; Pereira et al., 2018; Williams et al., 2018; Rangel-Buitrago et al., 2018b).

Of particular interest are the results of the Intervention Concerning the Erosion Causes (ICEC) approach, that consists in a range of five groups of strategies, such as *Protection, Accommodation, Planned retreatment, Use of Ecosystems, Sacrifice or do nothing* (Table 3).

These actions can be properly dimensioned based on the knowledges on coastal dynamics, urban settings, economics and associated values of the assets (Pranzini et al., 2015, p. 201; Williams et al., 2018).

Intervention Concerning the Erosion Causes (ICEC) strategies are still poorly tested for several reasons. Main limits are the fragmentated normative frameworks and the strategic interests of stakeholders and public; in fact, the decision-making process is strongly oriented by economic considerations that affect it to every level (Cooper and McKenna, 2008; Rangel-Buitrago et al., 2018b; Williams et al., 2018).

CURRENT COASTAL EROSION MANAGEMENT PRACTICES			EXAMPLE
Strategy	Adaptation objectives	Shoreline management	
PROTECTION	Increased robustness	Advance the existing defefence line	Land claim
		Hold the existing defence line	Hard Protection Soft Protection
ACCOMODATION	Increased flexibility		Flood Proofing Flood Agriculture Hazards Mapping Warnings Geoindicators
PLANNED RETREAT	Enhanced adaptability	Management reaignment	Management Realignment Coastal Setbacks
USE OF ECOSYSTEMS	Enhanced adaptability Restoration Risk reduction		Corals Sea grass Oyster reefs Mangroves Dunes
SACRIFICE	No active intervention		Abandonment

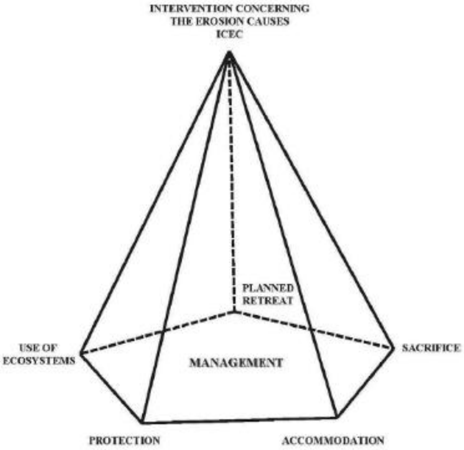


Table 6 Main coastal erosion management practices used and diagram (Rangel-Buitrago et al., 2018).

1. Protection

It represented a traditionally largely used palliative solution for the preventing of beach loss, before turning into the cause of erosion. On the other hand, through defense structures, humans were able to develop economies, and sometimes even extending land seaward. This mostly happened in sandy shores where defenses strongly affect littoral currents and sediment transport (de Jonge, 2009; Doody, 1992; Molina Gil et al., 2019; Pontee et al., 2016; Pranzini, 2018; Rangel-Buitrago et al., 2018c; Temmerman et al., 2013).

Protection strategy comprises *hard* and *soft* interventions that were adapted to every coastal context during the past two centuries, especially in touristic places. Hard engineering techniques aim to counteract erosive phenomena, as well as to protect the coastline through artificial structures. Soft engineering instead integrates more sustainable structures to co-work with natural counteractors (Bayle et al., 2020; Dean and Dalrymple, 2004).

They comprise several kinds of designs that use different materials and configurations aiming to solve different hydrodynamic "issues"; according with Paganelli et al., 2014 the most common can be distinguished as:

- *Hard adherent* defenses, such as seawall and revetments
- *Soft adherent* defenses, such as gravel stabilizations interventions
- *Detached* structures, such as emerged and submerged breakwaters and island platforms
- *Transversal* defenses, such as groins and headlands
- *Nourishments*
- *By-pass systems*
- *Drainages*
- *Protection and restoration* beach morphologies such as dunes

Groins and Breakwaters are the most common since they sensibly increase the beaches' extensions seaward, offering a useful space for economic activities too. Together with Headlands, Revetments and Sea walls the previous two types have been adapted to every sites' conditions, and sea state parameters.

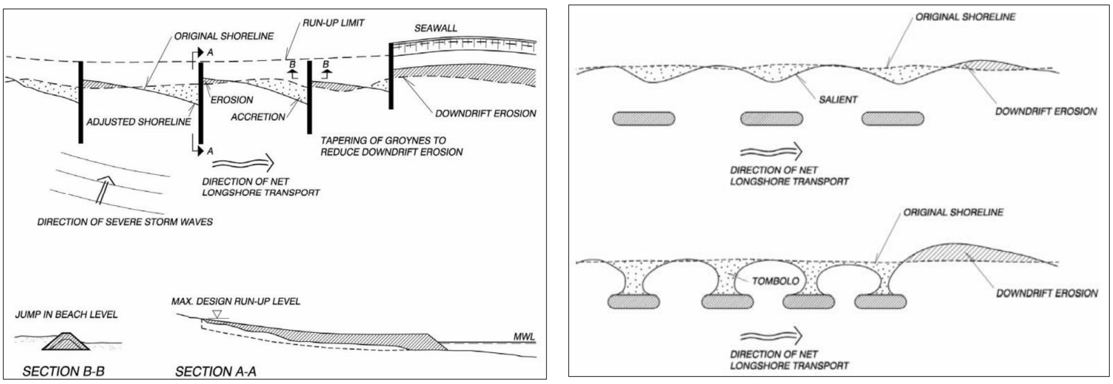


Figure 2.20 Hard structures functioning (A) Typical beach configuration with groins; (B) Typical beach configurations with detached nearshore breakwaters (images source: www.gfdrr.org/en).

Groynes consist of low, narrow jetties, usually perpendicular to the shoreline, that have the function to trap drifting sediment (IPCC, 2001); thus they are mainly realized to face gradients in the longshore transport. They produce a local reduction in the littoral drift around the groin with the consequent alongshore gradients in the littoral sediment transport, sedimentation and erosion around the groin; furthermore Groynes cause re-orientation of the bed contours orthogonally to the dominant wave directions., until an equilibrium is reached.;(Mohanty et al., 2012; Kristensen et al., 2016; Neshaei and Afsoos Biria, 2013) (Figure 2.21).

Figure 2.21 Example of a Groynes field where the shoreline in the left side is turned against the prevailing wave direction; the latter can be deducted from the rose diagram on the right side of the image (Kristensen et al., 2016).

They can be submerged to increase the sediment bypassing since they are more permissible of longitudinal transport (Paganelli et al., 2014). Also sustainable materials were used to introduce hard defenses within the coastal landscape, but some experiences show that even when they resulted resolutory and more attractive to coastal scenery they were substituted by classic block-made ones (Neshaei and Afsoos Biria, 2013; Pranzini et al., 2015; Rangel-Buitrago et al., 2018a). The sedimentological variations comprise the increasing of the beach in the sectors updrift to the septs, and coarser granulometric classes and steepness of the shore's profile progressively toward the Groynes. An opposite trend of the granulometric classes distribution is generally observed downdrift respect to the groin, that at a mesoscale correspond to a lack of sediment in the whole sector downdrift. Even the currents' pattern downdrift is hardly modified; indeed, a shaded area is formed in the vicinity of the lee of the groin, that causes the shifting shoreward of the breaking zone, with associated rip currents that activate a cross-shore transport as can be observed in Figure 2.22 (APAT, 2007).

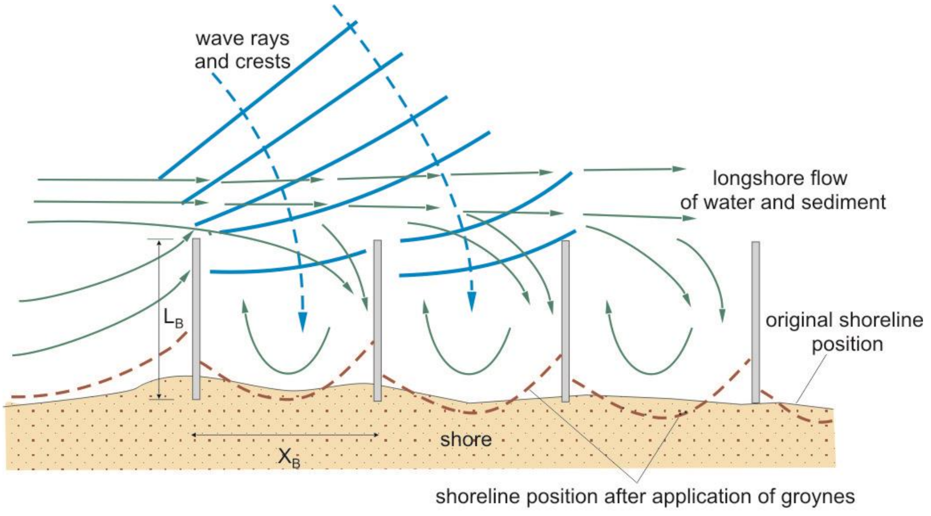


Figure 2.22 Interaction of Groynes, waves, currents and shore; image source: www.marinespecies.org .

As the groins can trap the sands moving longshore, *Breakwaters* and parallel structures reduce the energy of incoming waves. They retain sediment creating a sheltered zone between barriers and shore, and in the best scenarios, the growing up of a *tombolo* as sand deposit (Figure 2.23 B).

Breakwaters are particularly used to reduced sediment loss and actively protect the shore from extremes (Gómez and Aránguiz, 2020).

Differently from the groynes, they are capable to maintain the original hydrodynamic environment characteristics of sea areas regulating sedimentation rates (Yan et al., 2020), even if they behave as groynes once they build a tombolo interrupting littoral drifting. Similarly, the downdrift areas could suffer a lacking in sediment by passing. Even breakwaters need to be properly dimensioned; their orientation, as well geometrical shape (such depend on dominant wave direction and height, bathymetric features and used materials. Opposite effects from the expected ones were experienced and reported in literature, such as beaches' profiles changes.

Figure 2.23 Example of a 'salient' (left) and a series of 'tombolos' (right) (Deltares- GFDRR, 2016)

Basically, this common situation is due to the reflected waves that attract sediment suspended from the feet of the defenses toward the offshore, with a consequent scouring of the latter. It produces an increase of the wave height at the barrier front and a more aggressive action of those waves, while in the sheltered areas this will cause an increasing of time residence of water during extreme (Gómez and Aránguiz, 2020; Paganelli et al., 2014; Zanuttigh et al., 2005). Moreover, these dynamics, as well as the organic matter content, affect the abundance of benthic species. They populate more or less energetic zones of the shore, and in sheltered contexts will also populate surf zones and other areas that under normal conditions are characterized by high turbulence (Bertasi et al., 2007). As shown by Punzo et. al, 2016, reef-type breakwaters can reduce incoming wave energy to the shore and contemporary can create strong rip currents between the breakwaters' gaps (Trimble and Houser, 2018). They are responsible for the structures' instability and the arising of erosive patterns due to structural defects that are easily damageable by storms; these effects are visible on protected shores marked by several berms; nonetheless harmful situation can be created for swimmers that by rip currents are attracted seaward. If some of these defects can be solved through gravel feet at the bottom of the open inlets, or through drainages within the structures to reduce water surface elevation, common practices are the installing of further submerged structures on the onshore side of the open inlets.

From the following map (Figure 2.24), an intense ringing activity between structures and shore is described by red zones of high amplitude, affecting both the shape of the beach in this sector, and the looseness of sediment through the gaps between the barriers. This is a well-known process due to the rip currents (plumes of mean amplitude between the values of 2500 and 4000 in Figure 2.24 A). These values change in relation with the sea conditions; with rough state of the sea the mean amplitude values reach their maximum.

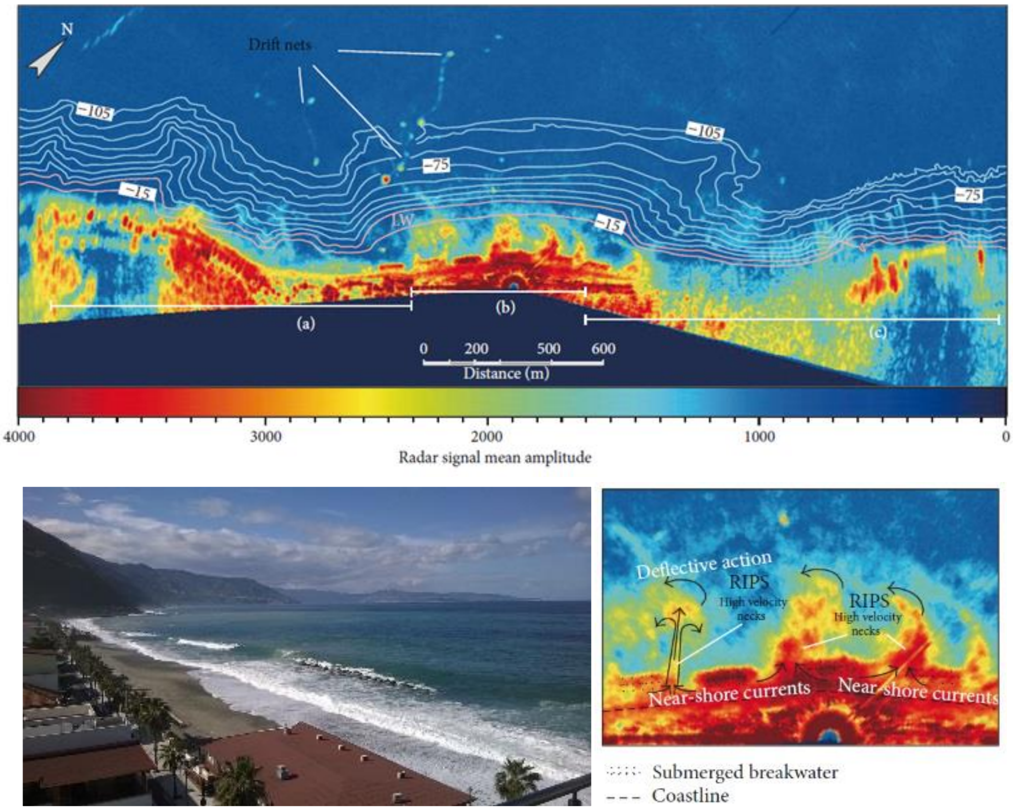


Figure 2.24 (A)X-Band Wave Radar image at Bagnara Calabra (South of Italy) location; (B) Reef-type breakwaters at sector b; (C) individuating of rip currents between the breakwaters' gaps (Punzo et al., 2016).

During these phases the rip currents after ringing in the back of the barriers run seaward through the gaps, firstly with high velocity, and secondly assuming the same direction of the surface currents (Bianco et al., 2018).

Hybrid shapes were tested and utilized specially to support the formation of a closed cell and the sediment accumulation in both sides of the groynes (Figure 2.25). They are good counteractors of the cross-shore sediments drifting and maintaining the original profile of the beach.

Hence, they reduce the incoming waves' energy as well as the littoral transport with sediment motion related mainly to waves action, making the backshore.

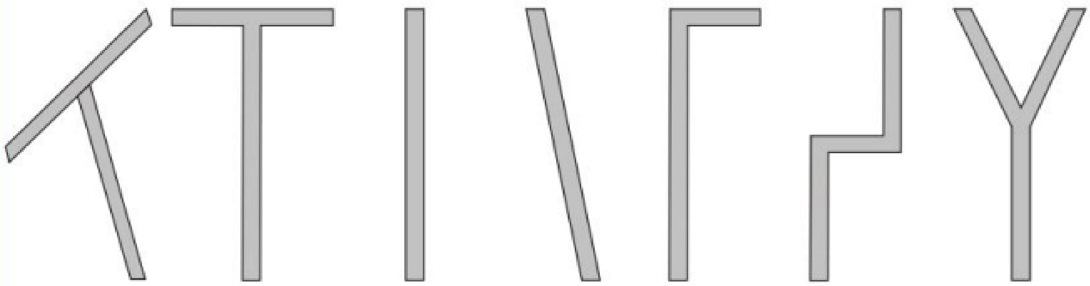


Figure 2.25 Composite shapes of groins (APAT, 2007).

Alternative versions were proposed widely even in Italy, that experienced coastal engineering since the 19 AD by Romans (Pranzini et al., 2015). During the period just after the World War II the spreading of urban centers around the coasts of Europe pushed coastal engineering to effort against the sea and toward the conquering of its space. Even materials used to build them were unaware or just popular to the construction industry of that time; indeed, they consisted of concrete, iron, and blocks from land mines.

They were addressed as measure of shoreline alignment, that after a period of *soft structures'* experimentation -basically the last 20 years- such as nourishments and permeable defenses come back popular because of the feasibility during emergency scenarios due to sea surges, and even hydrogeological extremes landward (Paganelli et al., 2014). Nowadays, effects related to both the group of structures are better known even if they are still performed as supporting structures for port adaptations, or to face coastal infrastructures instabilities. Examples on the Italian coast are very common, and were able to drastically change also the landscape of the places to a point that these sites are mostly remembered for the singularity of their defenses (e.g. the T groynes field at Paola, South of Italy in Figure 2.26 B). Italian cases can be found from north to south in almost every coastal region in both, the Adriatic and the Tyrrhenian coasts (Airoldi et al., 2005; Pranzini, 2004). Of particular usage were the T shape (Figure 2.26 A) that similarly to other composite shapes improve the shore increasing process, mostly if they are installed in field rather than singular (Özölçer et al., 2006; Pranzini et al., 2015).

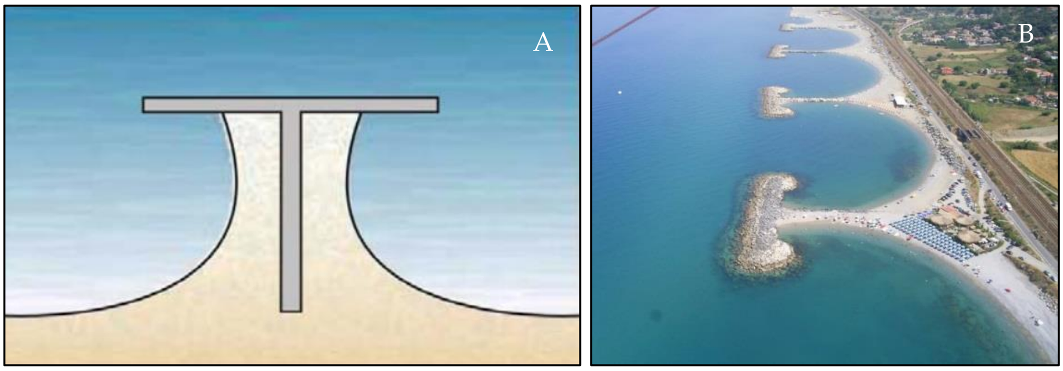


Figure 2.26 (A) Simplified design of a basic composite groin (Paganelli et al., 2014); (B) Composite groins field at Paola, South of Italy, where they were realized to protect the railway limiting the coastal zone visible just on the backshore; image source: www.confesercenticosenza.it

In Italy, the configuration observable in Figure 2.26 B was extremely popular to protect infrastructures such as railways and mass roads, or even as a consequence of the shifting of erosive focuses due to groynes and jetties. Field groynes are applied with the aim to sectorize littoral in some relatively small cells; T-head groynes and detached breakwaters are used to maintain a beach for recreation, and even to create boundaries between highest risk areas and urbans. This approach is particularly used when marinas and seafronts are present and protected through revetments and seawalls.

Especially where sediment discharge from land is reduced, the source is represented by cross shore paths, hence an artificial input is always necessary to give an initial conformation to the beach and enough space to humans' activities. What is particularly impacting of the groynes' field, and even breakwaters, is that they need a relatively long time and modifications to accommodate. An example is given in Figure 2.27 that pictures the situation at Montemarciano (Central Adriatic coast of Italy).

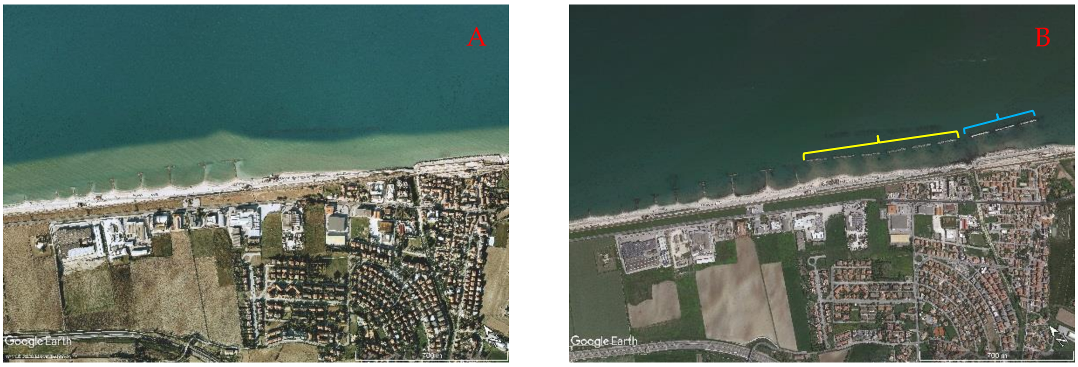


Figure 2.27 Groynes field at Montemarciano (Central Adriatic coast of Italy); (A) in 2007; (B) Situation at 2020; yellow bracket indicates the interventions realized in 2012, and the blue one highlights the breakwaters built in2017. Images source: Google Earth.

In plot A, a series of T-groynes are installed to probably increase the beach in the area, and most of all to defend the railway just in the backshore. Seven T-groynes were built, and two simple groynes in the left terminal side, with a gradual small length confine the intervention and allow a partial bypass toward the downdrift sectors. The groynes field is also supported, in defending from the dominant wave (that in the first plot is clearly from East to West), by four submerged breakwaters in the upper right side. In plot B, the same site is captured in 2020. The last T- groyne in the right side has been modified, and its breakwater removed to be shifted as the first of a series that was built between 2012 and 2013 -indicated by the yellow bracket. As can be observed in the same plot, three further breakwaters were needed and were built in 2017 to respond to the erosive shifting imposed by the initial intervention.

Another popular structure is represented by jetties; they very often are used and adapted to armor river mouths (Figure 2.28). In particular, the armor river mouth is used mainly to avoid sand cover-up at harbor entrances, as well as hydrogeologic mitigation measure, since modifying the rivers' channels their gradients can be controlled and overflow potential reduced. Especially in the first situation, the mouth is translated seaward, and the sediment discharged is often carried beyond the closure depth.

In Figure 2.28 A the isobaths at the armors crown is 3.5 meters, and the yellow polygon on the upper part of the image is the shore's portion expected to be nourished with the dragged sediment from the mouth channel, estimated around 20 000 m^3 /week. (Autorità di Sistema Portuale del Mar Tirreno Settentrionale et al., 2017).

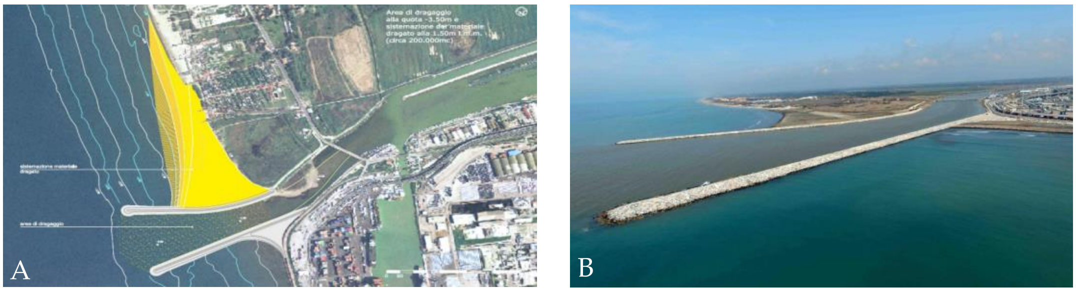


Figure 2.28 Armored river mouth at Arno River in Tuscany (Central Tyrrhenian coast of Italy); (A) design of the structure, image source: www.autoritaportualeregionale.toscana.it; (B) Armoring after its completion, image source Ing. Paolo Ghezzi.

Examples of armored river mouths are very common where water bodies are artificially controlled to mitigate flooding risk, or even to prevent harbors' mouths cover-up. An Italian case is presented in the Figure 2.29, where four sketch maps describe the situation verified at Ostia, in the Central Tyrrhenian coast.

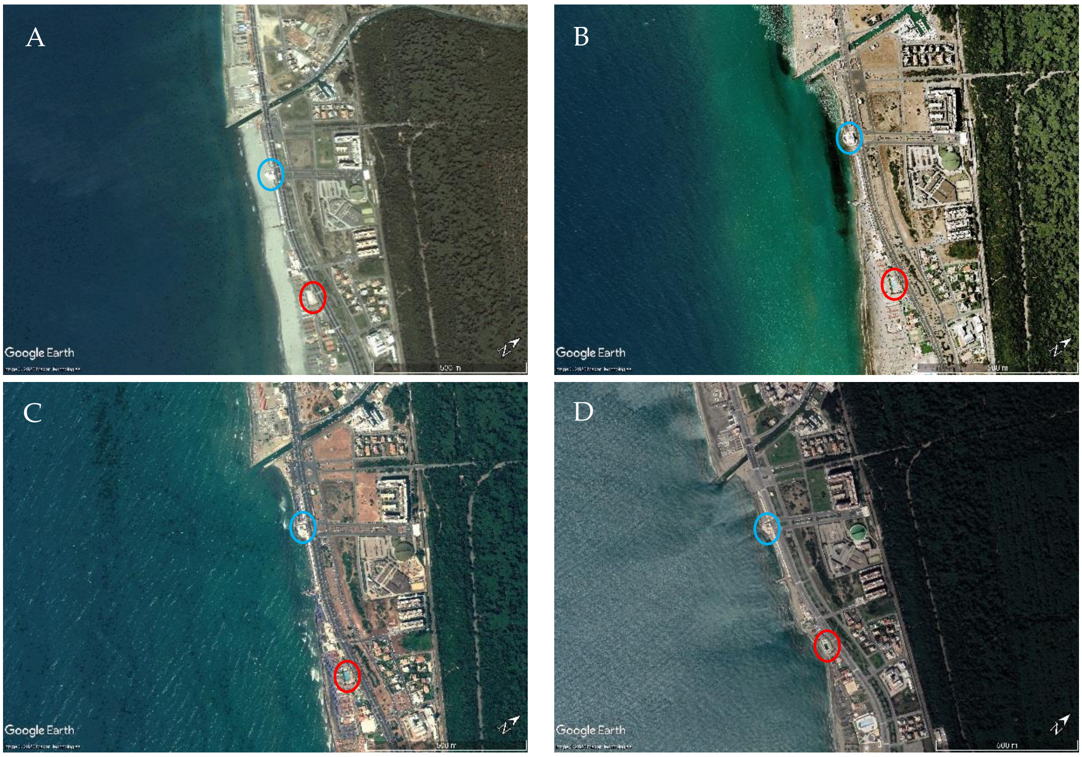


Figure 2.29 Armored river's mouth at Ostia (Central Tyrrhenian coast of Italy); (A) The Ostia's littoral in 2003; (B) Ostia's littoral in 2007; (C) Ostia's littoral in 2010; (D) Ostia's littoral in 2020. Images source: Google Earth.

In the subplot A the situation refers to 2003 when together with the jetty an artificial nourishment was realized to regenerate the beach. Sediment was already lost in 2007 (subplot B) when the wavy shaped beach of the previous plot changed in a rectilinear shoreline fixed by urbans.

The next two plots can observe how the erosive trend did not change after 2007, and the shoreline limit remained the one fixed by hard defenses protecting traffic services and buildings.

Headlands are land masses that simulate the effects that natural promontories have on downdrift curved-shaped bays (Figure 2.30). Headlands have a notable elevation on sea level and border beaches in order to create a sedimentary cell and reduce the sediment drifting to adjacent cells. They are functional to contrast oblique dominant waves and to block part of the sediment directed longshore. Basically, headlands produce an effect that looks like a good compromise between groynes and breakwaters. Moreover, by adapting headlands heads' shape, scours and vortex that usually stabilize the other two types of structures can be drastically minimized. What is important is that sandy beaches protected by headlands usually increase orienteering parallel to the dominant wave field (APAT, 2007).

Figure 2.30 Pocket beach confined laterally by two promontories at Cala Cortina (Cartagena, South of Spain).

Differently from the aforesaid structures, *adherent or passive* defenses do not have the purpose to increase or preserve the beach's deposits, but they just defend urbans from extremes, (APAT, 2007; Griggs, 2005; Paganelli et al., 2014). Indeed, they are used to face systemic high waves' attacks, that are very common for example in sites with long fetches, beaches with high slopes, and sites where the coastal zone is restricted, and the risk of anthropogenic properties is consequently high. Their application today appears necessary in those places where the impossibility to dislocate is objective. But, touristic and hence productive coastal sites build their economic fortunes on seafronts and marinas that constitute both, the coastal zone restriction cause and, consequently, the factor that increases risk. For these reasons, adherent structures at a first sight could appear the most appropriate during emergencies, but this is the main reason why all of them fail, especially once they are damaged (Griggs, 2005).

Revetments and Seawalls can be designed with several slopes and even shapes, such as vertical, concave or sloping, and simulate dunes' and natural beach counteracting action against waves, where these geomorphological deposits have been eroded or are not resistant enough.

Revetments (Figure 2.31) are armor protection layers made of blocks or light to heavy materials filtered by different sizes of materials, and protected to the toe that are installed to the cliff base of the dune's base to fix that hard line and preserve what is in its back. (Deltares- GFDRR, 2016; Van Rijn, 2011). Revetments require that armor stones are of sufficient size that is not moved by storm wave action; even the spaces between stones should be small enough to prevent wave penetration and washing out of materials through these spaces. The same issue must be solved in respect with the waves overtopping the wash cliff or dune's material and exporting it through the stones.

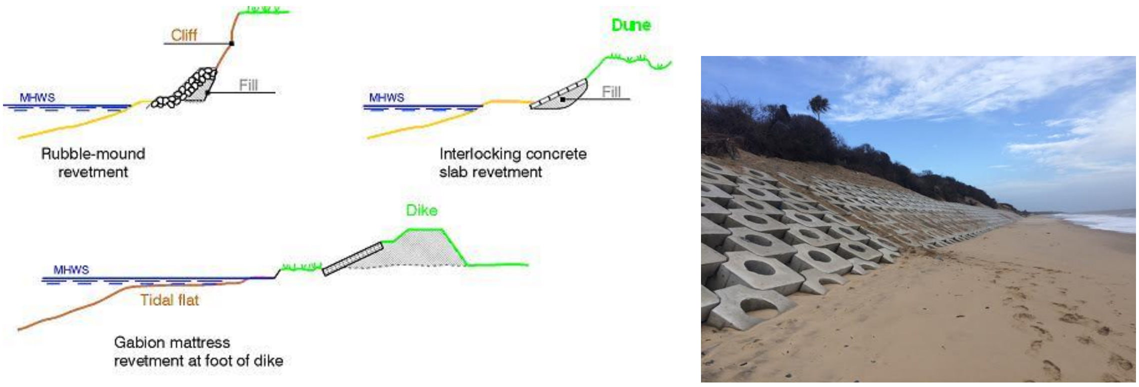


Figure 2.31 (A) Revetments types, image source: www.marinespecies.org; (B) Concrete block revetment at Dawlish (UK), imagine source: www.networkrailmediacentre.co.uk.

Seawall instead (Figure 2.32), is a vertical or lightly sloped massive structure that differently to revetments also protects from flooding and should be installed as the last option (Van Rijn, 2010). They are effective at preventing erosion behind the wall since they set a hard and not erodible limit. From the other side, seawalls do not provide any kind of protection to the shore face and the submerged beach. In fact, a turbulence regime is activated at the base and in front of the seawall by the impacting waves; consequently, sediment in these zones is eroded and the beaches in front of the wall generally are made of cobbles.

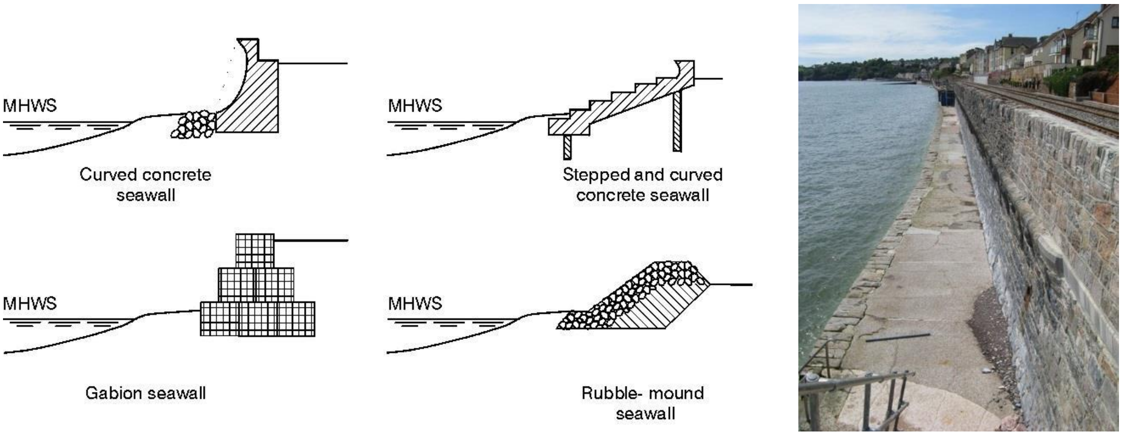


Figure 2.32 (A) Seawall types , image source: www.marinespecies.org (B) Seawall protecting railway at Dawlish (UK), imagine source: www.networkrailmediacentre.co.uk.

Benefits from these two systems are very hard to individuate, except if concerning the facing of the flood and coastal surge. In fact, in both cases the erosive phenomena will remain similarly to groynes and will shift downdrift. Differently from the latter, seawalls increase the cross-shore transport after waves' reflection on the structure (APAT, 2007; Van Rijn, 2010); for this reason, permeable configurations are very often used, such as a gabion seawall. They better dissipate waves' energy through the high permeability of the structure that can also accommodate displacements and limit the scours forming at the toe.

The types of defenses exposed are just a few basic ones from which adaptative designs have been perfected to limit scouring and local erosion at the structures' toes and vicinity. Moreover, modifications to the shapes of not adherent defenses (headlands, groynes, breakwaters) were perfected to avoid wave refraction from the structures to the shore, that can create localized erosive focuses. As can be understood from the descriptions of the most popular hard defenses, the effects are invasive of the morpho dynamics, and very few examples exist with inverted tendency. Once they are installed, structures rule the spatial distribution of accretion, erosion and stability on beaches (Molina Gil et al., 2019). From an ecological point of view, defenses create new features of intertidal and shallow subtidal habitats. They will increase as response to both, the exponential increasing of anthropic occupation, and sea-level rise and increased frequency of extremes (Bulleri and Chapman, 2010). Artificial structures such as seawalls affect the mix, spatial distribution and relative abundances of many species, and even create novel habitats which affect diversity, abundances, and distribution patterns of intertidal assemblages.(Chapman and Bulleri, 2003; Lam et al., 2009). Even the introduction of new artificial hard-bottom habitats can change species' diversity, favoring the spread of non-native ones at a both, regional and local scale (Airoldi et al., 2005). The effects are notable even when natural materials are used to build artificial substrata and artificial structures; in these cases, new habitats are produced but the changing concentration of biotas causes fragmentation and consequently drive the loss of ecosystems.

In any case, each artificial habitat cannot act as a natural one, and new ecologic accommodations mainly depend on the natural settings of the trophic system (Bulleri and Chapman, 2004). As for the seawalls cited before, pontoons and pilings were also recognized as responsible of the modifications to species' dispersal, since these structures represent some entry points for invasion for many exotic epibiota and their spreading in estuaries (Glasby et al., 2007).

After a long period of hard structures' experimentation, *soft interventions* started to be performed, since beach value for tourism was recognized worldwide (Pranzini, 2018; Pranzini et al., 2015). As well as in Europe and Italy, nourishments become the most used practices to stabilize the shoreline, and even to increase beaches for economic purposes (Pranzini et al., 2018). An exhaustive example is Spain, where during ten years (1983-1993) 14% of the total Spanish shoreline was artificially restored (Anfuso et al., 2001).

Nourishments consist in the dumping of sand on the shore in order to stabilize the sedimentary budget of the littoral. They absorb the storm's energy preventing erosion and inundations as shown in the Figure 2.33.

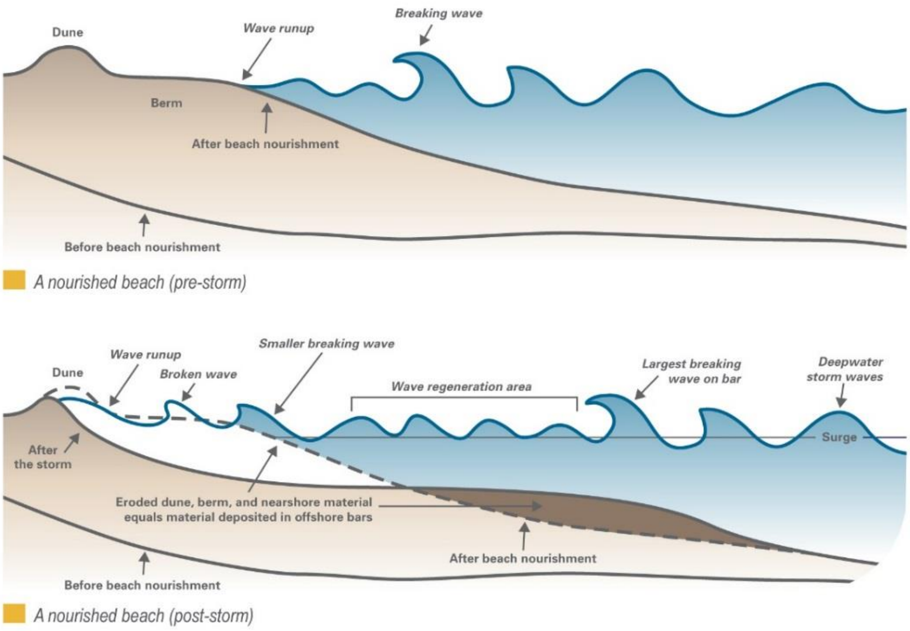


Figure 2.33 Simplified expected effect of an artificial nourishment in respect to waves. Image source: US Army Corps of Engineers www.nad.usace.army.

In the previous image two beach' profiles describe the situation pre and after a storm on a nourished beach. The formation of a bar arises from the sands eroded on the submerged portion of the shore and trapped seaward. On the bars the incoming waves will break reducing the wave's height of the ones that will reach the surf and swash zones. Thus, before the realization of a nourishment the beach profile needs to be determined in order to set the goal of the design and the *constructed fill*. The latter is the total quantity of sand that comprises the *design fill*, as the initial quantity necessary to reach the design's goal (profile in the upper part of Figure 2.33), and the *advanced fill* that consists of additional sands to use as recharges (APAT, 2007; Willson et al., 2017). Perturbances in fact are "physiologic" since the equilibrium profile will be hit by storms and even the intervention requires different phases and years to become stable (profile on the bottom of Figure 2.33).

Sediment can be dragged from marine reservoir or excavated from land mines. Right sediment to use is usually considered to have an average diameter equal or little bigger to the original one, maximum 1.5–2.0 times the native sand (Bitan and Zviely, 2020), and compatible mineralogic properties to prevent the formation of steeply profiles. Even chromatic characteristic have to be properly chosen in respect of the aesthetic of each site (APAT, 2007; Pranzini, 2018, 2004). Most of all, the functioning of nourishments is due to the quantity of sand over long periods of time, hence enough economic resources to be spent (Van Rijn, 2011).

Basically, sediment is dumped and spread by lorries and trucks when sands are quarried from land sources (Figure 2.34), or at least during the spreading phases if sands are provided from the sea (Figure 2.35)

As shown in Figure 2.34 A, sand quarries are individuated within ancient deposits of unconsolidated sands, as it happens for the fan delta's deposits in the picture. Alternative land sources were the rivers' beds. Nowadays, this practice is recognized as one of the main causes of sediment unavailability to coastal areas, until that during the last 15 years authorities at different levels started to limit its usage (Nicoletti et al., 2006; APAT, 2007; Van Rijn, 2011; Paganelli et al., 2014, 2014; MATT-Regioni et al., 2018; Pranzini et al., 2018).

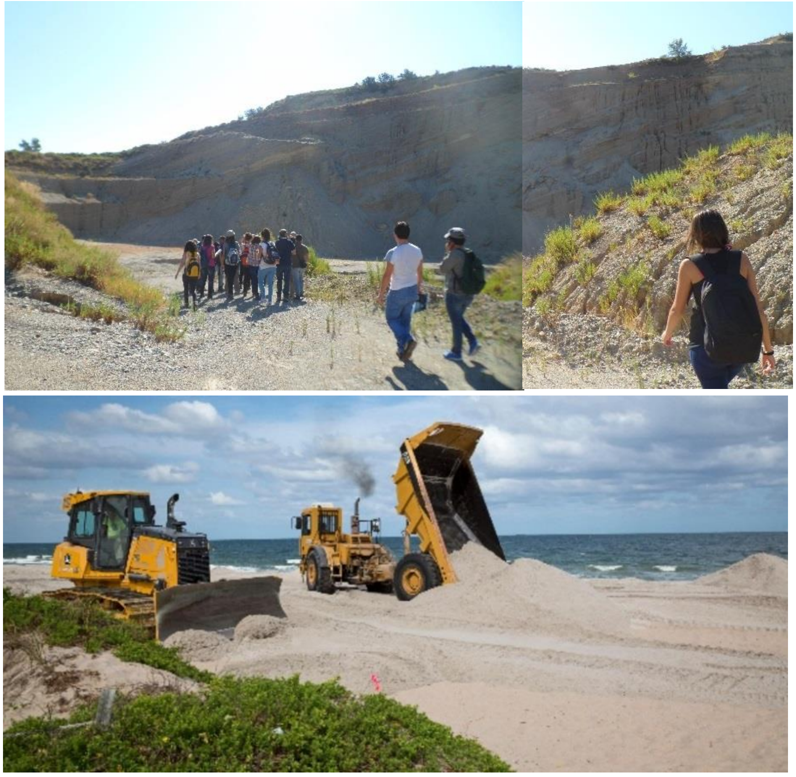


Figure 2.34 (A) Sand quarry on a fan delta Gilbert-type in Northern Calabria (south of Italy); (B) Trucks dumping and spreading sands on the dry beach at Fort Lauderdale, Florida, beach. Image source: Photo by Jim West/Alamy www.hakaimagazine.com.

The alternatives to that strategy is to borrow sands from the marine reservoirs or relict sands, that belong to ancient fluvial systems. They were submerged after the Holocenic sea transgression, and today hover over the continental shelves.

In the last case borrow reservoirs are individuated through previous geophysical, bathymetric, petrographic and mineralogic tests/surveys, that further than to determine sediment's characteristics must define the contours elements. They consider the silty coverage that has to be removed following strict prescriptions to avoid the turbidity and consequent ecologic impacts during and after mobilization (Nicoletti et al., 2006). Further restrictions exist in the case of dragged material from harbors (Figure 2.35 B). This practice foresees that material would be stocked in dump areas and treated following environmental guidelines. They are still debated to a normative point of view at bot, Italian and European normative scales.(Nicoletti et al., 2006; APAT, 2007; Paganelli et al., 2014; MATT-Regioni et al., 2018).

Figure 2.35 (A) Dredge during a beach replenishment in UK, image source*:* www.escp.org.uk/beach-nourishment; (B) Dredged material at the harbor mouth at Laghi di Sibari, Crati river's mouth (Calabria, South of Italy).

Even if they can solve negative budgets without impacting the littoral dynamics, they are more expensive than hard defenses, more difficult to realize because of the sediment availability. But the most dangerous effects are the ones related to the ecological impacts, which is the reason why nourishments are today limited and prescribed together with strong monitoring phases.(Pranzini et al., 2018).

Nourishments are resolutive if enough sand is available and the dredging and dumping costs are acceptable. Van Rijn in 2010 computed a cost between 10 and 15 million of Euro per year (100 to 150 Euro/m coastline per year) for the Holland market, and replenishments to be done every 2/5 years. Quantitative of sand and its characteristics are particularly important parameters once a soft solution is designed. Sediment availability directly affects the durability of the intervention, since 400-500 m^3/m are needed, and recharges should be planned together with support structures that protect the intervention. A sediment similar to the native one allows swift recovery of the benthic fauna, as well as avoiding a sharp transition from dissipative to reflective beaches (Speybroeck, et al., 2006).

Groynes are used to limit the sediment replenished laterally and to reduce the long shore's velocity, while breakwaters avoid the cross-shore motion, keeping control of the waves height that will reach the protected beach. In several cases the sediment is just discharged at one or more designed sites updrift, and naturally moved by longshore and cross shore dynamics.(Barnard et al., 2006; Bitan and Zviely, 2020; Di Risio et al., 2010).

The effects related to the functioning and construction of coastal defenses are strong even on the beach meiofaunal communities in ways that affect beach processes (Fegley et al., 2020). They concentrate in the water column as well as on and within the substrata, and similarly to the profiles used previously to zonate the shore, they can be represented schematically as follows in Figure 2.36.

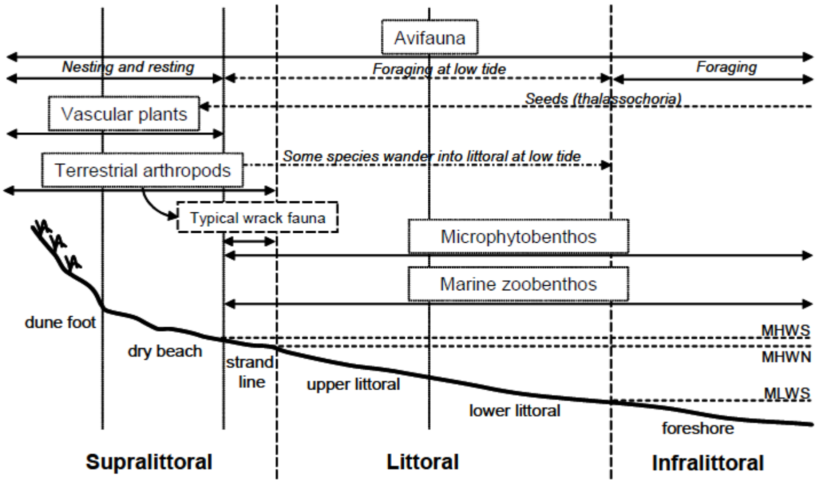


Figure 2.36 Scheme of a sandy beach's ecosystem, after Speybroeck et. al, 2006. Zones are named depending on the position in respect with the littoral zone, such as: Supralittoral from the shoreline to the dune's foot; the Littoral zone that similarly to the profile described in Figure 2.1 comprises the Shoreface; Infralittoral is the zone below the MLWS. MHWS= mean high-water level at spring tide; MHWN= mean high-water level at neap tide; MLWS= mean low water level at spring tide.

To assess the potential impacts of defenses on the ecosystem to a Mediterranean scale, a multi-disciplinary tool consisting of a matrix-system to evaluate the potential impact was proposed by the Italian Superior Institute of Environment Protection -ISPRA- in 2014 (Paganelli et al., 2014, 2013), within the European COASTANCE Project (www.msp-platform.eu/projects/coastance). The *Impact vs habitats and species* matrix allows us to assess the potential impacts expected on habitats and species of European interest, selecting a structure type. An ecosystem has an important function, for instance, to fix sediment to home innumerous specie's activities (habitat use), in both the beach's portions -emerged and submerged. Potential impacts on flora (*Kind of marine-coastal habitat*), and on the fauna (*Use of the habitat*) in a particular territorial unit (*Physiographic Category*) as prescribed by the European Directive Habitat (*Council Directive 92/43/EEC*, 1992) can be assessed through ten types of potential impacts described in the matrix as reported in the Table 4; moreover, impacts were further distinguished between disturbances that take place during the *Construction phases* (C), and disturbances that would take place as" normal" effect of the defenses' functioning, or *Operational phase* (O).

Code	Description of the main potential impacts
I-1	Loss of substrate linked to structure placement operations (also catch basin)
I-2	Loss of substrate variations linked to possible down-drift erosion phenomena and to the changed hydrodynamic conditions
I-3	Turbidity and suspended load linked to the movement of sediments
I-4	Loss and/or variation of substrate linked to sediment dumping on sea bottom and to the type of sediment dumped
I-5	Over-sedimentation (on all type of bottoms) and consequent bottom instability (soft bottoms only) linked to the movement of sediments
I-6	Eutrophication linked to the reduced water exchange
I-7	Trampling
I-8	Noise
I-9	Variations in the piezometric levels of the underground waters
I-10	Removal/movement of substrate linked to structure placement operations (drainage systems and drainage pipes)

Table 7 Main potential impacts from the Impact vs habitats and species matrix (Paganelli et al., 2013)**.**

Like sedimentary stock, ecosystems suffer sudden effects, and even long-term feedback. For instance, although different species of fish, larvae and mussels were observed in the Australian coast becoming able to colonize artificial substrata, their population's density changed. This caused food availability limits, and consequently a decrease on the average sizes of the individuals and their reproductive potential (Moreira et al., 2006). Even in this case, the tests were conducted within test sites where seawalls were installed, and even here they appeared to have a relevant impact. Very few exceptions were indicated in literature. They regarded experiences such as tidal inlet or erosion with poor sediment availability. In these cases downdrift groynes and jetties could respectively prevent longshore drifting to the exits into the inlet and intercept enough sediment to restore the sectors suffering lack of sediments (Griggs, 2005; Van Rijn, 2010). But as aforementioned, the negative feedbacks that usually arise from hard structures are likely to compare and transform small scale interventions to the cause of regional phenomena.

The main modifications from hard structures interest the vertical distribution of species and nutrients, and the consequent dominant intertidal and shallow subtidal habitat. This is the response of the ecosystem to the changing of slope and topography, that also provokes the cross-shore migration of sediments.

They are strictly affected in both, its distribution and availability. For these reasons, Protection strategies today should be considered only to preserve vulnerable areas. Conversely, at the present time it is still applied where countries choose to develop other industrial fields onto the coasts. They economically substitute the potential coastal tourism's incomes with others, such as, industrial harbors, or even developing a modern tourism made of resorts and swimming pools where "coasts are replaced by sea.

With these contexts the cost benefit analysis and the economic aspect is evidently the biggest aim of coastal development programs within CEMs. The tendency to keep building hard defenses in fact is still strong, while promotion and supporting campaigns to contrast hard defenses have been officially taken just in the closest past (Salman et al., 2004). Nowadays, this is practicable using the knowledge we have on coastal systems, and even regarding the feedbacks that take place where coastal systems are transformed in vulnerable areas.

Armored shorelines are today worldwide very diffused; already in 2005 Griggs wrote that about 10% of the Californian coastline was already armored, especially in that regions where humans' activities reached the highest densities. Impacts and costs are both very high; in the same places coastal sceneries, losses of regenerative potential (Garcia-Ayllon, 2018), and sediment supply were coupled to a range of costs from $6,000/m to $25,000/m.
Other examples of defenses' costs were reported by Van Rijn, 2011, relative to European prices and rates (Table 8). They comprise the structures that we have briefly investigated previously; other types of solution such as dune rehabilitation and drainages will be explained later in the Nature Based Solution section (2.6) within this chapter.

Type of structure	**Construction + maintenance Costs over 50 years (Euro/m coastline per year)**
Straight rock groynes	50-150
Rock revetments	100-200
Shoreface nourishments (every 5 years)	100-200 (if sand is easily available)
Seawalls	150-300
Beach fills (every 3 years)	200-300 (if sand is easily available)
Submerged breakwaters	200-400
Emerged breakwaters	250-500

Table 8 Investment cost of shoreline protection measures, modified after (Van Rijn, 2011)

From the table above sand nourishments are the most expensive and complicated to maintain. Their lifetime in fact is just 1-2 years, and the prices vary sensibly depending on the sand availability. For this reason, other structures such as groynes or breakwaters are more used, and even because the risk assessment does not consider their effect on the morphodynamics and sedimentary stock depletion.
Indeed, in Italy beach erosion is process resulting almost exclusively from sediment supply reduction, and harbors construction on sandy beaches. Pranzini in 2018 reported about morphological constrains in coastal areas because of infrastructures and activities related as the first cause of coastal erosion, before tourism. The Figure 2.37 has been extracted from the same paper, and is also available in the last national study on Italian coasts (MATT-Regioni et al., 2018).

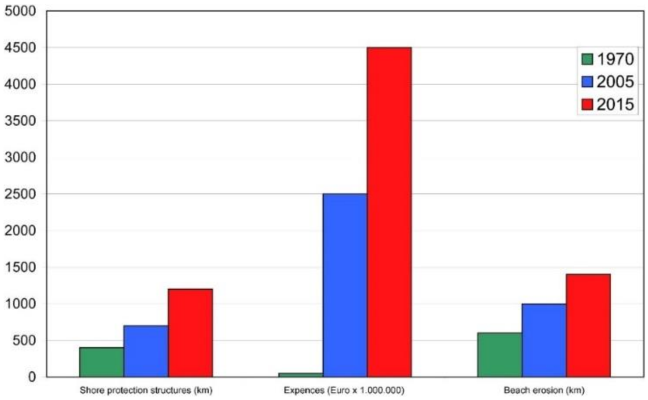


Figure 2.37. Shore protection works and beach erosion trend in Italy (Pranzini, 2018).

In 2015, an extension of armored coasts exceeded 1000 km for a total expense of 4.5 billion Euros. The crucial data is the kilometers of eroded beaches that increases together with expenses and protected lengths.

As explained previously shore protections through defenses can cause strong changes in the morphodynamics and reduction of the active beach. Coupled with the climate changes effects, these practices generate a significant threat for coastal organisms and further the loss of habitats. The examples of seawall are the most representative of some processes such as *coastal squeezing* and *coastal narrowing* (Pontee, 2013). These kinds of defenses literally fix the coastline creating hard limits that confine habitats and ecosystems between them and the sea (Figure 2.38).

Normally, organisms move landward in response to erosive forces and SLR. With the last scenario the constriction of habitats to these narrow areas is defined as coastal squeeze, that is further affected by the increasing frequency and magnitude of extremes (Speybroeck, et al., 2006). Differently from squeezing, coastal narrowing consist in the decreasing of the coastal zone width, that not always produces the loss of habitat. Pontee, 2013 gave some clear example related to the salt marsh erosions caused by wave climate or the migration of intertidal channels, that are not directly produced by defenses, neither implicating any habitat loss.

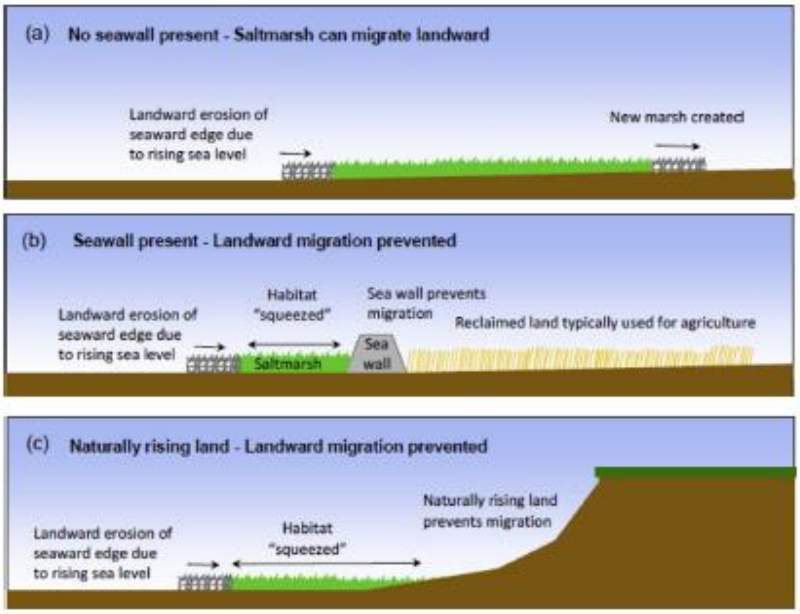


Figure 2.38 Coastal squeezing dynamic (Pontee, 2013).

These processes could be generically classified as humans' made effects, or urbanization's effects. *Urbanization* consists in the conversion of land from a natural state or managed natural state to cities through which an increasing percentage of the population come to live in settlements that are defined as "urban centers."

Urbanization process spread during the XVIII century, when elites' tourism required more enjoyable and healthier beaches. Services connected to tourism, such as infrastructures and resorts, were intensified during the next century and drastically increased in the XX century (Martins et al., 2009) changing biotic and abiotic conditions that even today are not completely absorbed by the environment (Bulleri and Chapman, 2010). Again, these effects are mostly driven by wrong management policies, that still today especially at a regional and local scale miss sustainable criteria to regulate the usage of the littorals.

This is the case of France reported by Meur-Férec et al., 2008, where during the last century people moved to coastal settlements (Figure 2.39). These trends affected the natural littoral organization after the realization of secondary residences, harbors and tourism recreations (Meur-Férec et al., 2008).

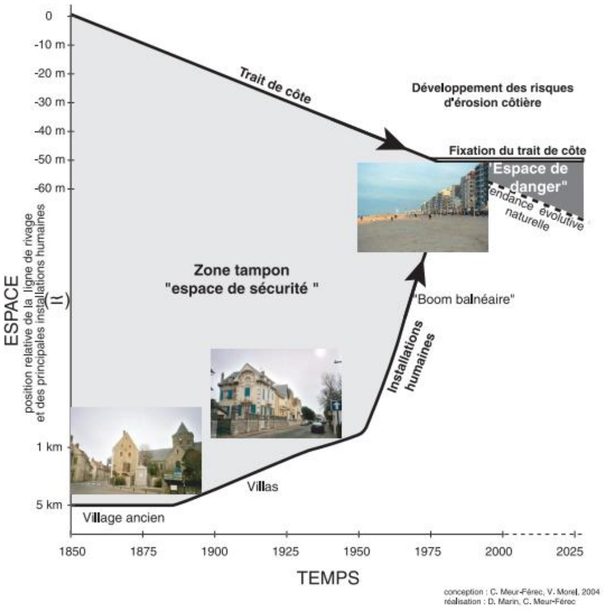


Figure 2.39 Dynamic of the coast occupation by the urban settlements after (Meur-Férec and Morel, 2004)

Urbanizations provoke natural depletion, and more in general the activities that deeply affect the coastal resilience cannot be achieved at any meaningful timescale (Cooper and Pilkey, 2012; Griggs, 2005).

2. Accommodation

Accommodation is a practice that needs a high degree of knowledge of the physical parameters, as well as cost benefit analysis. Basically, it consists of us keeping use of the areas exposed to floods and extremes without preventing their impacts. It foresees that humans' activities would continue to be applied but with a good level of preparedness that would avoid great damages, and at the same time ecosystems and sediment to be naturally restored. To its application modern construction methods and land change projects would respect natural spaces and the so-called Nature Based Solutions represent an innovative approach to couple the two aims.

The ecosystems would benefit from this strategy since their migration landward would be permitted, and the coastal squeezing will have less chance to occur.

It appears clear that population living on the coasts should settle at least far from the coastal zone (as defined by EU), while management must foresee monitoring plans and usages that most of the time consists in agriculture and natural areas. Thus, economic values in this case are seriously threatened, and for this reason accommodation is not so used to solve erosion issues in urbanized contexts.

3. Planned retreatment

Conversely to accommodation, planned retreatment has been experienced several times where extremes did not give the opportunity to adapt defenses, facing emergency scenarios.

As a planned strategy it consists in the set back from the shore, that can be done just after a precise cost benefit analysis. Further occasions as already mentioned are the ones of impossibility to perform defenses, or where they result more expensive than to relocate exposed goods to other areas. Space that would host the shifted activities is not always available, and the presence of private properties within the coastal zone complicate the decisions about their relocation (Crooks and Turner, 1999; Griggs, 2005; Pilkey et al., 2016). Griggs already investigated on feasibility of planned retreatment in the U.S. and as we are understanding from these few lines it is mainly an economic problem, since the values that private investors give to their properties always exceed the real values; moreover, the alternative is to reinforce the vulnerable areas, that means even to create artificial spaces that can be actively occupied and become an opportunity even for the building industry. The same author addresses this dynamic as the main responsible for the increasing of 400% of armoring coasts in California from 1971 to 1992. This kind of strategy could seriously face the realization of hard structures for longer life duration designs, preserve ecosystems and offer more natural and enjoyable landscapes.

Another peculiar case of impossibility to relocate is represented by historical and cultural heritages, that are threatening, especially in the Mediterranean area. Indeed, our coasts in the past were approached severally by new colonizers and inhabited by the biggest cultures of the past. Witnesses persist on our coasts, where erosion still did not destroy them. Few examples are present in the South of Italy, Spain, and Greece; here the poor management plans consist of hard protections as the most common of the strategy (Figure 2.40).

Figure 2.40 (A) Damages caused by high waves during 2015 at Monasterace Marina (Ionian south coast of Italy); (B) Hellenic archeological site (IV century BC) protected by the structure is individuated by the white arrow; image source: www.bivongitheristis.altervista.

4. Use of Ecosystem

It represents a new strategy that is till poorly tested, but that is finding great interests within the scientific community. Even for the use of ecosystems a deep knowledge of ecological and physical parameters is strictly required to avoid further stress on vegetal associations. In fact, ecosystems have the natural ability to reduce extreme wave effects (Shepard et al., 2011), and their growth can keep pace with sea-level rise by means of sediment accretion if available through its fasten and capture (Kirwan et al., 2010). They can provide other benefits that go beyond the realm of the coastal protection (e.g. supporting fisheries and tourism, reducing CO2, amongst others) (de Jonge, 2009; Gracia et al., 2018; Munang et al., 2013).

. Furthermore, the use of ecosystem implies its substitution to protection strategy, even if its effects are not everywhere homogeneous (Temmerman et al., 2013).

Examples comprise the restoration of wetlands, dunes' coverage, and biogenic reef, and nonetheless to plan designs that would allow the habitats in set back after extremes or climate change effects. Management based on habitats use can be applied worldwide, particularly in areas that have space between existing urbanization and the coastline.

5. Sacrifice, or do nothing

Finally, the last option is to abandon the structures, and every other action made on the coasts to protect or even restore, and let the coastal processes invade the lost spaces again.

Property loss is an unlikely planned expectation, and indeed strategies that foreseen it rarely were adopted. But, in some cases, the expenses to defend or even to adapt are higher than to just leave and settle somewhere else.

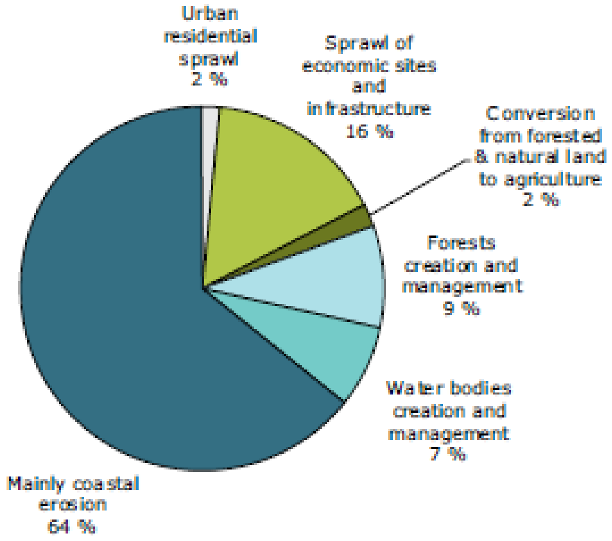
All the options we just cited, still need to be further investigated; in fact, the knowledges concerning costs and physical characteristics of the system, or even proper national and local policies are very weak at the present time. This will minimize expenses and most of all the occurrence of risks for future coastal sustainability (Sterr et al., 2000).

As already denoted the main gaps concerning the organization and sharing of data, that are rarely available even if sometimes public administrations acquired them twice or more ("Shoreline Management Guide," 2007). The competition between authorities, and the scarce use of scientific contributions to the management increased sensibly the normative fragmentation.

The importance of this project is strictly related to the need that Italy and Europe have incorrectly managed to transition areas in a more sustainable way than the one adopted at the present time, to prevent natural disasters and the depletion of natural resources, such as soil or beaches.

According with EUROSTAT, in 2007, almost 196 million people lived in the 446 EU coastal regions, corresponding to 43% of the inhabitants of the 22 Coastal Member States, and most of this coastal population was concentrated in 194 cities with over 100 000 inhabitants located within 50 km of the sea. However, it is more difficult to establish a universal definition of coastal zone about its geographical boundaries since these depend on the aims of the study. For instance, in Denmark, the Planning Act (1991) defines the landward boundary of the coastal zone as a 3 km inland from the coast, and the seaward boundary as the shoreline, but in Spain, under the Shores Act (1988), the landward is up to 200 m from the inland limit of the shore 16, and the seaward the same as in Denmark. The European Commission operated from 1996 to 1999 the European

Demonstration Programme on Integrated Coastal Zone Management (ICZM), with the aim of providing "technical information about sustainable coastal zone management, and stimulate a broad debate among the various actors involved in the planning, management or use of European coastal zones. According to the EC Demonstration Programme on ICZM, coastal zones are defined as "as a strip of land and sea of varying width depending on the nature of the environment and management needs. It seldom corresponds to existing administrative or planning units. (Lavalle et al., n.d.).
However, in Europe the EEA defined the main characteristics of coastal erosion drivers, that match with some considerations we already did in the previous chapters. Figure 2.41 resumes these causes as not just coastal erosion stressors, but even in the view of ecosystems' depletion (EEA, 2010).



Note: Geographical coverage: EU except Greece and the United Kingdom.

Figure 2.41 Causes of changes to coastal ecosystems (European Environment Agency, 2010)

Nowadays, the normative framework that is observed at a European level consists of:

- EU Water Framework
- Directive 2000/60/EC
- Integrated Coastal Zone Management (ICZM) (European Commission 2002; European Commission 2008)
- and for the management of flood risk (European Commission 2007)

Moreover, the actions made by the Italian Government to respond to the Bolkenstein Decree - 2006/123/EC - (European Parliament, 2006) denoted that also the applicability of normative rules are hardly integrated. The national constitution in this case is applied to maintain the sovereignty of the territories, showing how important and influent the economics are. After the Directive 2006/123/EC, the concessions on the maritime domain must be released after a transparent evaluation of the competitors every five years, to assure the free market competition. In 2009 the European Commission sent a default notification to Italy inviting the government to correctly apply the decree. After 10 years (2019) the last Finance Bill presented by the government in charge, extended the concessions to 2034! This fact results in a huge bureaucratic and expensive

congestion, but it has highlighted that 33.3 % of the Italian coastal regions do not have a decree that regulates the numbers of concessions, even if in Italy 60 % of sandy coasts (2007.6 km) are occupied by seaside establishments and private business. In these regions the over occupation of the beaches represents a threat to the distribution of benefits, and the automatic renew of concessions for long periods can create favorable conditions to the stabilization of hard structures on the shore.
Through the National Guidelines for the coastal management -Legislative Decrees n. 152/2006, n. 49/2010 and n. 90/2010 - Italy conformed to the previous European Directives, and each region is authorized to issue its own normative law within which they mainly demand to the local authorities (municipalities) the planning and control of maritime domain in their territories. Consequently, the document named Piano Comunale di Spiaggia (PCS) contains the local plans that is studied in respect with the regional guidelines (Piano di Indirizzo Regionale -PIR).

2.3.2 Coastal Erosion Assessment

Risk assessment is temporally consequent to the *Vulnerability assessment*, that focuses to understand coastal erosion mechanisms, to define the exposed socio-economic values, and to plan options to face this issue. Generally speaking, vulnerability to environmental hazards means the potential for loss, and that to be identified needs to evaluate at least three tenets (Cutter et al., 2003), such as:

- ✓ an exposure's model
- ✓ the assumption that vulnerability is a social condition, or a measure of societal resistance to hazards
- ✓ the integration of potential exposures and societal resilience with a specific focus on places or regions

After we answer the questions "*what is exposed to the hazard? and how much? s*trategies to control, reduce and even transfer risks that would directly affect also productive sectors can be dimensioned. In fact, vulnerability and exposure displays the degree of the risk, and the definition of classes and future scenarios of the risks.

Several methodologies were developed to determine vulnerable areas to coastal erosion, as well as the degree of severity to which they are exposed. Morphological trends are usually computed to determine shoreline displacement, and the most common is the DSAS plugin of the ArcGis suite from Esri (Rangel-Buitrago et al., 2015; Thieler et al., 2009). This tool is based on a Transect Based Analysis (TBA) of the shoreline and calculates the distance (meters) between the oldest and the more recent shoreline that is usually acquired to the usage of a Global Positioning System (GPS). Following the Italian guidelines for the assessment of coastal erosion, quantities of displacement should be expressed in cubic meters (m^3) in order to calculate volume of sediments in input and output from the beach's sectors in a more exhaustive Area Based Analysis (ABA) (Anfuso et al., 2016; MATT-Regioni et al., 2018). Geographic Informative Systems (GIS) are powerful software that permits us to compute and interrogate big databases supported by satellite and aerial images.

Risk assessment procedures, and Vulnerability methods are nowadays well known, and even their computation using indices represent some of the most advanced experiences. Theese methodologies can be classified according to different characteristics, but an exhaustive classification between risk's classes are not exact (Anfuso and Martínez Del Pozo, 2009; Bonetti et al., 2018; De Girolamo et al., 2006; Di Paola et al., 2011; Kantamaneni et al., 2018, 2017; Ranieri et al., 2016b; Serafim et al., 2019; Veltri and Morosini, 2003).

Physical and morphological parameters have been proposed through these studies to build models and evaluate the sensitivity of coasts. The main gaps we would cover modifying or even creating new indices are necessary to integrate and define a resilience assessment (Rumson et al., 2019b). We think that this evolution would integrate approaches from diverse fields of research, matching normative requirements that allow public and private stakeholders in the coastal management.

Crucial information to complete the main picture of the assessment can arise from geomorphological mapping, that even if was already addressed as a main tool for the urban planning, very rarely is used by managers (Shrestha et al., 2005). Indeed, it registers the interaction and results of involved matrices in the coastal system -comprising humans' activities- and topography.

The using of the most modern technologies for the Earth observation were widely applicated to the study of coastal risks, but often have produced generalized geomorphological settings that were lately scarcely integrated to the risk and resilience assessment.

A main direction to carry on a coastal erosion and resilience assessment is shown in the Figure 2.42 (McLean et al., 2001).

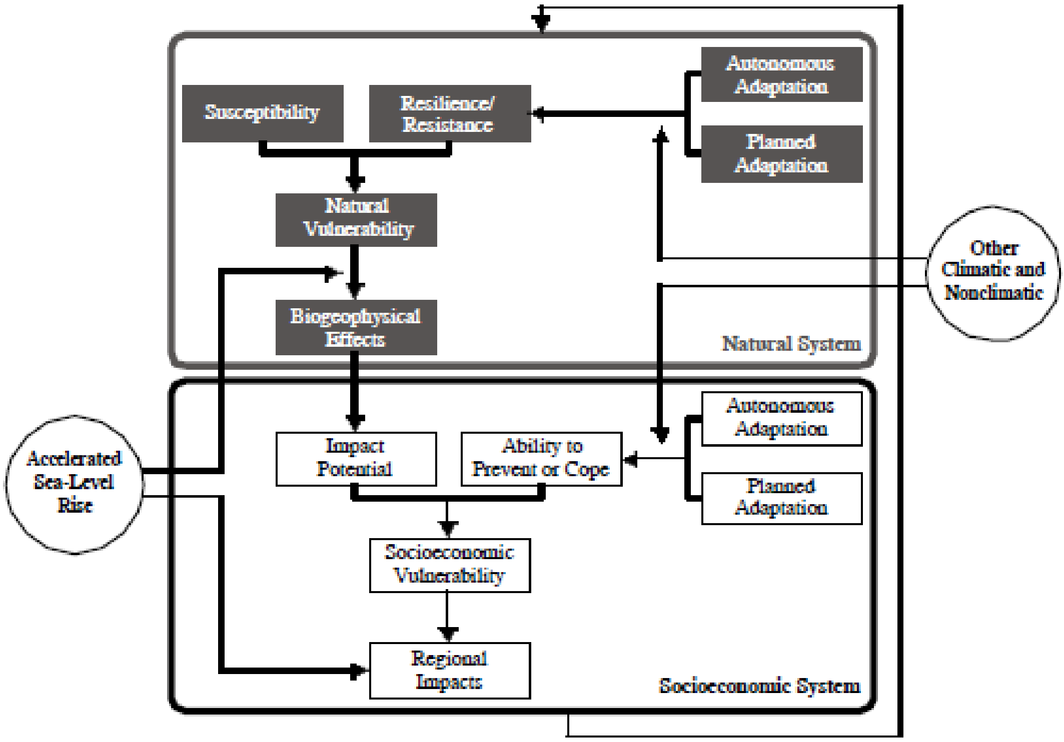


Figure 2.42 Conceptual framework to integrate Coastal Vulnerability assessment and resilience assessment (McLean et al., 2001).

Within the Figure 2.42 it can be understood how the approach we chose considers the capacity of the system to cope with several types of effects, that are usually not considered in the classical approaches. Further than morphological, even biogeophysical impacts are integrated in the risk's model. To this last, and generic example, it is not clear which features to include in the assessments, but as we explained previously in the State of the Art's Chapter (section 2.4) the effects due to coastal defenses are never included by the referenced authors. To this topic the results of the research line followed at the University of Cartagena by Garcia-Ayllon (Garcia-Ayllon, 2018; Garcia-Ayllon, 2018) represent the crucial phase to integrate in the classic method, together with geomorphological features (Bianco et al., 2020). Territorial changes indicators calculated by Garcia-Ayllon permit to include different groups of elements, to weigh them and to obtain proper values. Indices in literature are made to be applied worldwide, and even the requirements of European, and international community focused to create indicators that can be used and compared all over the world. This approach is not always resolutive, since very often a tested index does not give supporting results if applied in different settings (Cutter et al., 2009).

The parameters to include as indices are linked by a coevolutionary relationship (Sterr et al., 2000), and each index consists of a single indicator or an aggregation of indicators useful to simply illustrate and communicate complex phenomena, including trends and progress over time (EEA, 2006; OECD, 1993). As measure tools, the indices allow us to pass qualitative information of a territorial system's theme -even more than one- to a quantitative one (Kappes et al., 2012; Totaro et al., 2020).

Rangel-Buitrago et al, 2020 defined Hazard Index as a number that depends of Susceptibility and Forcing of coasts; if the first one measures the probability of an area to become damaged, the second is a value that gives an idea of the magnitude of the erosive process.

The same authors proved that Susceptibility is driven by the type of coast, hence its geomorphological characteristics and geological settings (Rangel-Buitrago et al., 2020).

Although the index-oriented methods allow us to insert any variable (physical and socio-economic) in the computation, these parameters are affected by the anthropogenic perspective that humans dominate nature, and also that, in the case of coastal erosion, defenses and hard structures are needed to preserve human's goods (Cooper and Jackson, 2019; McGranahan et al., 2007; Serafim et al., 2019). The value given to the benefits we have from the environment results always higher than the value of the involved natural resource in itself, and this is likely one of the main reasons why adopted strategies fail.

Nowadays, the classical methods have been replaced by innovative computation that integrate resilience and feasible natural-oriented approaches, since the scientific community understood the benefits from assess human risks to the ecosystem, rather than ecosystem risks to human interests (Cooper and Jackson, 2019; Totaro et al., 2020).

Actions and decisions that human beings made on the coasts drastically modify the natural systems to more usable environments. Nowadays the concept of sustainability in this field is used widely, and often without too much sense; advantaging of the capacity of the natural environments in fact, we satisfy our needs, but most of the resources we deplete are not renewable, and environmental functions (De Groot et al., 1992) are in some way overexploited irreversibly.

2.4 Coastal Resilience Assessment

Resilience can be defined as the ability of a system, community or even an individual exposed to hazard or traumatic event to cope and recover from the effects of a hazard. Within this definition even the preservation and restoration of its basic structures and functions is included
Literally, resilience means the ability to "resile from" or "spring back from" a shock, and the degree of capacity to resile is determined by the degree to which the exposed community has the "*necessary resources and is capable of organizing itself both prior to and during times of need*" (UNISDR, 2009).

Resilience assessment, in our case, registers the actual conditions of a site at the moment of the evaluation, hence could also constitute the point to which the coastal system should jump back after the occurrence of an erosive event, advantaging of its resilience potential (Klein et al., 2011). To plan resistant and resilient strategy to coastal areas can be considered the only smart action that would really permit to each natural system to preserve its characters and save the potential to regenerate themselves. In Figure 2.43 Lu et al described the dynamism that are supported by a natural system to cope with stressors, considering the space needed to accommodate changes, as well as the time that will be spent to reorganize (Lu et al., 2012). Resilience potential someway defines the limit of capacities to cope, that once is overpassed, represents a stress point after which any recover from the impact would be possible.

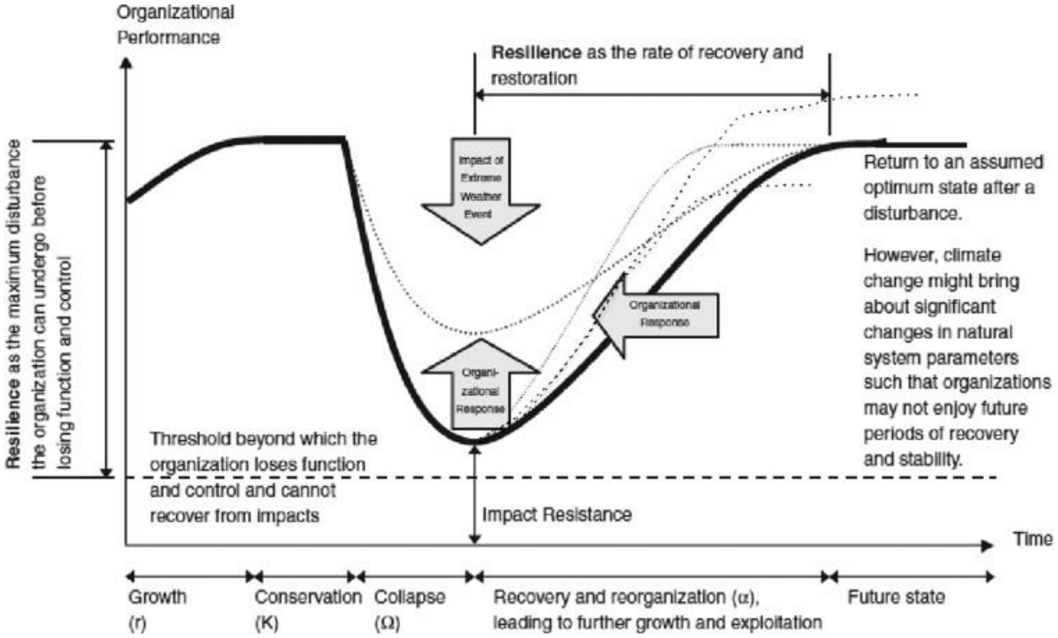


Figure 2.43 Resilience framework after (Lu et al., 2012)

Indices for the urban resilience were calculated, but mainly regards habitats status or urban capacity to re asset (Gargiulo et al., 2020).
Regarding coastal erosion assessment resilience still represents a utopic target hardly reachable, because of the same reason the foresees hard protections, or that want the coast to be usable and provided of services for recreation.

Even if in the last decades scientists, planners and decision-makers gradually realized that the adaptive approaches are needed to both, reduce risks, it is very difficult to find urban setting where resilient plans are translated in real designs (Totaro et al., 2020).

Climatic changes pushed toward a comprehension of these Adaptative projects to respond and moderates harms (UNISDR, 2009). Many disaster risk reduction measures can directly contribute to better adaptation.

Similarly to resilience potential *Adaptive capacity* is defined as the property of a system to adjust its characteristics or behavior, in order to expand its coping range under existing climate variability, or future climate conditions. Under this point of view resilience assessment could offer the opportunity to know physical limits that should not overpassed, and hence increasing coping capacity by supporting counteractor processes (Burton et al., 2004)

The resilience assessment we want to compute would consider different elements hardly comparable from a place to another. The natures of these elements, and the weight they have in the coastal system depend on the feedback that each of them release. This can be done using territorial changes indicators as has been already proposed by several studies (Garcia-Ayllon, 2018; García-Ayllón, 2017; Kumar et al., 2016; Lu et al., 2012; Sousa et al., 2011). Integrating the two methods vulnerability classes in which stressors and counteractors of the coastal erosion can be combined with the social justice index would be provided.

This approach also pushed coastal engineering to find new and resilient solutions to substitute to the hard ones (Hossain et al., 2012). Nature Based Solutions (NBS) in fact are a modern idea of projects inspired by natural processes. Their application is already well documented, and mainly focuses on the maintaining and restoring of natural settings. An example are the dunes' restoration projects in the Figure 2.44, that instead of replenishing or implanting vegetation associations to fix the eolian sands, aim to avoid their loss by the controlled accesses and the blowout creation (Paganelli et al., 2014).

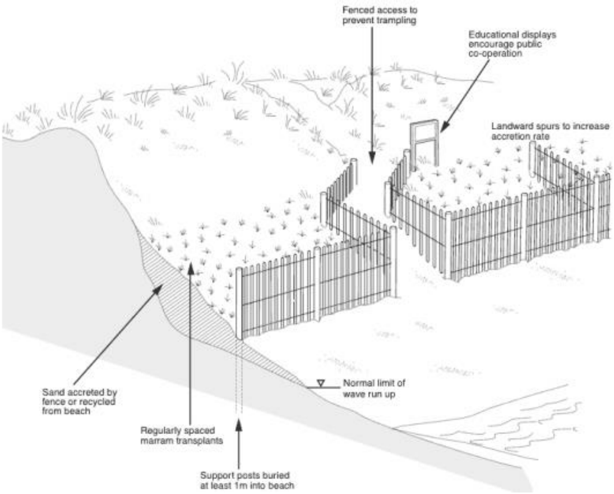


Figure 2.44 Dune's blowout control through controlled accesses (www.snh.org.uk)

Cost benefit analysis of NBS and effects related were already investigated successfully (Deltares-GFDRR, 2016; Narayan et al., 2016), and addressed ad a real alternative to soft and hard defenses. What is missed is the quantification and evaluation of the existing structures, and the real feedback they release to the natural system.

Resilience assessment through an index-oriented approach is possible if adapted at local or beach scale.

3. INVESTIGATION HYPOTHESIS

Research line of the present study is very articulated, since we already described coastal system and management comprises matrices that have completely different sources. Already within the State-of-the-Art Chapter we investigated CEMs and the modalities with which classical assessments are carried out. We criticized the way they are performed, and most of all the gap that exists between assessment and resolutive actions. Indeed, management actions made by administrators very infrequently follow the prescriptions and results of the assessments. Decision - making process in this field must encompass bio geophysical, economic, institutional, and socio-cultural factors to guarantee the sustainability of development plans, as well as the right distribution of derived benefits. Sedimentary stock can be strongly affected by human induced phenomena. These feedbacks directly affect the sediment availability on the active beach, through the creation of services on the maritime domain territory, that comprise touristic, fisher and harboring ones. During the time frame 2007- 2010, coastal tourism in Italy represented 25% of the new visits, with more than 60 % of the tourists that visited coastal sites preferring areas with low urbanization levels and cultural heritage (Petrella et al., 2019). These trends reflect the up mentioned data regarding the findings of the EEA, that in South Italy and Spain individuate increasing pressure.

Concessions are issued by the Italian Minister of Infrastructures and Transport, that in 2018, issued 52,619 of them to private investors, occupying a surface of about 19 x106 m2 of sandy beaches (Legambiente, 2018). More than half of these concessions (27,335) are used by touristic services, such as beach clubs and beachfront resorts, and they involve a total of 528 different institutions, such as Municipality Administration, Regional offices, coastal authorities (Ministero delle Infrastrutture e dei Trasporti, 2018). In Italy tourism represents 5 % of the Gross Domestic Product (GDP) that in 2018 was 2,084 Trillion Dollars (Petrella et al., 2019; World Bank, 2020). These data were analyzed since they show the measure with which maritime domain is occupied by economics, that directly advantage from the beaches' sedimentary stocks.

Italy has approximately 7500 km of coast, 4000 (53%) of which are sand or gravel beaches (Pranzini, 2018); its length covers 6734.2 km also comprising the two main islands of Sicily and Sardinia (respectively the biggest and the second biggest island in the Mediterranean region). 50 % of Italian coasts are sandy (3346 km), 34 % are rocky, and the last 16 % is occupied by anthropogenic urbans; it reflects the vulnerability of Italian coastline considering the relationships mentioned in the previous paragraph.

Even the normative rules adopted at the present time in Italy are very weak and fragmented; they are demanded from the European Committee to national authorities, who themselves demand firstly to regional and provincial and later local. Normative guidelines even exist for mapping activities, such as the Urban planning and the geomorphological mapping. They are two fields that we will investigate to produce mapping tools through which infer morphological trends.

The assessment we performed is composed of the morphological components that we have determined based on shoreline and bathymetric quotes of the seabed displacements, together with sedimentological changes within sediments samples. These data were acquired by the Department of Earth Sciences of the University of Florence during the timespan 2000-2018 and are summarized in the Table 9.

Unit	Length (km)	Shorelines	Bathymetries	Samples
San Vincenzo	13	9	3	100

Table 9 San Vincenzo's dataset

These data, together with sea state parameters available from the Beach Erosion and Protection in Tuscany Project, and on the institutional website www.mareografico.it (wind's data), were used to define the physical conditions of which the test site is composed.

A second stage comprised the geomorphological mapping of the municipal maritime domain of San Vincenzo, that were integrated with the previous data providing a complete overview on the area.

Normative to assess the condition of the examined coastal area, and to map it were followed basing respectively on the last guidelines updated by the Italian Superior Institute for Environment Protection and Research (ISPRA), and the Region of Tuscany ("Linee guida per la realizzazione della Carta Geologica eGeotematica alla scala 1," n.d.; "Regione Toscana - DB Geologico," n.d.; MATT-Regioni et al., 2018).

Further supporting data were the satellite images available at National cartographic portal (Ministero dell'Ambiente e della Tutela del Territorio e del Mare) also obtained from Landsat 8. Those supports were used to analyze the different settings that the site assumed during and after the realization of the touristic harbor at San Vincenzo, that represents the biggest impacting structure ever realized there.

The methodology represents an innovation of the classical vulnerability approach, that further than determine exposed areas to coastal erosion risk, and economical values determined through GDP or regional and local businesses, will be performed through an index oriented method that also consider the effects of humans' activities on the sedimentary stock. This research line allows us to classify stressors and counteractors of erosive processes, as well as feedback released on the ecosystem, that provide knowledges on the resilience potential of the tested littoral areas.

Normative cited before are also investigated to highlight the main gaps, and even resources that could help to make ICEC a resolutive and applicable criterion.

The relationships that exist between the social justice arising from the coasts - or the way in which human rights are manifested in the everyday lives of people, at every level of society (Cooper and McKenna, 2008; Edmund Rice Centre, 2002)- and the usage of the beaches as a recreative function. A similar approach has been already applied to environmental management (Dobson, 1999; Kasperson and Kasperson, 2001; Syme and Nancarrow, 2001), considering different aspects between social justice and sustainability. In our study these aspects are linked to the potential of resilience of the beaches since they are able to show particular effects due to the increasing density of the concessions on the maritime domain, and hence coastal erosion phenomena affecting the sedimentary stock threat, and the distribution of benefits. Following this approach, we want to demonstrate how even prices and choices on the economy of the coasts are at fault of the natural potential of regeneration of the natural environments such as the coastal ones.

4. METHODS AND TIMELINE

Generally talking, Italian management plans focused on the infrastructures and hard defenses realization. Through Urban Local Plans (Piano Strutturale Comunale), and Beach Plans (Piano Spiaggia Comunale) the municipalities align with the Provincial and Regional ones on the management of the administrative territory. Since flood risks plans and risk mitigation actions are always realized within emergency scenarios, the environmental impact evaluations are not required during the hard defense designs.

Vulnerable areas to coastal erosion risk are determined by analyzing bathymetric and shoreline's displacement trends inferred from field surveys. This approach should allow us to investigate the sedimentary stock' status and anthropogenic processes that work on sandy beaches, following the workflow presented by Bianco et al., 2020 (Figure 4.1)

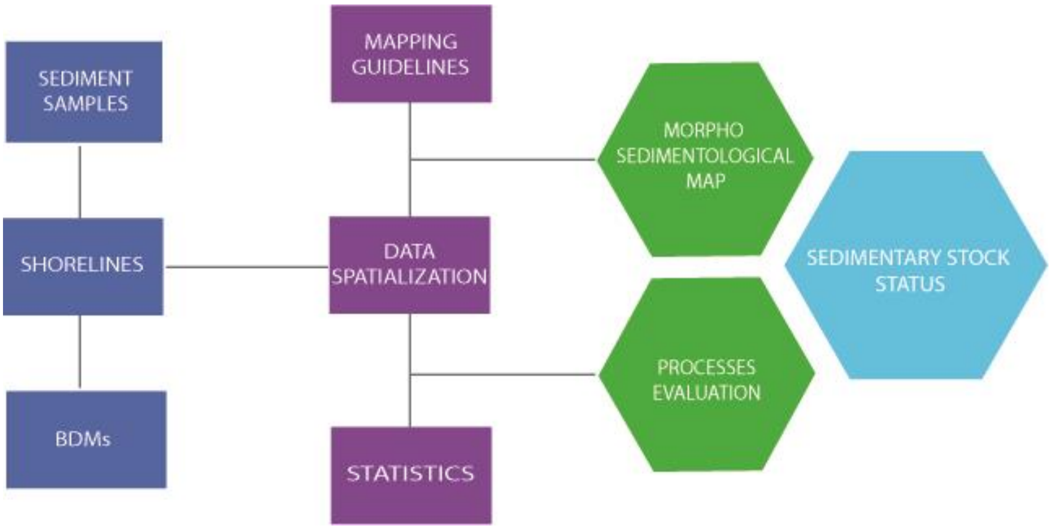


Figure 4.1 Workflow followed for sedimentary stock analysis.

By drawing a morpho sedimentological map supported by geomorphological and sedimentological parameters this method aims to perfect the ones already performed by other authors, that differently have always distinguished between geomorphological and ecological assessment.

Our research idea will comprise the prices' analysis of the touristic sector of a chosen test site; this would consider the real amount that each tourist would really spend to enjoy recreation services, suggesting how, and how much they affect morphologically and economically the sediment availability and the real economy.

This kind of investigation could be conducted looking for values on the most common and used online platform in Italy, that later would be spatialized within the beach's extension.

Willing To Pay (WTP) method already experienced by other, statistical trends of the economies, and questionnaires resulted very subjective; moreover, the numbers of interviewees, the questions to propose, and the different education of tourists bring us some doubts on the efficiency of these methods, without accounting of the different perception of risk and resilience that each of them have.

The risk for social justice that derives from coastal occupation is still poorly investigated from the scientific community, especially in Italy; it is demanded to different level authorities that should issue an adequate number of concessions, to allow free swimming and access to the beaches. This happens in some of the most updated normative in Italy, that unfortunately do not cover the whole national territory. So, guidelines in the mapping procedures, as well as in the concession issued will be studied to individuate the main gaps, as well as proposing an applicable resilience assessment after the understanding of physical trends that affect the shore.

The computation of indices that take account of the morphological, social, and economic is completed by the link with the potential of regeneration. It must consider the analysis of natural features and the modification affecting the areas after management actions.

This is a crucial stage of the assessment since the degree of subjectivity must be lowered as much as possible, and the feedback has to be spatialized recognizing real limits.

The next workflow (Figure 4.2) condensate the indices computations and highlight the stages through which the assessment will be carried out.

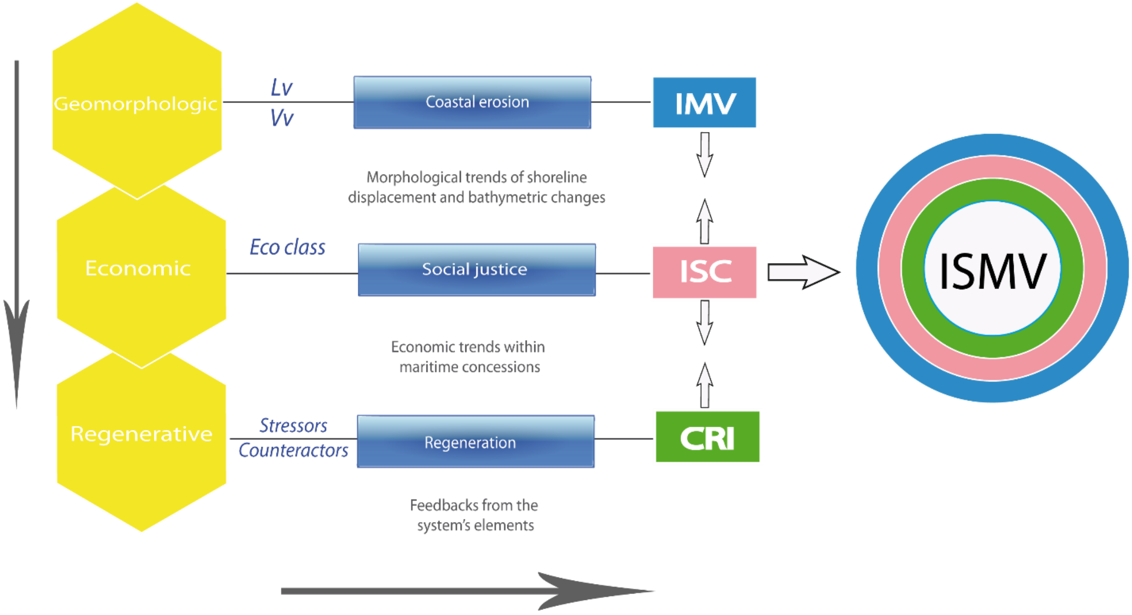


Figure 4.2 Workflow summarizing the work phases. Solid arrow on the left side of the diagram indicates the temporal succession of assessments (yellow hexagons); the solid arrow on the bottom reflects the computing process from factors, such as the Linear variation of the shoreline (Lv); Volumetric variation of the submerged beach (Vv); Economic classes (Eco Class); and Stressors/Counteractors analysis. The third pillar consists of the vulnerabilities that have to be determined. They are respectively the Index of Morphological Variation (IMV), the Index of Services' Cost (ISC), and the Index of Coastal Regeneration (CRI). The final Index that will be derived is the Index of Social and Morphological Vulnerability (ISMV).

4.1 The Maregot Project's Framework: San Vincenzo test site

The test site for our research was individuated within the MAREGOT Project. It is co-financed by the European Found to Regional Development, that is a cooperation area between Italy and France, and it has the goal to plan and support the prevention from the risks derived from coastal erosion. MAREGOT is part of a larger program called Interreg Italia-Francia Marittimo 2014-2020. Within it tests areas in the Regions of Sardinia and Tuscany were chosen as pilots' regions, since they are affected by coastal erosion phenomena, even though they have different and specific local peculiarities.

It would increase the economical competitivity of these Mediterranean areas supporting sustainable, smart, and inclusive strategies. One of them comprises the study of the transboundary regions' coastline through innovative technologies, to model and make decisions oriented to limit the usage of hard structures.

San Vincenzo is a municipality located in the north western Italian coast of the Mediterranean area. It comprises a coastal stripe 13 km long, extending NW-SE in the Livorno Province of the Region of Tuscany (Figure 4.3). The coastal stripe consists of sandy beaches interrupted just by the touristic harbor, which individuate the most urbanized portion of the San Vincenzo's maritime territory. Tourism represents the main industry of the municipality that attracts more than 1 million people per year -average of the last 13 years- (Regione Toscana and ISTAT, 2019). In 2015 the population comprised 6910 citizens (Comune di San Vincenzo, 2016) concentrated in 33.14 Km^2, while a total of 81 maritime concessions are irregularly distributed within the 13 Km length. They have been released by different authorities, and 35 of them are businesses managed by the Local Municipal Authority.

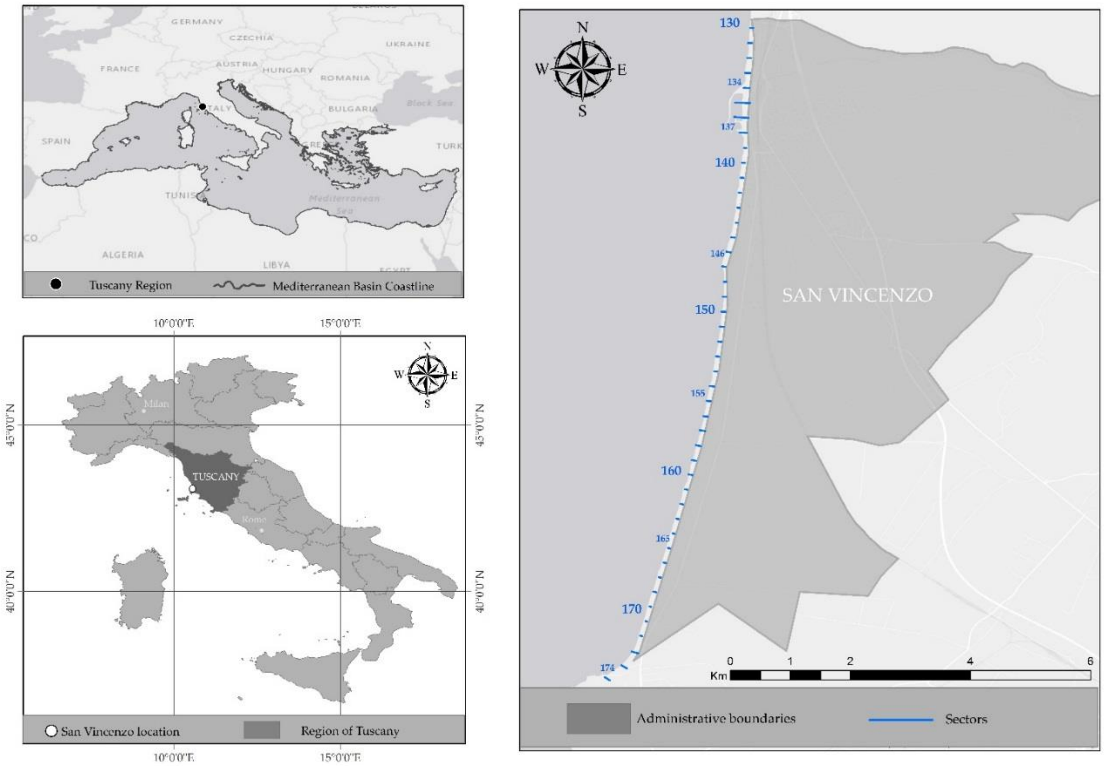


Figure 4.3 Geographical features of San Vincenzo; on the top left plot the test site location within the Mediterranean basin; on the bottom left part the framework within Italian regional organization can be observed and Tuscany region individuated; in the right part of the figure the San Vincenzo territorial domain with the segmentation of the littoral area.

For our assessment it has been divided into three sub-units (A-B-C) individuated by different hydrodynamics behaviors and anthropogenic structures that modified the natural settings of the littoral creating visible effects in the littoral currents, as well as the different management decisions.

The Sub-units individuated were further divided in sectors and numerated following the Region of Tuscany's coast segmentation, such as:

- North Harbor area; it goes from sector 130 to 134 and comprises the northern part of the municipality's maritime domain. It is about 1 km long and is occupied by 22 concessions consisting of establishments/associations/diving centers. It stops southward with the San Vincenzo's Harbor.
- South Harbor area is comprised between sector 138 and 146. It is 2 km long and hosts the harbor building and 49 concessions. Hard defenses here consist of a groin at sector 138, while at 142 the main channel of the area flows. The end of the sub-unit is marked by the sector 146 (La Punticella location), where longshore currents converge.
- The southern area is comprised from sector 147 to 174; it is almost 7 kilometers long, and it is interested by 10 concessions concentrated right in the first kilometer in its northern part, after which the Sub-Unit comprises a Natural Park.

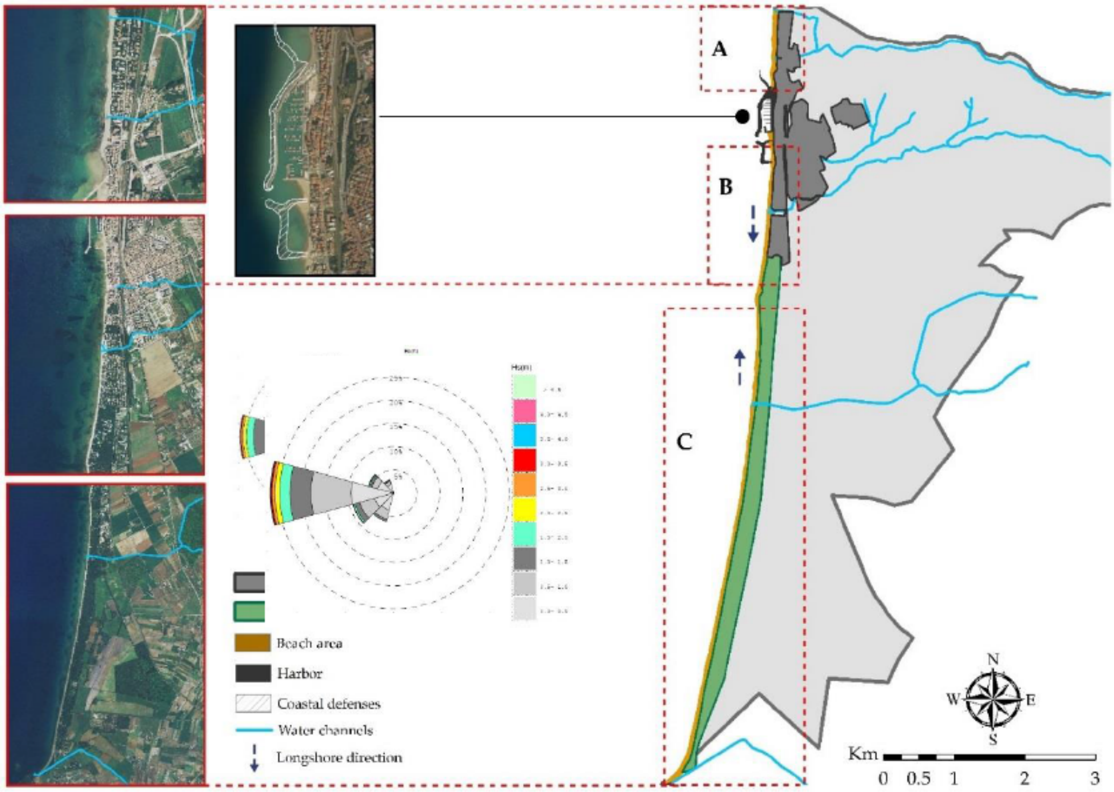


Figure 4.4. Partition of the San Vincenzo Unit and main physical attributes; the rose diagram relates with sea state (University of Florence and DEAM, 2007).

Some warnings were advised highlighted by previous studies (Mazzanti, R. et al., 1980), such as the comparing of erosive trends in the most preserved part of the littoral, as well as the disappearance of vegetal dunes' associations. Further events that probably stressed the coastal status comprise the building of a touristic harbor, the land reclamations, and the defenses realized parallelly with the harbor, during the last 60 years. All these features represent potential drivers of coastal erosion considering the above-mentioned references and trends; on the other hand, previous assessments on the area considered it a stable one in respect with coastal erosion. Our assumptions are made on the evidences within the literature; thus, San Vincenzo's coastal stripe should have an intrinsic potential of regeneration that provides it a site resilience. In some way it helped the coastal system to face to extremes, anthropogenic, as well as the depletion of dune's vegetation coverage.

To analyze the building phases of the harbor, hence the main modification caused by human's intervention, some aerial and satellite images were integrated through the GIS suite. These images were selected from the regional cartographic portal of the Region of Tuscany and is also available from Landsat 8. They relate to the periods 2004, 2006, 2013 and 2017 (Figure 4.5).

Figure 4.5 Harbor area evolution; from the left the images relate with the periods: 2004, 2006, 2007, 2013, 2017.

The sediment management at San Vincenzo has been made to confront emergency scenarios occurred and documented in Bianco et al., 2020. Particular attention was paid to the hydrodynamics that are very peculiar. In fact, the area has been isolated from the rest of the sedimentary cell by several hard structures on the northern side. Within the San Vincenzo's Coastal – Unit, longshore currents assume two directions -respectively N-S in the upper part, and S-N in the lower- meeting at a convergence point in the middle of the Unit. Another relevant element is the harbor, that represents a pass toward the offshore for the longshore currents flowing N-S. Other elements that affect the shore are the artificial reef built to create a closed basin at the harbor mouth, and the small canalized water channels. Although they poorly affect the sediment's discharge, their inputs were detected in Bianco et.al, 2020 on a sedimentological base

4.2 Morpho sedimentological mapping

Sedimentological analysis performed at the Centre of Geotechnologies of the University of Siena were utilized to calculate the main physical properties of the samples. They are Sorting (phi), Mean Mz (phi), and Fine fraction (%).

A geodatabase reporting these features has been built using the Esri ArcMap suite that allows their visualization and spatial interrogation.

The same suite was used to spatialize sedimentological data on the whole extension of the surveyed area (that in this case considers just the harbor).

To compare and infer sedimentological changes a grain size map was extracted and digitalized from Mazzanti et al., 1984. The trends in grain-size changes and mobility of the sediment allows us to observe geomorphic drivers in the sediment drifting in both directions - cross shore as well as longshore., while the average diameter (Φ) of samples was used to classify sediment's class of the beach.

4.3 Diagnostic indicators of territorial changes

Physiographic Categories were distinguished using morphogenetic, litho-morphologic and pedologic homogeneities, as shown in the Table 10. (Paganelli et al., 2014, 2013)

ID	Physiographic Categories
M1	Marine waters, mobile substrata
M2	Marine waters, hard substrata
M3	Posidonia oceanica prairies
W1	Estuarines and tide environments
W2	Swamp and ponds prone to tides
W3	Lagoons and coastal salt marshes
D1	Emerged beach
D2	Embryonic dunes and mobile dunes
D3	Continental slope of the mobile dunes, fixed dunes and stabilized sands
D4	Humid dpressions infra dunes and of the back dunes
C1	Rocky coasts and environments

Table 10 Physiographic Categories composing the territorial units, as defined by the European Directive "Habitat" (Council Directive 92/43/EEC, 1992).

The Index of Social and Morphological Vulnerability (ISMV) was computed to classify the active beach's vulnerability to coastal erosion, and to investigate the response that active beach gives to the space reduction. Morphologic trends, Economics, and Stressors/Counteractors elements of the area were introduced in the assessment through three respective sub-indices. They are the Index of Morphologic Variation (IMV), the Index of Service's Cost (ISC), and the Index of Coastal Regeneration (CRI). The calculation of these indices comprised conversion of trends in classes of vulnerability to obtain non-dimensional indices, as well to spatialize data.

The index of social and morphological vulnerability (ISMV) shows how cost of the services and morphological trends can affect both the resilience potential and the distribution of benefits. Within the vulnerability assessment, also a review of the normative framework was carried out to integrate the ICEC strategy in the administrative context in which it can be resolutive. The analysis individuated areas at a high, moderate, and low vulnerability. The solutions we propose aim to support the potential of resilience of the site, as well as considering the social injustice phenomena that can arise from our management decisions.

Through a vulnerability assessment, the Index of Social and Morphological Vulnerability (ISMV) was calculated. It indicates the level of vulnerability of a coastal site, considering phenomena that reduces the space for ecosystems and limits the citizen's right of free access and swimming. The index has been used as classificatory of the vulnerability classes, in addition to expressing the potential of resilience of the area. It is assumed to calculate the latter using morphological trends affecting the sedimentary stock since it represents the space necessary to support resilience (Bhamra et al., 2011; Bridges et al., 2015; Klein et al., 2011, 1998; Salman et al., 2004). Using territorial change indicators allows us to investigate each component, and to observe the feedback that they release. They provide crucial indications on the processes we can support or contrast, as coastal managers.

In our study morphological patterns of the site have been used to categorize the beach's sectors, while the maritime domain's concessions have been analyzed to attribute them an economical value. Previous papers (Anfuso and Martínez Del Pozo, 2009; García-Ayllón, 2017; Kantamaneni et al., 2018; Polsky et al., 2007; Rani et al., 2015) successfully covered vulnerability and resilience assessments, using different approaches. In the first case the use of land cover changes and shoreline displacement rates were combined with capital use considering each economic acting from 500 m to the shoreline landward. To produce vulnerability categorization classes' values were crossed. Capital use analysis is mostly referred to bigger scale assessment, such as regional or national, because they need to be comparable with other studies with the same or bigger scale, and solutions should include at least regional plans. Differently, our evaluation was conducted quantifying the value as the price to access the services provided on the beach. The economic assessment is not extended to those businesses that do not interest the beach directly. This choice arises since sediments availability at the test site is managed just to a beach level, hydrodynamics show a relative independence of this coast's portion to the rest of the belonging sedimentary cell, and the main channels that flow at San Vincenzo's beach have been regimented for land reclamation since the late 1700 (Mazzanti, R. et al., 1980).

An investigation was conducted on the web to obtain economic values, that later have been spatialized within the beach's sectors. It represents a risk for social justice that affect several regions in Italy. Social justice reflects the way in which human rights are manifested in the everyday lives of people, at every level of society (Cooper and McKenna, 2008; Edmund Rice Centre, 2002), and that has been already applied to environmental management (Dobson, 1999; Kasperson and Kasperson, 2001; Syme and Nancarrow, 2001). Considering different aspects between social justice and sustainability we could highlight that coastal erosion phenomena affecting the sedimentary stock threat both, resilience potential of the beaches, and the distribution of benefits.

The risk to restrict the right of free swimming and accessibility to the beaches by people, strictly depend on the management solutions carried out at the test site during the last 15 years (enlarging phases of the harbor). Considering these elements, the coastal stripe was first divided into three Sub-Units first, and then into sectors comprising homogenic territory portions of 250 m long.

4.3.1 Index of Morphological Variation (IMV)

The Index of Morphological Variation analyses the morphological trends of the active beach These comprise shoreline and bathymetric quote displacement. The active beach was individuated as the area between the backshore limit and the closure depth, -7 m (calculated with a return time period of 50 years). The upper limit of the beach was digitalized on the basis of satellite images from Esri 2018; it is represented by hard human-made structures in the sub-units A and B, and the base of the dunes within the unit C. Data obtained from the raster difference between two Bathymetric Digital Models -respectively from 2014 and 2018- have been spatialized on the whole extension of each sector in the submerged beach, and the variation of the quote of the seabed (m3/year) calculated. Similarly, shoreline displacement rates (m/year) were calculated per each sector. The two groups of values were converted as vulnerability classes -three per each group- as explained in the Table11.

Class Linear Variation	Range Values
1	6 - 0.05
2	-0.02 -0.48
3	-0.75 - -6.5

(a)

Class Volumetric Variation	Range Values
1	0 -2
2	-1 - 0
3	-4 - -1

(b)

Table 11 (a) Classes of linear variation of the shoreline displacement; (b). Classes of volumetric variation of the seabed.

The IMV was calculated per each sector first, and later per each Sub-Unit as:

$$IMV_{sector} = Vv_{(sector)} Class\ Vol\ Var_{(sector)} * Vl_{(sector)} Class\ Linear\ Var_{(sector)} \qquad [16]$$

where, Vv is the volumetric variation factor of the seabed,

Vl is the linear variation factor of the shoreline;

$$IMV_{sub\ unit} = \sum IMV_{sector} * Z / \lambda \qquad [17]$$

where Z and λ are respectively the area of the sector and the sub-unit considered, expressed in Km^2.

As we saw before these classes round from a minimum value of 1, where shoreline and bathymetric trends are accretionary; the maximum value of 3 is assigned to high erosive trends of the shoreline displacement and decreasing of the seabed's quote. Hence IMV value results in a range between 1 and 9.

4.3.2 Index of Services' Cost (ISC)

This sub index literally considers the price that common users must spend to benefit from the services that occupy the maritime domain territory. These businesses directly take advantage of the beach, creating accessibility's modification to the maritime domain.

At San Vincenzo, a total of 34 concessions cover 38,426.03 m^2 of maritime territory. They were analyzed regarding the typology of business, the surface they occupy, and the cost of their services. To determine their costs different sources were considered. This needed to be standardized since rates can variate depending on the touristic operator, owner, or online platform that sell the offers, and of course the type of offer. The businesses that take advantage of the concessions issued by the local municipality, are of two typologies:

1. *Beach establishments*: they offer daily, weekly, or monthly rates to rent beach umbrellas, beach chairs and beach loungers. 2 people were considered for a daily basic offer; it consists of one umbrella, one beach chair and one beach lounger (or two loungers). This

offer does not include the cost of showers -that cost an average of 0.5 € per shower- the cost of further loungers or chairs, and even the use of the toilets.

2. *Resorts*: they own private beaches where the same items of the establishments are offered with the same period rates, but the requisite to access the beach is to rent a room or an apartment. Resorts represent 65.7 % of the concessions; criteria to individuate the standard offer are the same for establishments. Hence, a room or apartment (depending on the resort policy and availability) for 2 people was selected in the options that foresaw the access to the private beach. Even in this case the beach items provided by the resorts consist of one umbrella, one beach chair and a beach lounger (or two loungers). All the resorts give free shower and toilets for their guests. Another variable in the standardization of the offer is the inclusion of room and board. The solution which included breakfast was selected since it is the most economical and is offered by all the resorts in our area, also Bed & Breakfasts.

Rates has been selected from the official structure's booking systems, and where they were demanded to specialize on-line platforms the most common used in Italy were selected, such as Booking.com (www.booking.com), and TripAdvisor (www.tripadvisor.it). An Appendix (Concessions) is included as an online resource in which concessions' number, typology, occupied surface, name, price, coordinate (in WGS84 reference system), date and platform of the offer estimation, sector of the beach they occupy are provided.

Prices of both the structure's typologies vary depending on the seasons and even the week of the year. The period of evaluation has been chosen analyzing the Tourism Database of the Region of Tuscany (Regione Toscana and ISTAT, 2019). The Database is made using statistical data from the Italian Institute of Statistic (ISTAT), and it is interrogable through queries directly from the institutional web site.

Reduced data were used to create a raster through the Esri ArcGis suite. The matrix contains spatialized values interpolated through an Inverse Distance Weighted operator (IDW). This method assumes that the variable being mapped decreases in influence with distance from its sampled location (Philip and Watson, 1982; Watson and Philip, 1985). It fits our target to spatialize a price value since the surface we obtain shows the influence of the price on a portion of territory, where the purchasing power of a more distant location will have less influence; in fact every user will pay just for an umbrella per day in a single establishment.

The ISC was calculated per each sector first, and later per each Sub-Unit as:

$$ISC_{sector} = ICO_{sector} * ICO_{conc} \qquad [18]$$

where,

$$ICO_{conc} = {}^{C}/_{U} \qquad [19]$$

$$ICO_{sector} = \sum (ICO_{conc})_{sector} \qquad [20]$$

C is the area of ach concession within the considered sector,

U is the area of the sub-unit within which the considered sector is located.

The ISC $_{\text{Sub-Unit}}$ can be calculated as:

$$ISC_{\,Sub\ Unit} = \sum_n^1 ISC_{\,sector} \,/ \sum_n^1 \frac{Z}{\lambda} \qquad [21]$$

Z is the considered sector area, and λ is the considered Sub-Unit area.

4.3.3 Index of Coastal Regeneration (CRI)

The Index of Coastal Regeneration is calculated to consider Stressors, that support the reducing of space, and Counteractors, that provide space/sediment. The ratio between the two classes of elements represent the potential of each Sub Unit to regenerate themselves (García-Ayllón, 2017). Counteractors were considered water channels and the sand dunes at Rimigliano National Park (Sub-Unit C), while Stressors are hard defenses and concessions. Weights between 2 and 3 were attributed to these elements as reported in the Table 12.

Counteractors	Values
Dunes/Park	2
Channels	3

(a)

Stressors	Values
Concession	2
Hard defences	3

(b)

Table 12 (a) Weight attributed to Counteractors elements; (b). Weight attributed to Stressors elements.

Using the values attributed to each class CRI was calculated as:

$$CRI = \frac{Rp}{Cp} \qquad [22]$$

where *Rp* is the sum of Restoring Processes in each sector of the Sub-Unit considered, and

Cp is the sum of Counteractors in each sector of the considered Sub-Unit.

4.3.4 Index of Social and Morphological Vulnerability (ISMV)

ISMV is a dimensionless indicator that relates all the sub -indices, and that indicates the degree of relative resilience in the three Sub-Units. It variates depending on both the groups of components of the coastal system, economic and morphologic ones, on their natures, nonetheless on their density in the unit considered. It was calculated as:

$$ISMV_{subunit} = \frac{\cup * CRI}{\pi * IMV * ISC} \qquad [23]$$

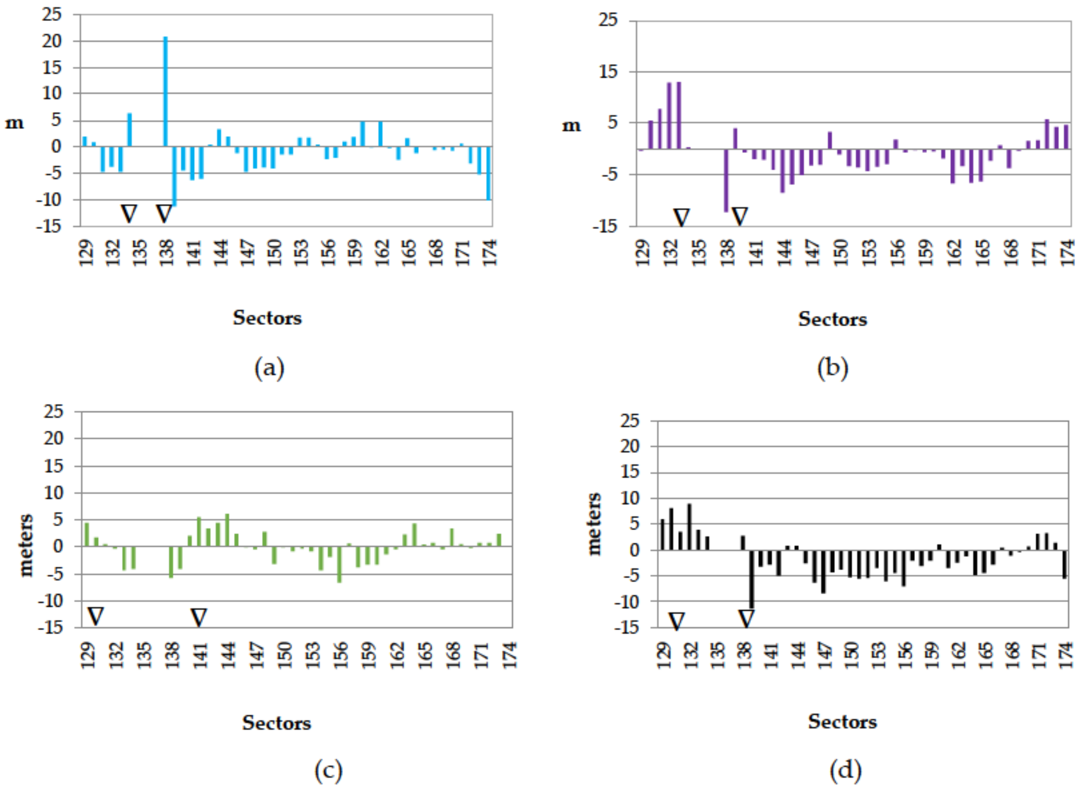
Π is the total area occupied by concessions in the Sub-Unit considered.

5. RESULTS

Basically, the model we considered covers the tourist industry and the sedimentary stock of the active beach, as the space hosting the ecosystem and human activities.
Sedimentary stock's status was evaluated through the morphological trends, and its physical characteristics represented by the morpho sedimentological map.

5.1 Shoreline's displacement

The fact that sedimentary inputs have been mostly provided artificially are clearer in the small-time timeframe (Figure 5.1). Some positive peaks in the graphs are exceeding 3 m and they relate to artificial nourishments and building works.



(a) (b)

(c) (d)

Figure 5.1 Shoreline displacement at San Vincenzo test site in the timeframes (a) 2005-2010, (b) 2010-2014, (c) 2014-2018, (d) 2018-2005. Sectors from 135 to 137 belong to the harbor area; the symbol indicates artificial nourishments or hard works (Bianco et al., 2020).

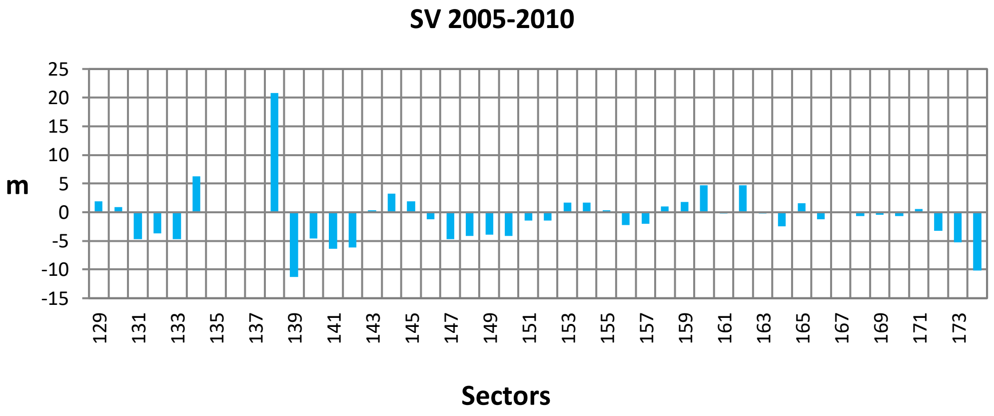


Figure 5.2 Shoreline displacement at San Vincenzo during the timeframe 2005-2018.

Alternate patterns, between drawing back and increasing from the shoreline were observed, even if especially in the southern part loss prevailed.

The maximum amount of loss is of 5 meters, while some increasing focuses occur at sectors 134, 138 and 139, that are just due to the replenishment. Sectors 138 and 139 register the building of a closed submerged reef built to protect nourishments and the landward areas within these sectors. Differently, the drawing back at the sectors 172 to 174 look more natural related than anthropic.

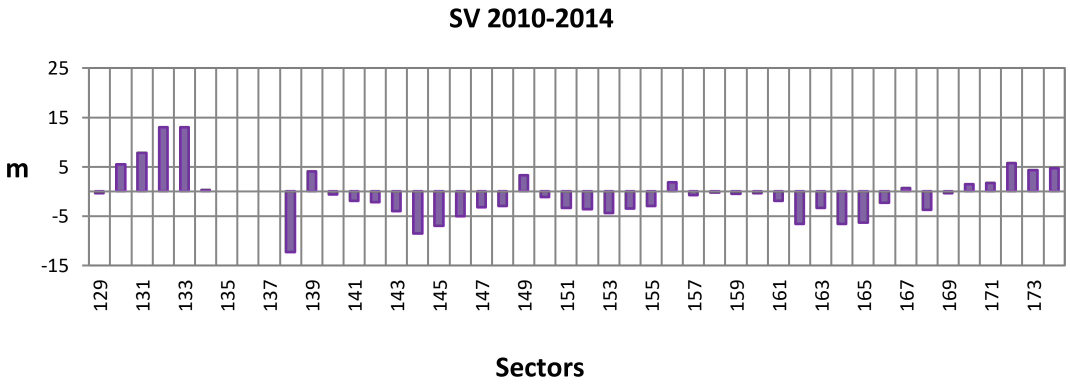


Figure 5.3 Shoreline displacement at San Vincenzo during the timeframe 2010-2014.

Once the building phases ended the displacement's trends inverted; a big increase can be observed from Figure 5.3 in the sectors 131 to 133 of about 13 meters, as well as in the sectors 138 and 139 in the southern side of the structure.

Other inversions occur from sector 143 to 145, and generally in all the rest of the littoral southern of the harbor. Different tendency is always present in the last four sectors where the geomorphological mapping clarified the existence of a Pleistocene submarine canyon connected with the old fluvial system, and that probably intermittingly attracts the discharge of sediment.

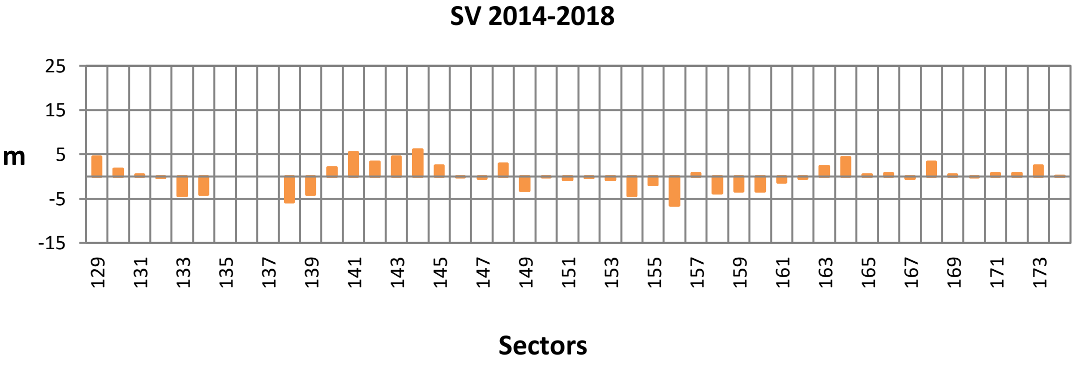


Figure 5.4 Shoreline displacement at San Vincenzo during the timeframe 2014-2018.

The period 2014-2018 is the most important data to analyze since it represents the phase after the harbor completion and registers the first response of the coastal system to the structure.

From the histogram in Figure 5.4 sectors from 129 to 131 (northern part) are increasing, while the lasts sectors of the sub-unit A are drawing back. Sub-unit B, in the southern side of the harbor a small increasing (4-5 meters) can be seen within sectors 140 to 145.

All the rest of the Unit registers a decrease in the shoreline position, except for some sectors where the increase is never higher than 5 meters.

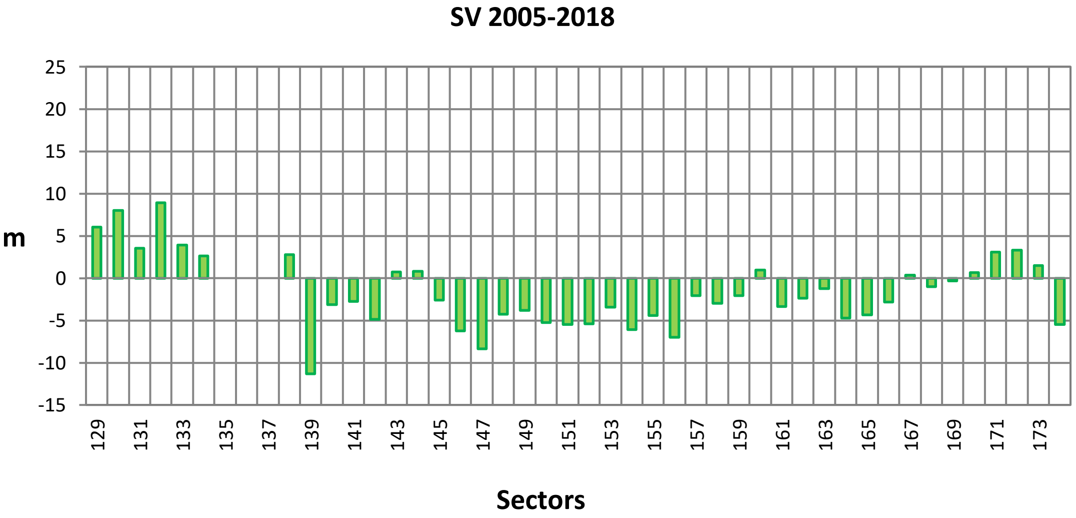


Figure 5.5 Shoreline displacement at San Vincenzo during the timeframe 2005-2018.

On the long-term analysis base (period 2005-2018) a clearer difference between loss and gaining of sediment by the shore is highlighted between the two areas respectively northern and southern of the harbor. The first one shows a positive trend increasing of a maximum value of about 8 meters (from sector 129 to 134), while in the southern part of the Unit (sub-unit B and C) the shoreline is constantly drawing back.

However, the variations rarely exceed the 5 meters distributed in 13 years, that would indicate a substantial equilibrium.

Moreover, in terms of temporal variation, the comparison between graphical patterns of the harbor area -sectors from 129 to 140- and the ones just on the southern sectors -sectors from 141 to 145- highlight a marked difference of the dynamisms, that appear smallest once we move southward.

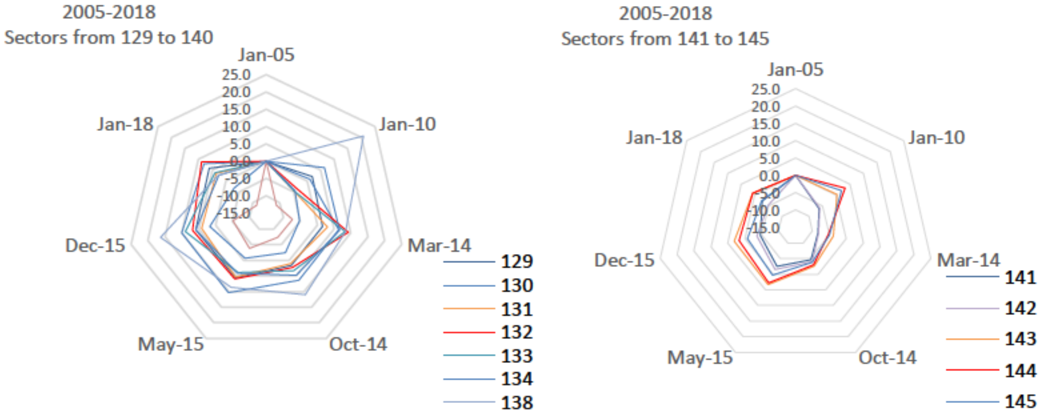


Figure 5.6 Radar diagrams of the sectors from 129 to 145 in the period 2005-2018.

The radar diagram in Figure 5.6 marks the different patterns in the areas closer to the harbor, and the sectors far from it, also showing some peaks that are likely produced by humans' intervention and that we think can seriously conceal the real dynamics.

An important conclusion from the results obtained is the opportunity to group the sectors of the littoral in classes of behaviors, to a more precise investigation. They are plotted as diagrams as it follows.

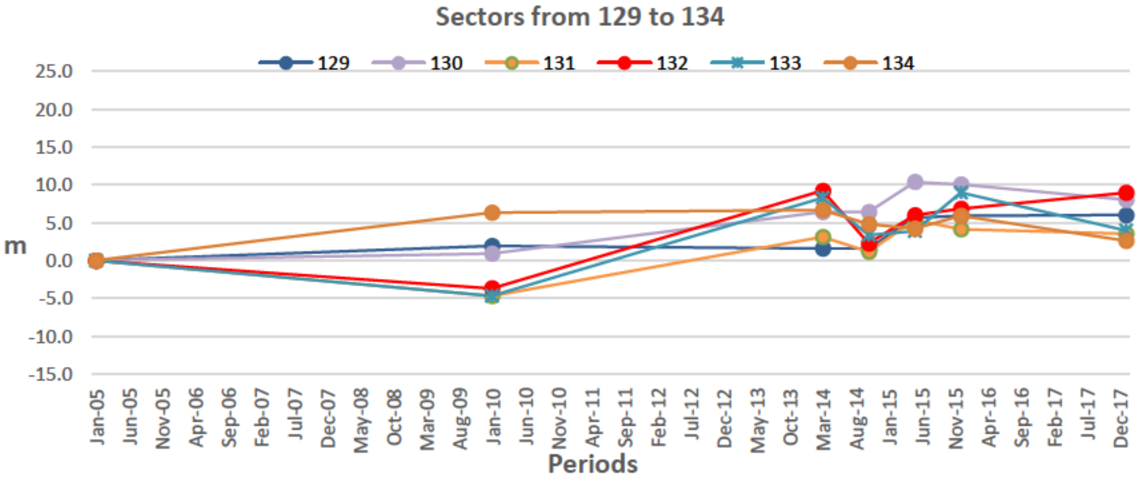


Figure 5.7 Shoreline displacement within the sectors from 129 to 134 (sub-unit A) in the period 2005-2018

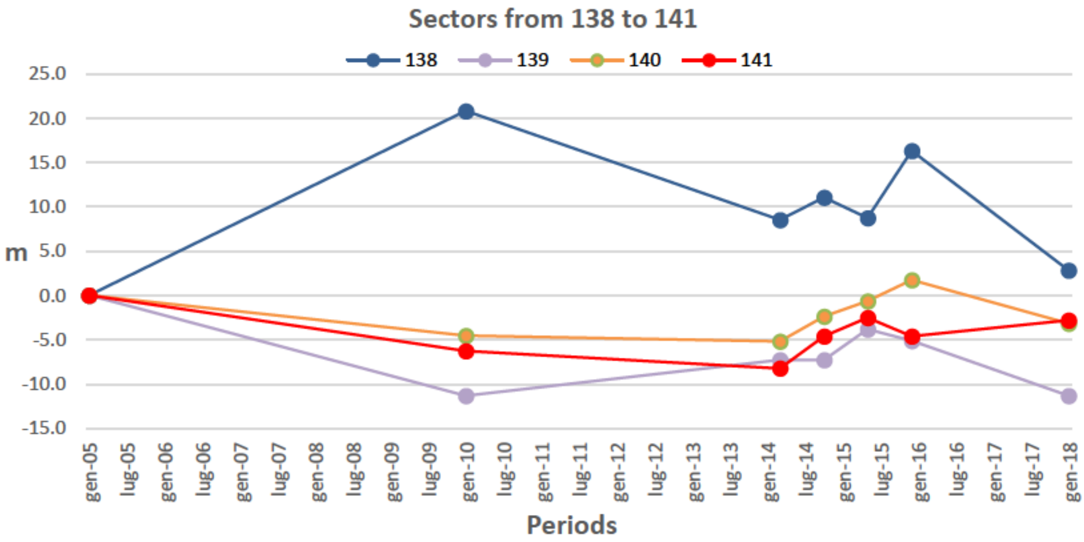


Figure 5.8 Shoreline displacement within the sectors from 138 to 141 (sub-unit B) in the period 2005-2018

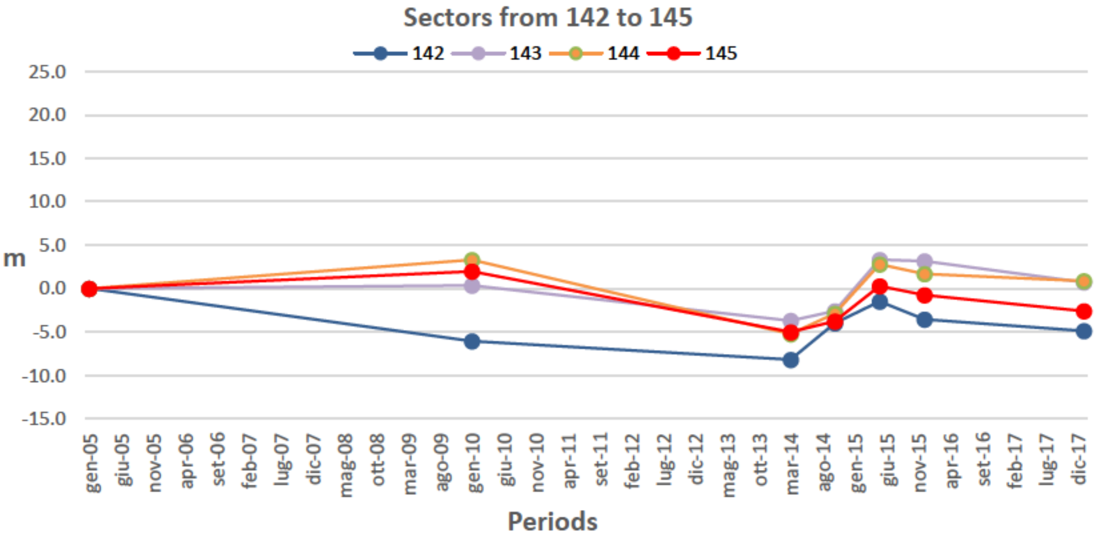


Figure 5.9 Shoreline displacement within the sectors from 142 to 145 (sub-unit B) in the period 2005-2018.

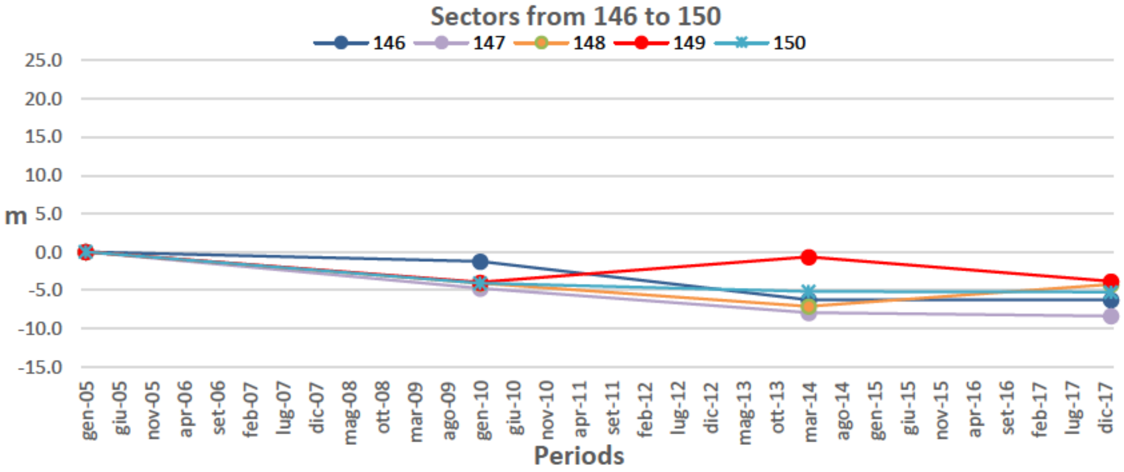


Figure 5.10 Shoreline displacement within the sectors from 146 to 150 (sub-unit C) in the period 2005-2018.

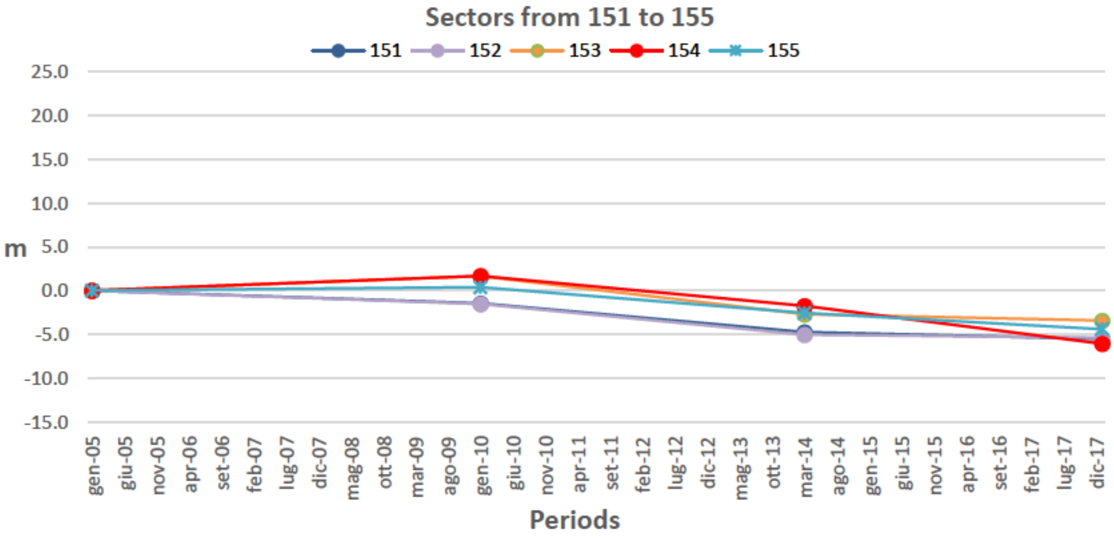


Figure 5.11 Shoreline displacement within the sectors from 151 to 155 (sub-unit C) in the period 2005-2018.

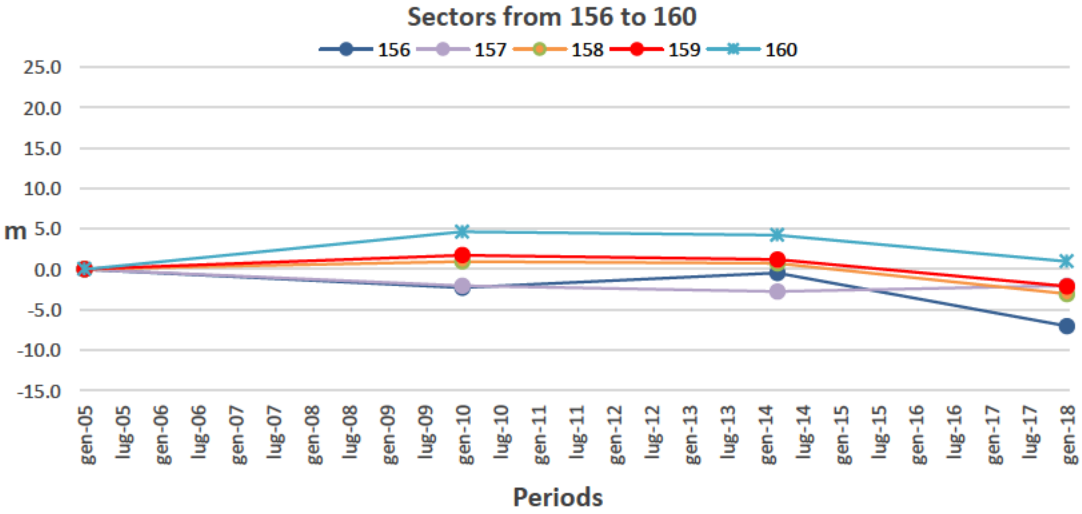


Figure 5.12 Shoreline displacement within the sectors from 156 to 160 (sub-unit C) in the period 2005-2018.

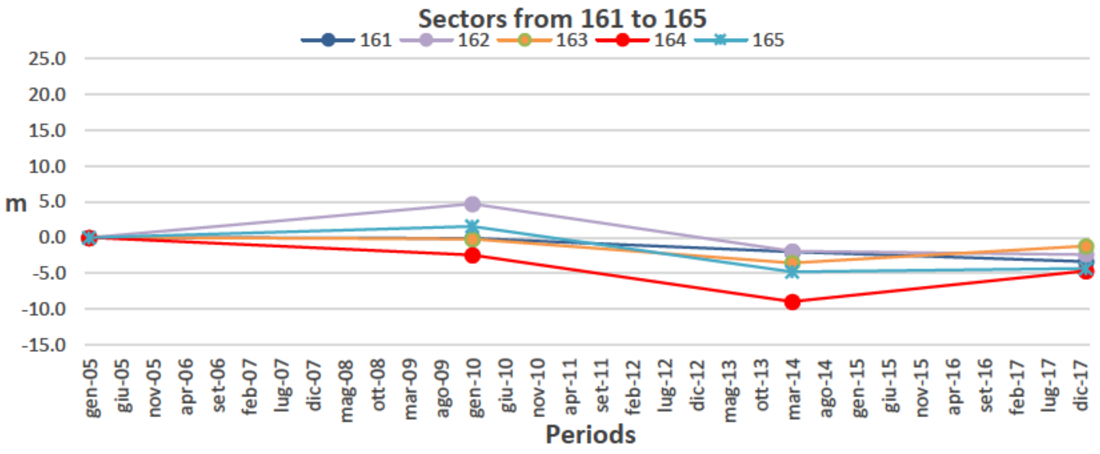


Figure 5.13 Shoreline displacement within the sectors from 161 to 165 (sub-unit C) in the period 2005-2018.

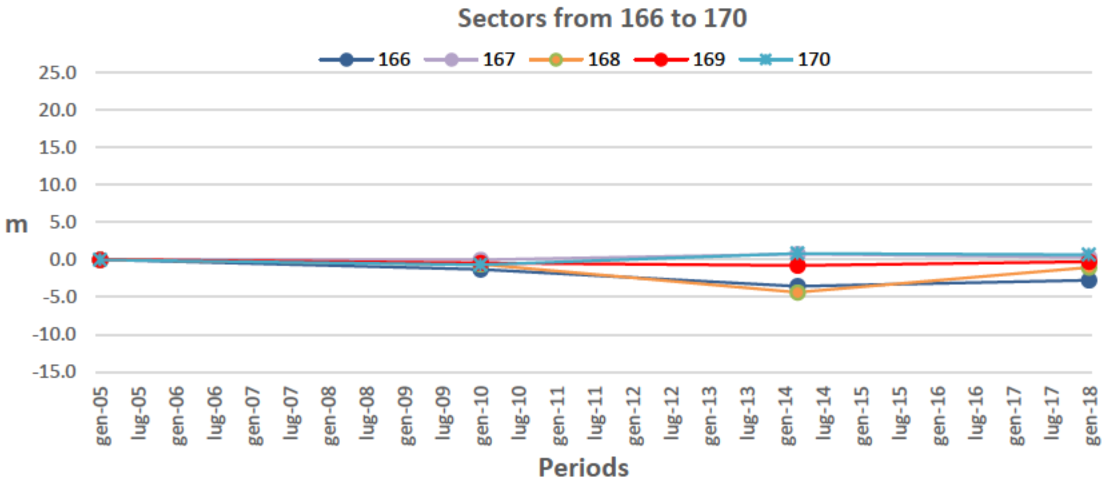


Figure 5.14 Shoreline displacement within the sectors from 166 to 170 (sub-unit C) in the period 2005-2018.

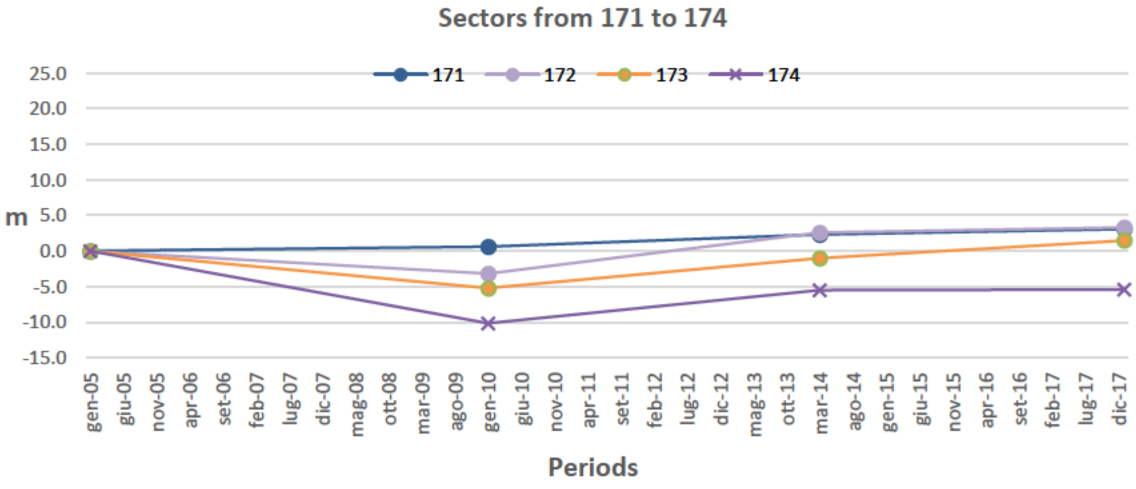


Figure 5.15 Shoreline displacement within the sectors from 171 to 174 (sub-unit C) in the period 2005-2018.

The graph in Figure 5.16 shows the modification affecting the shore, and the effects of shoreline management performed in the sub-units A and B, while in the sub-unit C more natural dynamics result in less stressed patterns.

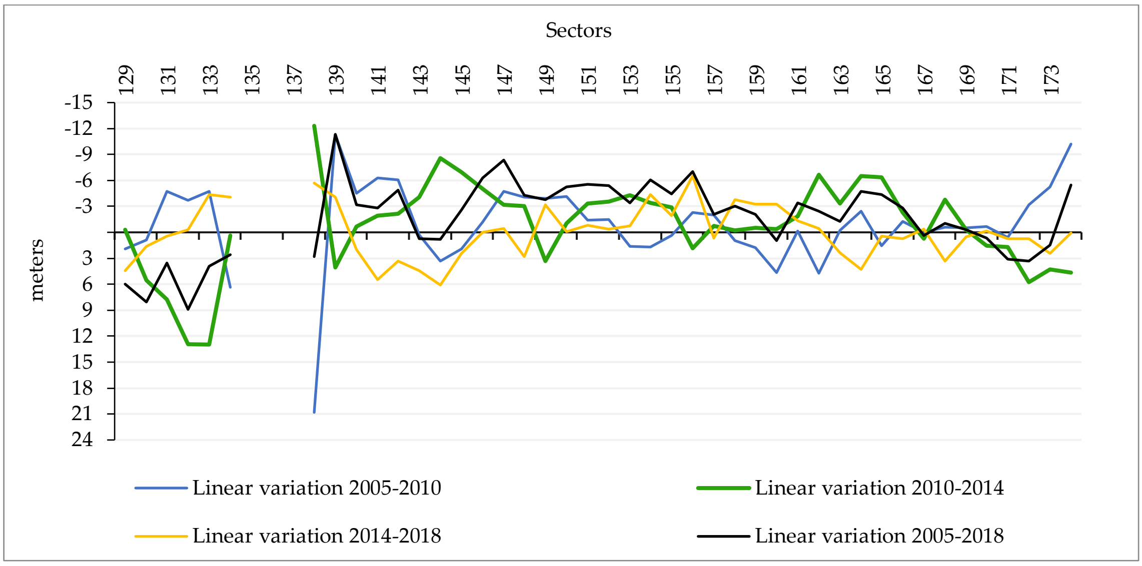


Figure 5.16 Shoreline displacement calculated per consequent timeframes, except for the black line, which represents the total displacement 2005-2018.

The black line in the graph concerns the longest time frame analyzed (2005-2018); biggest differences occur closer to the harbor, and in minorly within the sub-unit C.

5.2 Bathymetric variations

Bathymetric data are restricted to the northern portion of the San Vincenzo area (comprising sub-units A and B). They indicate that the volume of sediment in the submerged beach decreased close to the harbor, from sector 133 to sector 138. Conversely, in the sectors 132 and 142 these volumes decrease to about 25.000 cubic meters (Figure 5.17).

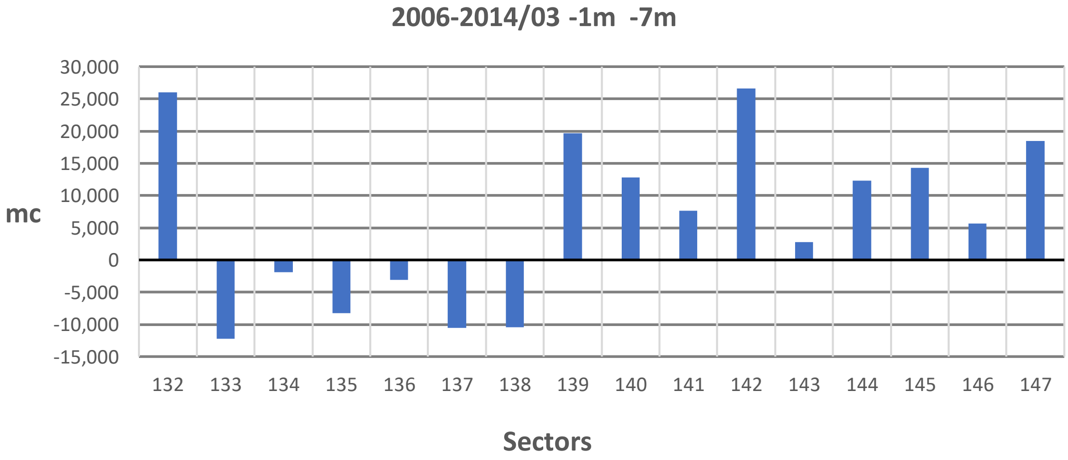


Figure 5.17 Volumetric variations between the isobaths “1m” and “7m”, in the period 2006-2014 (March).

A decrease in the volumes of the submerged beach can be observed in the harbor neighborhoods (133 to 138) within the analyzed small period; differently, in the three sectors from 132 to 135 the quotes increase to 25,000 cubic meters. This increasing pattern is confirmed in the rest of the sectors (139 to 147).

The same classification of sectors following similar behavior that we presented for shoreline's displacement are provided as follows for the volumetric tendencies of the seabed's quotes.

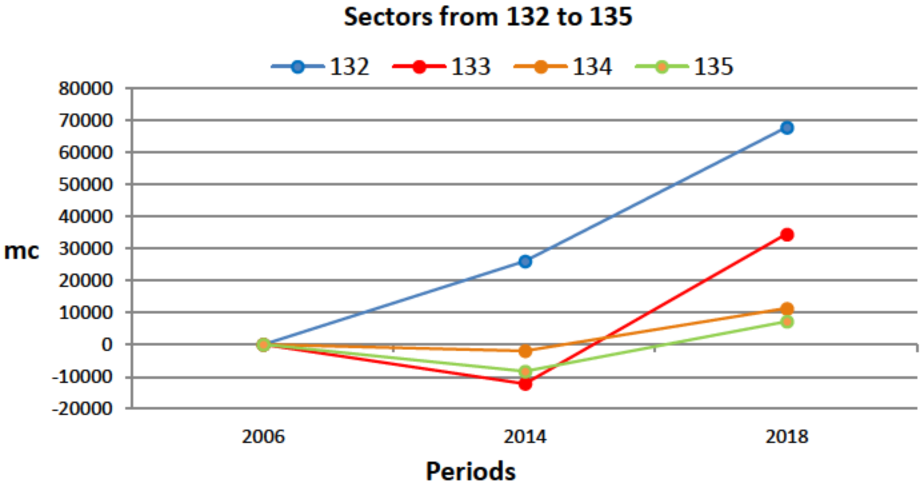


Figure 5.18 Volumetric variations between the isobaths "1m" and "7m", for sectors from 132 to 135 in the period 2006-2018.

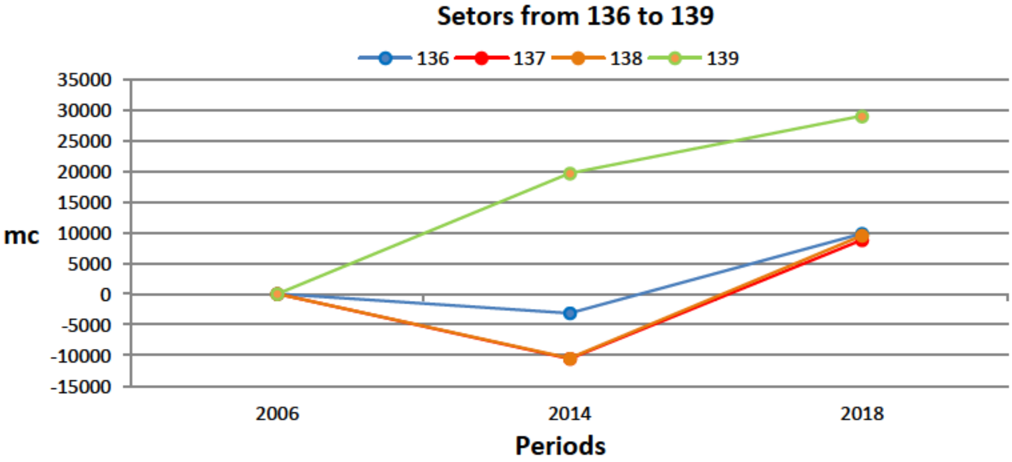


Figure 5.19 Volumetric variations between the isobaths "1m" and "7m", for sectors from 136 to 139 in the period 2006-2018.

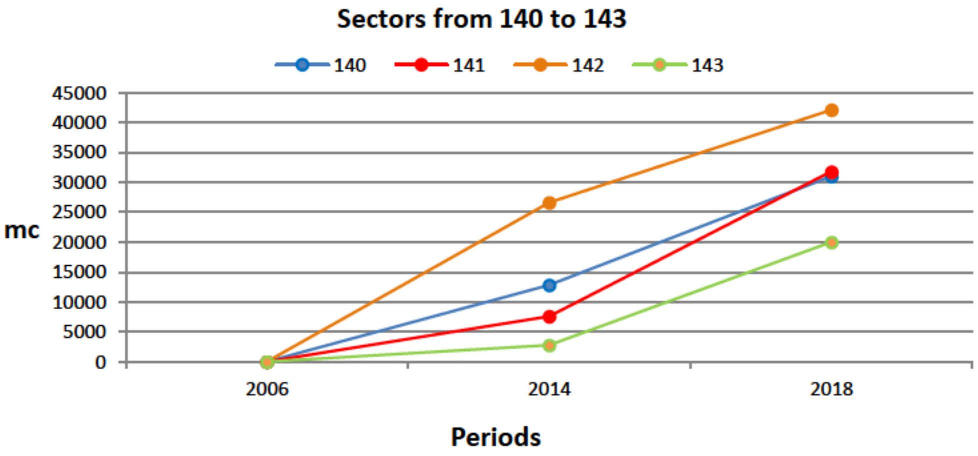


Figure 5.20 Volumetric variations between the isobaths "1m" and "7m", for sectors from 140 to 143 in the period 2006-2018.

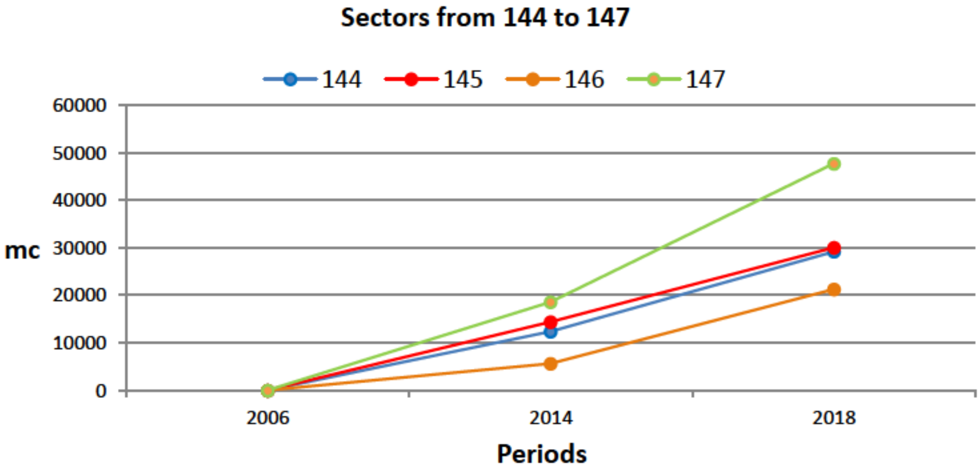


Figure 5.21 Volumetric variations between the isobaths "1m" and "7m", for sectors from 144 to 147 in the period 2006-2018.

In the last period of analysis (2014-2018) the whole coastal stripe shows a generalized increasing of the volumes. It reaches 40,000 cubic meters within the sectors 132 and 133 (Figure 5.22); in any cases more than 10,000 cubic meters, except in the sectors 139, 153, 154 and 157.

In particular, the sector 153 suffered a very weak growing of the sediments' volumes, that are probably related with the fluvial dynamic of the Botro ai Marmi channel flowing within this sector.

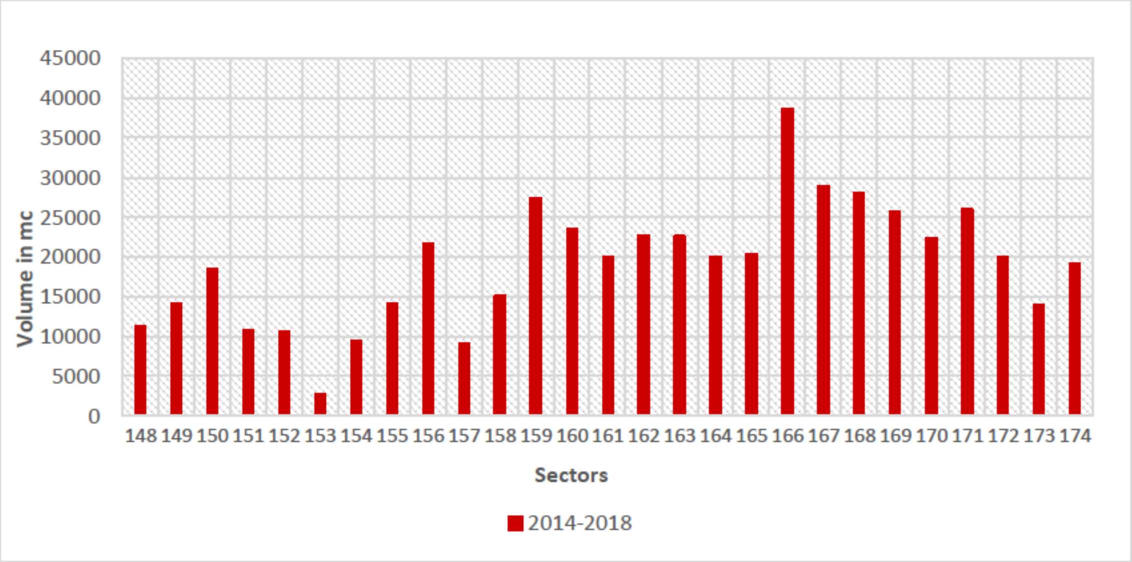


Figure 5.22 Volumetric variations between "-1m" and "-7m" depth in the period 2014-2018 (May) at the Southern part of the San Vincenzo's Unit -sub-units B and C- (Bianco et al., 2020).

Even in the last period 2014-2018 a peculiar bathymetric stripe in the nearshore passes from a situation of balance, or at least small lowering within sectors 132 and 156, to an increasing of the seabed's quotes.

They alternatively lost and gained sediment from the sector 148 to the sector 168, while seaward a positive (increasing) trend is verified. Different is the situation for the last sectors of the Unit, where the submarine canyon evidently affects the sedimentary discharge.

The bathymetric stripes cited above are localized respectively, in the first three meters of depth, and the second one from -5 m seaward, except for sectors 172, 173 and 174, where the old fluvial system is connected to a submerged canyon that can intermittingly drive the discharge process. The following histogram (Figure 5.23). summarizes the trends described above, showing the alternation erosion/sedimentation, and how they occurred in the 13 years of investigation.

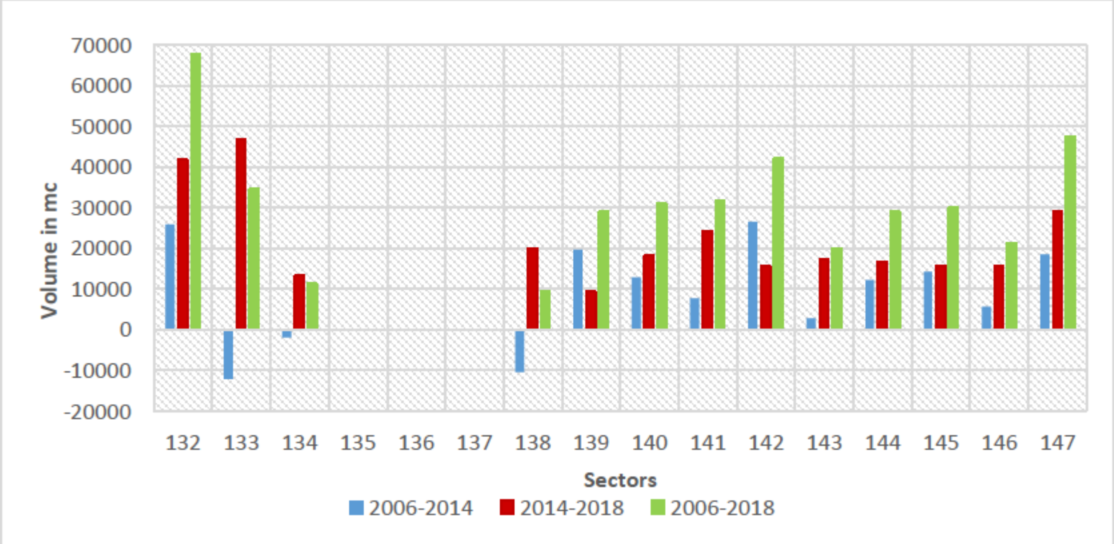


Figure 5.23 Volumetric variations between "-1m" and "-7m" depth at North Harbor and South Harbor Sub-Units; the time frame 2006-2018 represents the total volumetric variations calculated (Bianco et al., 2020).

The green pillars in Figure 5.23 prove the wide increasing of sediment in the submerged beach in the harbor area.

The variations are scarcely related, or even show opposite tendencies within the areas southward of the harbor, until the sector 167.
Substantially, to a drawing back of the shoreline corresponds a positive balance of the sediment in input. This fact indicates that sand asses extracted from the emerged beach are not trapped on the offshore on the average period, from the capture point.
Differently, for the rest of the sectors the shoreline's variations are modest, and the volumetric balance always positive

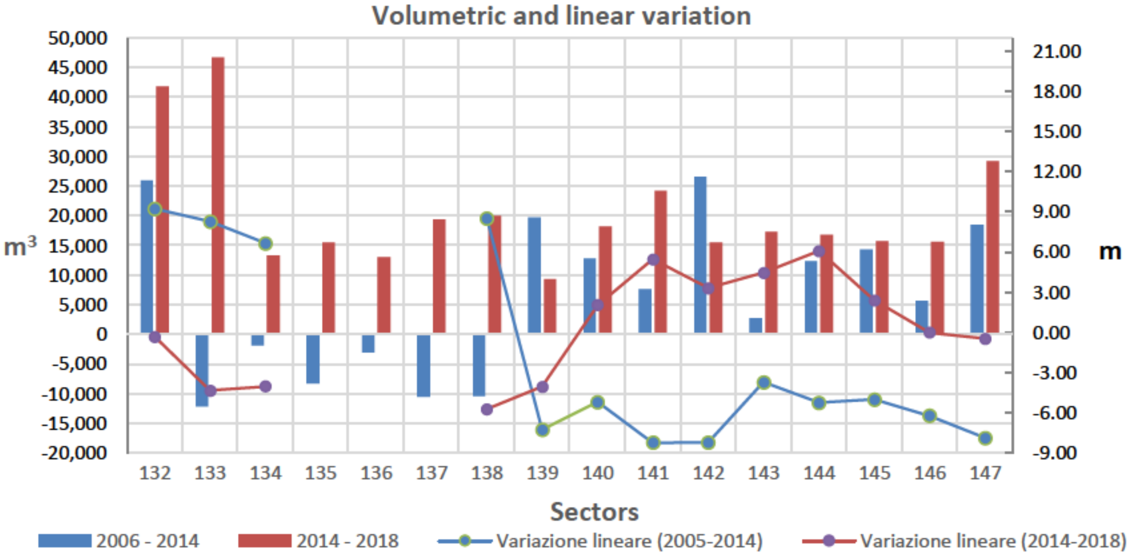


Figure 5.24 Volumetric and linear variations within the harbor area during the periods 2006-2014 e 2014-2018.

The concessions have been issued by different authorities to regulate the use of the areas from multiple points of views. These features were considered for the calculation of the ISMV since they directly interact with the coastal zone, although at this scale of assessment they could not be considered in the management. Solutions will regard the sedimentary stock on which the active beach is over imposed physically and administratively. These two methodologies were integrated to enable dimensionless computing of the diagnostic indicators, as well as to spatialize the data. The sedimentary stock has been analyzed and quantified on San Vincenzo's coast, in Italy.
The morpho sedimentological map drawn, highlights successfully the processes acting, and geomorphological features fixes physical natural boundaries as well as identifying human-pressured areas.
71 % of the sectors result in accretion in the submerged beach until the period of harbor's completion. Conversely, from 2014 to 2018, a direct relation between shoreline and bathymetric variations results in the lowering of quotes for 52.3 % of the sectors as well as drawing back from the shoreline.

The differences between the 2014 and 2018 level of the seabed (Figure 5.25) represent the changes that we have determined through the parameters V (volume of sediment) and Q (average rate of lifting / lowering of the seabed).

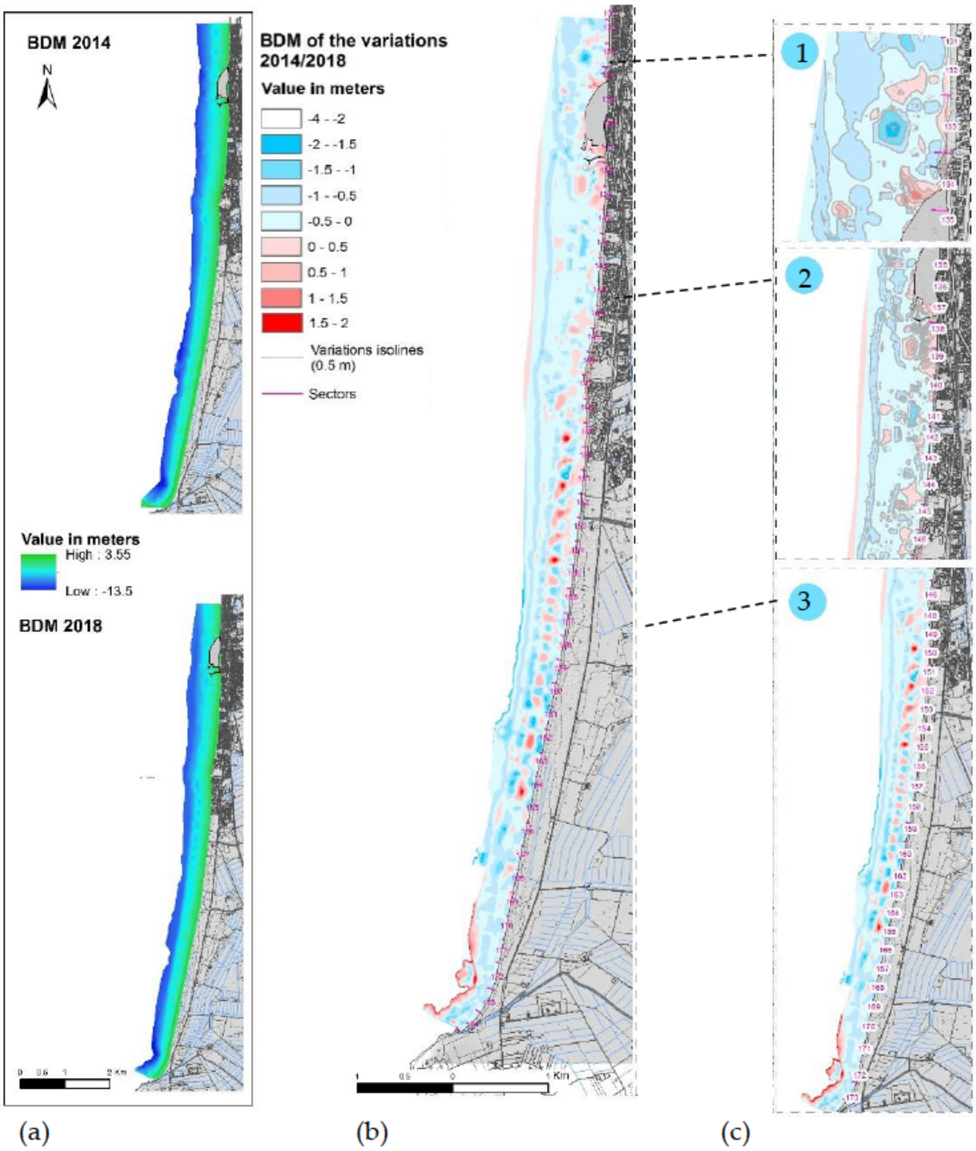


Figure 5.25 a. Bathymetric Digital Model of the years 2014 and 2018; b. Differences in the seabed's top surface registered between March 2014 and June 2018; c. Sketch maps of the subunits (Bianco et al., 2020).

Bathymetric maps (Figure 5.25) were compared, together with histograms, to explain the submerged beach sectors' evolution during the years.
Classes of patterns are classified using different colors such as:

- Green portions represent high value of quotes' increasing.
- White classes relate with stability conditions.
- Red ones register the decreasing of quotes.

Integrating the morphological and sedimentological parameters and trends we measure as mentioned above, the morpho sedimentological map (scale 1:10,000) was drawn for the whole coastal stripe of 13 Km in length and cover landward with a distance of about 2,5 km (Figure 5.26).

The map also contains important modifications to the regional cartography, as well as information on the emerged and submerged beach that provides crucial information about morphodynamics, resilient and stressors of the coastal erosion.

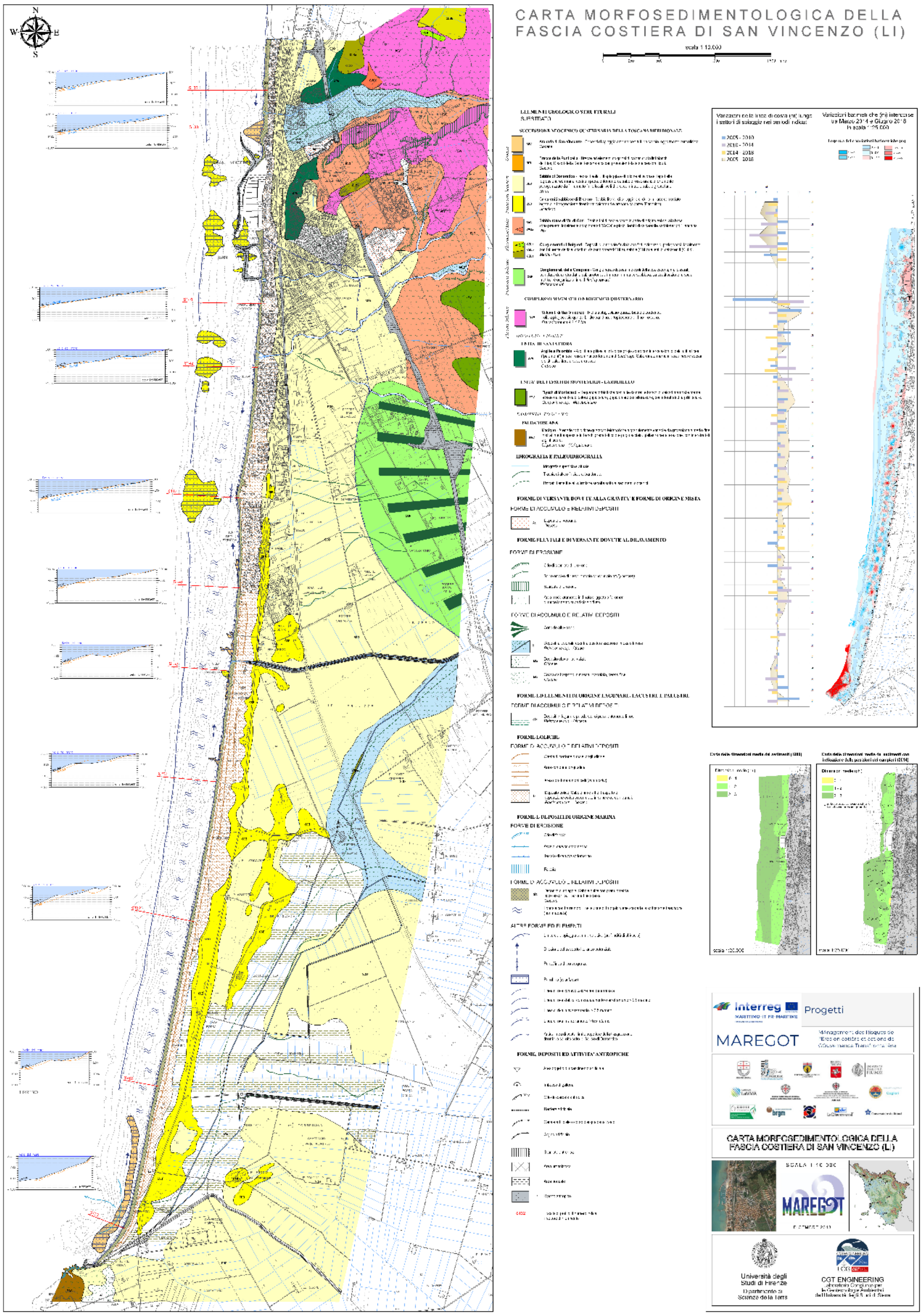


Figure 5.26 Morpho sedimentological map of San Vincenzo (scale 1:10,000).

The tourism industry is largely developed, and the density of concessions results high.
The sub-indices that support ISMV better explain how past management solutions, focusing on artificial structure to stabilize the shore, created hard borders, and stressing behaviors due to the economies that directly interact with the sedimentary stock. They consist of establishments and resorts that rent beach spaces during the tourist seasons or even permanently. A summary of the sub-indices and ISM calculated is provided in Table 13, and in the map plotted in Figure 5.27.

	Sub-Unit A	Sub-Unit B	Sub-Unit C
Area Analyzed (m^2)	37,361.955	73,225.420	180,592.812
IMV: Index of Morphological Variation	0.11	1.43	1.84
ISC: Index of Services' Cost	0.15	0.74	0.20
CRI: Index of Coastal Regeneration	0.33	0.37	4.11
ISMV: Index of Social and Morphological Vulnerability	1.21	0.01	1.57

Table 13. Indices calculated for Sub-Units A, B, and C.

Morphological patterns were detected ranging from a maximum erosive rate of -6.5 m for shoreline displacement, and -4 m as bathymetric lowering of the seabed, to a maximum increasing value of 6 m for shoreline and 2 m for bathymetry, respectively. The maximum values are clearly due to artificial nourishments and hard structures built within the nearest sectors to the harbor. The classes range from a minimum value of 1, where the shoreline and bathymetric trends are accretionary, to the maximum value of 3 as high erosive trends of the shoreline and decreases the seabed's quota (Table 14).

Class Linear Variation	Range Values	Class Volumetric Variation	Range Values
1	6 - 0.05	1	0 -2
2	-0.02 -0.48	2	-1 - 0
3	-0.75 - -6.5	3	-4 - -1

Table 14 Classes of linear variation of the shoreline displacement; and volumetric variation of the seabed

The volumetric variations always presented an increase in the seabed of between 0 and 2 meters. The only factor (Vv) attributed was 1, and the IMV was totally dependent from the shoreline displacement. At Sub-Unit A, 50% of the sectors had a Linear Variation factor (Lv) of 3 in the sectors affected by nourishments and coastal defenses (133 and 134), whilst the remaining 50% was equally divided between Lv of 1 and 2. Sub-Unit B had 70% of its sectors with an Lv factor equal to 1, whilst 10% had Lv 2, and 20 % had Lv equal to 3. At Sub-Unit C, 36% of the sectors had Lv 3, 18% had Lv 2 and 46 % had Lv 1. The IMV was calculated for each sector first, and then weighted on the Sub-Unit surface. Its value in the three Sub-Units varied considerably, from just 0.11 in Sub-Unit A, 1.43 in Sub-Unit B, to a maximum of 1.84 in Sub-Unit C. The higher the value of IMV, the lower the erosive trend of the Sub-Unit's shoreline was. In Sub-Unit A, the sectors with high rates of retreatment (from -0.75 m to -6.5 m) represented 50% of the sectors, whilst in Sub-Unit B this was 20%, and 37% in Sub-Unit C.

Prices for the 3rd quarter of the year were used to categorize six Economic Classes, Ec, shown in Table 2. Those classes ranged from the cheapest (*Ec* = 1), where the services are provided by beach establishments and cost 21.5 €/day, to the highest (*Ec* = 6) where the prices reach the maximum of 297 €/day and services are provided by resorts. The Natural Park authorities restrict the normative on the territorial usage to preserve the ecosystem there, and the services they offer are basic and completely free. They provide wooden paths which enable access for mobility impaired users, and the preservation of the dune system, didactics and promoting the sustainable development of the area; the *Ec* was 1 for these sectors.

Economic Class	Values Range (€/day)
1	0 - 21.5
2	21 5 - 30
3	30 - 33
4	33 - 100
5	100 - 190
6	190 - 297

Table 15 Economic Classes based on concession services' cost.

The ISC Index is high in Sub-Unit B (0.74), low in Sub-Unit A (0.15), and medium in Sub-Unit C (0.20). It is subordinately affected by the density of concessions in the Sub-Unit considered. Within Sub-Unit B, 50% of the sectors cover areas with a high price for services (Classes 5 and 6); 72.3% of them consist of resorts, and in some cases more than 60% of the sectors' areas are occupied by concessions.

Conversely, Sub-Unit A has the lowest ISC (0.15); this is due to the absence of class 6-concessions, and in just one case, one of the sectors had more than 20% of its area occupied. The concessions are better distributed within Sub-Unit C, and there are no concessions in the last 21 sectors southward. What increases the ISC in this portion is that 100% of the concessions are resorts. Their price ranged from 213.67 to 249.14 €/day, with just five concessions occupying an area of 10,935.00 m^2. The Index of Coastal Regeneration (CRI) considers the potential of the coast to support human activities. Elements in the Unit were classified as potential supports or contrasts of erosive trends; it depends on the feedback that these elements released to coastal dynamics and the sedimentary stock, highlighted in the geomorphological assessment of the area. They were classified and weighted as shown in Table 16.

Counteractors	Values
Dunes/Park	2
Bars	3
Channels	4

(a)

Stressors	Values
Concession	2
Buildings	3
Hard defenses	4

(b)

Table 16. (a) Weight attributed to Counteractors elements; (b). Weight attributed to Stressors elements.

The CRI was 1.21 at Sub-Unit A, 0.01 at Sub-Unit B, and 1.57 at Sub-Unit C. Particular attention should be paid to the value of 0.01 at Sub-Unit B. This is the most urbanized portion of the coastal stripe, although the harbor sectors were not included. It hosts 67.6 % of the concessions in the whole San Vincenzo coastal zone. Stressors are largely diffused in the Sub-Unit; buildings are present in the 200 m distance from the shore in all the sectors, with just two sectors not hosting concessions (sectors 141 and 146). Additional ones are represented by coastal defenses, such as a groin downdrift of the harbor mouth, and the artificial reef mentioned in the first paragraphs of this work. A low CRI was computed for Sub-Unit A, where buildings in the first 200 m of the backshore were present in all the sectors. In addition, hard defenses have been built in the last sector (134) of Sub-Unit A to contrast the waves reflected from the harbor. In Sub-Unit C, even though coastal defenses are completely absent, a main road running N-S borders the Park. The road is far more than 200 m from the shoreline in the northern and central part, whilst in the southern one it reduces the coastal zone to less than 200 m. From the other side, sand bars in Sub-Units B and C trap the beach sands within the closure depth -between the isobath -3 m and -4 m- and together with sand dunes increase the CRI. Sand dunes were only diffused at Sub-Unit C and are preserved by the Natural Park Authority that limits the use of its territory. Channels flow in all the Units, and although they affect more sectors in Sub-Unit B than in the other Sub-Units, here the CRI was 0.37.

The ISMV index was calculated for three Sub-Units of the area of study at beach level. It was found that at unit level, the area affected by a high vulnerability to erosion was 33% of the sectors, 19% had a medium vulnerability, and the remaining 48% ranged between stability and accretion. In the following figure (5.27) indices and main characters used to classify the coast depending on the ISMV index were spatialized through the ArcGis suite. The map gives an exhaustive idea of how morphological and social related parameters were classified as stressors and counteractors, as well as the way they work releasing different classes of feedback.

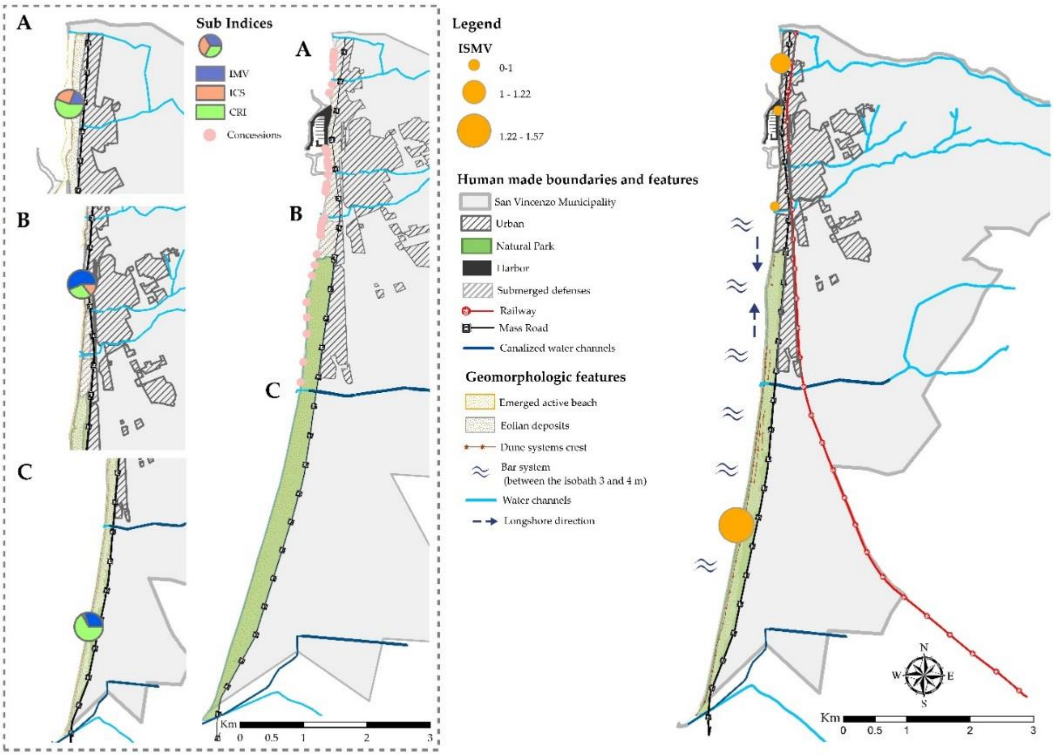


Figure 5.27 ISMV Index and the elements considered for its calculation are provided in the large plot map on the right. Small plot maps on the left relate with the Sub-Units (A-B-C).

6. DISCUSSION AND FUTURE RESEARCH LINES

A model that integrates vulnerability categorization and diagnostic indicators of territorial was applied to a real study case in San Vincenzo -Italy. Indicators enabled different groups of elements in the coastal system to be combined, and their feedback to be observed in a cause effect-oriented analysis.

The ISMV was calculated for three Sub-Units (A, B, and C) divided on a morpho-sedimentological base to determine the resilience potential (Bianco et al., 2020). Even though both Sub-Units A and B are bordered by the urban center, only Sub-Unit B presented an ISMV close to zero (0.01). For Sub-Unit A, the ISMV was 1.21, but the highest value was found for Sub-Unit C (bordered by a Natural Park) (1.57). Although these results appear logical if related with the presence/absence of urban areas and natural areas, we can see that the values of Sub-Units A and C are quite similar. The sub-indices that support ISMV better explained the behavior of the latter and gave indications to adopt and to support resilience. Previous studies (Benassai et al., 2015; Ietto et al., 2018; Rangel-Buitrago et al., 2020) were considered to set usable indices for future advances in this matter. They analyzed the risk of exposed values being damaged, or even of citizens being injured. The hazard that arises from the present vulnerability assessment relates with the risk that the sedimentary stock of the active beach (managed at a local level) could be spoiled and not regenerated. It should be integrated within these methodologies. On the other hand, a resilience assessment was also carried out considering previous studies, based on diagnostic indicators (García-Ayllón, 2017; Rumson et al., 2019a). Both groups of studies highlighted certain limits; they comprised geomorphological features missed to properly set the analyzed system, data sources and numerous metrics hard to evaluate at a large scale (beyond regional). They have been partially solved in the present study by limiting the assessment to a local administrative level, where resolute nature-based solutions could be integrated.

In 2005 the harbor started to be enlarged, and wide use of the sediment dragged were discharged on its closer sectors to both sides, northern and southern.

The trends investigated, that could make us think that an equilibrium between the structure and the hydrodynamic was obtained, already catch our attention since the field survey phases.

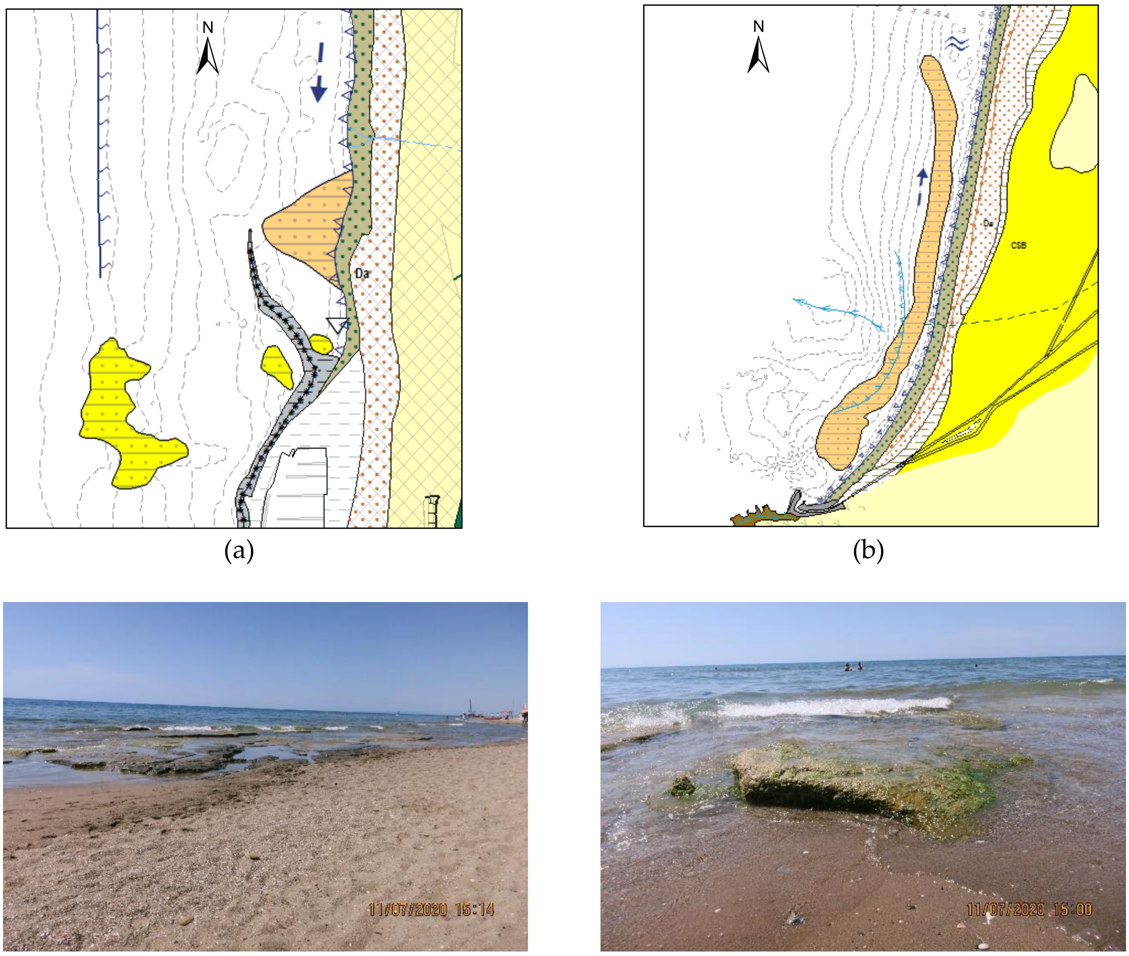
Some natural, as well as man-made effects confirmed during the data elaboration and mapping were better investigated. Here, a beach rock deposits and breccias have produced alternate feedback. Indeed, sometimes they counteracted erosive effects, while in some cases they were located at retirement sectors. These deposits have been widely dragged and discharged to the closest sectors of the harbor as artificial sedimentary input, since these sectors were affected by induced reflected waves on the submerged groynes in the northern sectors -in respect to the harbor position (Figure 6.1).

(a) (b)

Figure 6.1 North harbor area (sector 134). (a) The red arrow shows the reflected wave by the breakwater during the working phase in 2006; (b) beach rock fragments used to nourish the erosive spot (Bianco et al., 2020).

Beach rock deposits were mapped and recognized on a geological basis such as:

Arenarie di San Vincenzo's succession (late Holocene); it consists of light compacted beach sands. The *Arenarie di San Vincenzo*'s beach rock always shows an erosive behavior of the shoreline, except when it has been covered by the dragged sediments (beach rock as well) on the harbor area. Here a groin protects it, and the displacement value is in fact greater than 0.5 m/year. These deposits are absent in the rest of the harbor area, where they were probably removed during the urbanization phases; again, they intersect the shore in the southern area (less anthropized). At sectors 171, 172, 173 and 174, the *Arenarie di San Vincenzo* borders a canyon connected to the ancient hydrographic system.

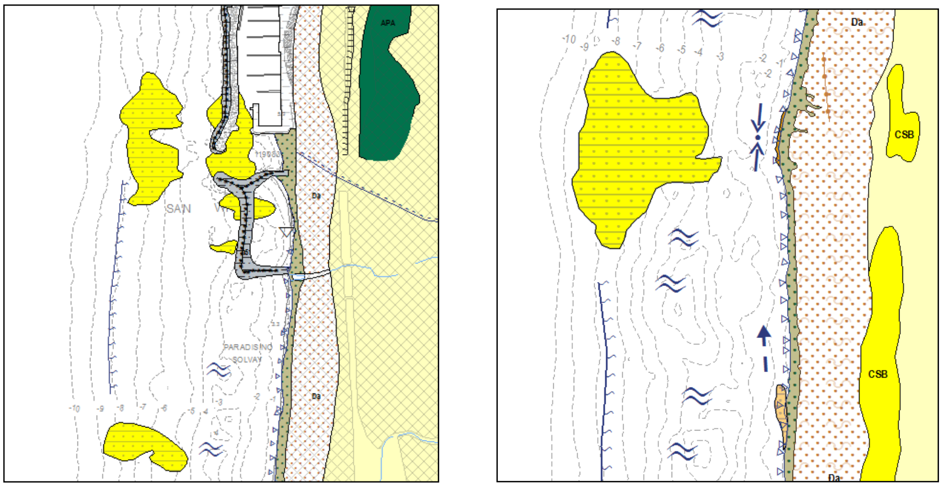


(a) (b)

(c) (d)

Figure 6.2 Arenarie di San Vincenzo formation ASV (late Holocene) are represented as light brown deposits in the submerged beach; (a) at sector 134; (b) from sector 171 to sector 174, where a Pleistocene canyon is bordered by Arenarie di San Vincenzo's beach rock; (c) and (d) show two outcrops of the same formation within the Rimigliano Park

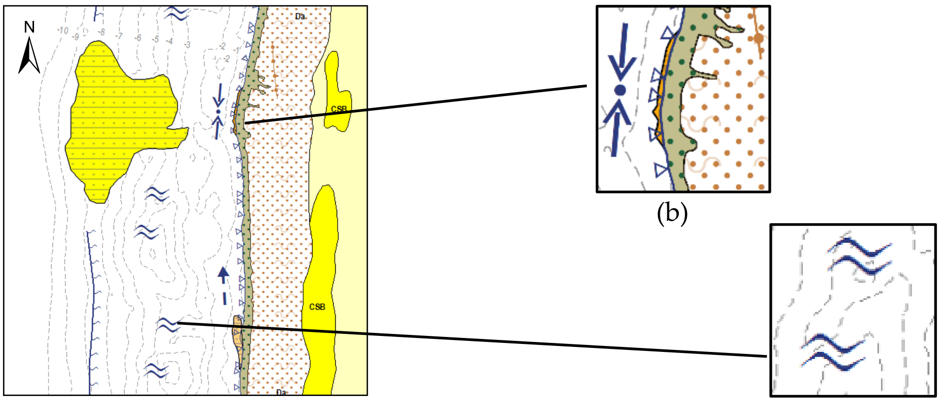
Calcareniti sabbiose del Biserno (late Pleistocene). It is mapped within the whole submerged beach, including the harbor area where it has been dragged, and the harbor structure superimposed. These deposits are calcareous and cemented sandstones originated from fine dunes' sand, and littoral sands, cemented after the Tyrrhenian transgression. Calcareniti sabbiose del Biserno represent the surface on which the sand bar system drifts, from the isobath -3 to -5 almost continuously throughout the whole unit.



(a) (b)

Figure 6.3 Calcareniti sabbiose del Biserno CSB (late Pleistocene) are represented as yellow deposits; (a) at the harbor are; (b) at La Punticella location.

Brecce della Punticella (early Holocene). It is composed of angular and white limestones (Lias), jaspers from the Tuscany series, and limestones belonging to the Ligurian successions. These deposits, contrary with the other formation up mentioned, have been already related to the anthropic activities of the Bronze Age (3300-1200 years BC) by Mazzanti et al., since the angular clastic materials do not face any effect related to transport agents, such as a river or channel, and the presence of iron dross suggests that they have been treated and discharged as waste material.



(b)

(c)

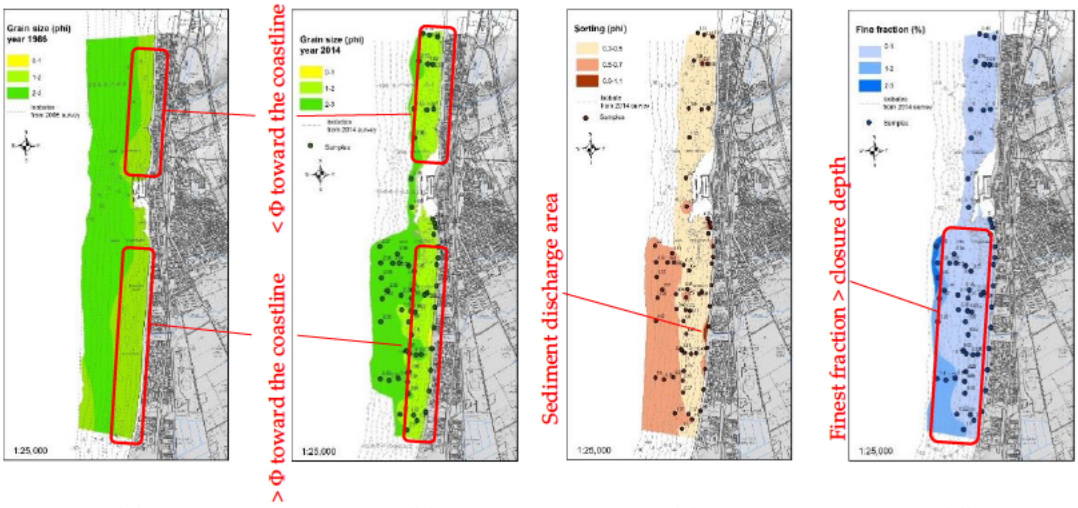
(a)

Figure 6.4 (a) Sketch map of la Punticella Location; (b) la Punticella Location formation BPT (early Holocene) represented by brown deposits, and convergence point of the longshore currents represented by blue arrows; (c) active sand bar system.

The analysis of bathymetric data through BDMs successfully compare different raster volume quantities of the sedimentary stock. The error due to the accuracy of measurements, is acceptable, given that the instrumentation used assures a 0.02 m resolution, and the bias in the vertical measure corresponds to 5 % of the depth (Cervenka et al., 1994; Jakobsson et al., 2002; MATT-Regioni et al., 2018; Teh et al., 2017). Moreover, in our case it highlights the relations with shoreline displacement trends and geomorphic shapes.

A homogeneous and basically stable bathymetric stripe is observed in the nearshore; it alternates stability conditions and lowering of the seabed, except in the closest sector of the harbor, where It uplifts until 2 meters. A further area is recognized seaward; differently, it is interested of an alternation between stability and increasing of the quotes, except in the harbor neighborhoods where the seabed lowers.

Maps have been set down onto the bathymetric features of 2018 for the submerged side of the beach, and through the topographic support belonging to the regional cartography of Tuscany where they were linked landward (Figure 6.5). Surveys carried out related just to the harbor area since they were done to specifically monitor the effects of the harbor's realization.

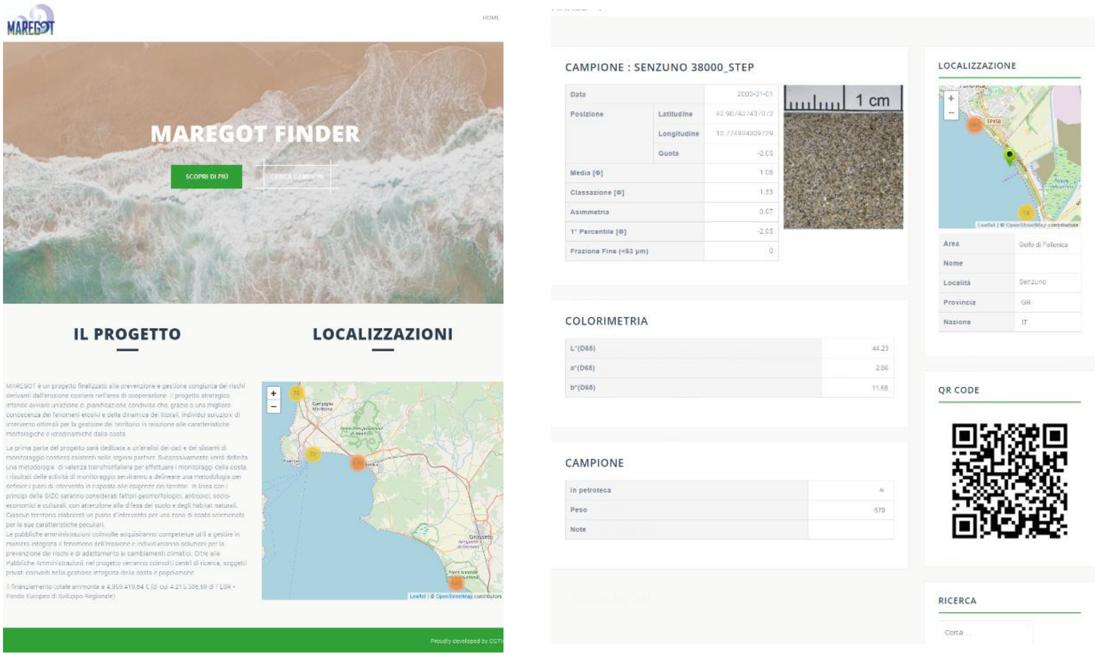


(a) (b) (c) (d)

Figure 6.5 Sedimentological maps; (a) Mean (Mz) grain-size map (Φ) extracted from 1986 report by the University of Florence; (b) Mean (Mz) grain-size map; (c) Sorting map (Φ); (d) Fine fraction map (%).

Main sedimentological characteristics are: Sorting (Φ) 0.3 - 0.5, Grain size (Φ) 2, and Fine fraction between 0 and 1 %. Thus, it can be classified as a Medium to fine sand, using the Udden-Wentworth sedimentary grain-size scale (Blair and McPherson, 1999). The same grain sizes that were determined in the 1986 report today cover the foreshore, showing a migration of the highest phi values (finest classes) toward the coastline. Almost all the active beaches in the harbor area is covered by a single grain-size class of sediment (0.3 – 0.5 Φ), and a discharge area is recognized as having a high grain-size class of sediment (0.9 – 1-1 Φ) corresponding to the channel's mouth at sub-unit B. The following map (d), regarding the fine fraction, shows that, although the fine fraction content is weak, it is similar in all the active submerged beach. However, its value increases toward the offshore, after the closure depth in the sub-unit B. These parameters lead us to think that sediment density is assumed to be constant; moreover, the weak action of the channels (canalized), and the isolation of the area from the main source (Cecina River) allow us to consider that the physical properties of the sediment are constant. The sedimentological parameters obtained by our analysis were further used to build a physical and multimedia petroteca hosted at the Centre of Geotecnologies at the University of Siena.

Figure 6.6 shows some examples of the samples classified and registered; through a QR code attached to each of the sample's box can be scanned and directly connect any provide to the MAREGOT webpage. They are linked to a multimedia sheet that hosts the sedimentological parameters, the description of the beach profile, as well as the georeferenced path that provides geographical information of the location of each of them.



MAREGOT è un progetto finalizzato alla prevenzione e gestione congiunta dei rischi derivanti dall'erosione costiera nell'area di cooperazione. Il progetto strategico intende avviare un'azione di pianificazione condivisa che, grazie a una migliore conoscenza dei fenomeni erosivi e della dinamica dei litorali, individui soluzioni di intervento ottimali per la gestione del territorio in relazione alle caratteristiche morfologiche e idrodinamiche della costa.

La prima parte del progetto sarà dedicata a un'analisi dei dati e dei sistemi di monitoraggio costiero esistenti nelle regioni partner. Successivamente verrà definita una metodologia di valenza transfrontaliera per effettuare i monitoraggi della costa. I risultati delle attività di monitoraggio serviranno a delineare una metodologia per definire i piani di intervento in risposta alle esigenze dei territori. In linea con i principi della GIZC saranno considerati fattori geomorfologici, antropici, socio-economici e culturali, con attenzione alla difesa del suolo e degli habitat naturali. Ciascun territorio elaborerà un piano d'intervento per una zona di costa selezionata per le sue caratteristiche peculiari.
Le pubbliche amministrazioni coinvolte acquisiranno competenze utili a gestire in maniera integrata il fenomeno dell'erosione e individueranno soluzioni per la prevenzione dei rischi e di adattamento ai cambiamenti climatici. Oltre alle Pubbliche Amministrazioni, nel progetto verranno coinvolti centri di ricerca, soggetti privati coinvolti nella gestione integrata della costa e popolazione.

Il finanziamento totale ammonta a 4.959.419,64 € (di cui 4.215.506,69 di FESR - Fondo Europeo di Sviluppo Regionale)

CAMPIONE : SENZUNO 38000_STEP

Data		2000-01-01
Posizione	Latitudine	42.907437437072
	Longitudine	10.774934309729
	Quota	-2.05
Media [Φ]		1.08
Classazione [Φ]		1.33
Asimmetria		0.07
1° Percentile [Φ]		-2.05
Frazione Fine (<63 µm)		0

LOCALIZZAZIONE

Area	Golfo di Follonica
Nome	
Località	Senzuno
Provincia	GR
Nazione	IT

COLORIMETRIA

L*(D65)	44.23
a*(D65)	2.66
b*(D65)	11.68

CAMPIONE

In petroteca	si
Peso	570
Note	

(a) (b)

Figure 6.6 (a) MAREGOT Project home page; (b) Technical information page available per each sample.

Sub-Unit A is located updrift with respect to the harbor; it consists of a restricted coastal zone bordered inland by the urban center. It covers a surface area of 37,361.955 m^2 (12.8% of the total beach area, except the harbor), 17% of which is occupied by both kinds of concessions (establishments and resorts), with different price classes. They result in an ISC of 0.58 that describes an easily reachable accessible area, where free spaces are available, and the low cost of the services permits access for every kind of guest. Although longshore currents flow North to South, and directly feed this Sub-Unit, the shoreline in the sectors closest to the harbor drastically decreased; here artificial nourishments, and submerged defenses were needed to stabilize it. The IMV was in fact exceptionally low (0.11) and depended solely on the shoreline displacement. Nourishments are clearly a palliative action, because the submerged structure did not work as nourished sediment trappings. The Index of Coastal Regeneration (CRI) was the lowest within the whole Unit (0.33). Geomorphological dynamisms in the submerged beach were unable to build positive feedbacks, or even to contrast the erosive trends. The ratio between stressors and counteractors was incredibly low, and the restriction of the coastal zone results in an active coastal narrowing (the average distance between shoreline and the urban center in the Sub-Unit is 35 meters). An ISMV of 1.21 was the medium value calculated; the pressurizing elements detailed are clearly the main causes of the erosive trends, while potentially restorative features have been hardly weakened through the channels' regimentations, and the shoreline anthropized by hard defenses and harbor. The low CRI and low IMV within the same sub-unit indicate that the ecosystem cannot be used to enhance adaptability, or even to restore or reduce the risk, since the space to seaward or inland phenomena does not exist. The only existing source of sediment is represented by the small channels, for which watershed management plans are needed. They were deeply impermeabilized to limit erosive and transport potential, yet did not acquire a critical role, since San Vincenzo is hydrodynamically isolated from the rest of the sedimentary cell. Protection defenses could be designed based on sustainable criteria and nature-based oriented. Further investigations on this aspect should be conducted on the beach rock deposits mapped and frequently used as nourishment material (Bianco et al., 2020). Feedback from these kinds of deposits are ambiguous (Calvet et al., 2003; Cooper, 1991; Vousdoukas et al., n.d., 2007), and generally the beach rock is exposed where erosive patterns act.

Through the sub-indices calculated to derive the ISMV the most common coastal solutions were indicated for each of the sub-units. In the areas with high IMV, the continued usage of land at risk could be supported to allow the conservation of the ecosystems. Contrary, high values of ISC correspond to a relevant risk of accessibility reduction, thus considering the planned retreatment of some concessions, as strategy. Finally, CRI relates with the possibility to support the ecosystem, where the presence of a preserved coastal zone between the coastline and urban areas allows for ecosystem development. The sub-division of the area reflected the coastal dynamic trends, which differ among the three sub-units, as well as singling out two administrative domains of the maritime territory: the municipal authorities and the Natural Parks entity. The Index of Social and Morphological Vulnerability (ISMV) constituted the morphological variation of the coastal zone, and the economic data was the price of the services offered at the test site. These economies directly interact with the sedimentary stock since they consist of the establishments and resorts that rent beach spaces during the tourist seasons or even permanently.

The main graphic in Figure 6.7 represents a comparison between the ISMV and the sub-indices is provided; the weight of each sub indicator in the total ISMV can be inferred per each of the Sub-Unit. The sub plots show the application of each of the most common coastal solutions supported by the indicators. ISMV relies with the relative Potential of resilience of the sub-units calculated from the vulnerabilities' sum. IMV plot explains the degree of potential Accommodation per each of the sub-unit, considering continued usage of land at risk without attempting to prevent the area from being damaged by natural events allowing conservation and migration of ecosystems. ISC relates with the Planned Retreatment of concessions that create social justice risk as it was defined in the present study, as "the risk to beach accessibility reduction because of both, space reduction and high-price classes". CRI plot gives indications on the ratio between Stressors and Counteractors of coastal erosion, suggesting where the Use of the ecosystem can be supported. Requirement of this strategy is the presence of a preserved coastal zone between the coastline and urban areas to allow for ecosystem development.

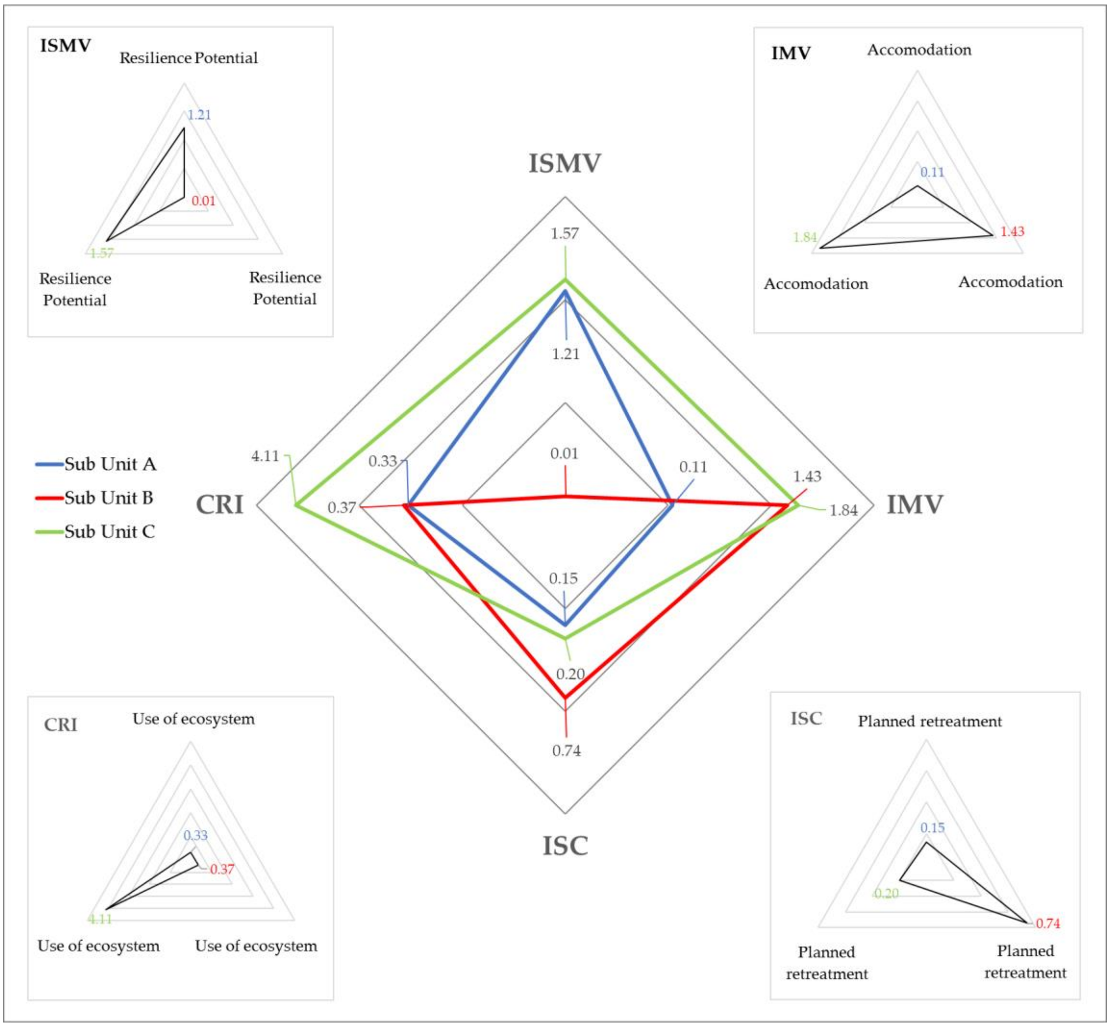


Figure 6.7 Comparison between the ISMV and the sub-indices (the weight of each sub indicator in the total ISMV can be inferred per each of the Sub-Unit. The sub plots show the application of each of the most common coastal solutions supported by the indicators).

Future researches should be proper conducted to investigate the feedback that the beach rock's deposits release to coastal systems, since they cover all the Mediterranean region (Figure 6.8).

(a) (b) (c)

Figure 6.8 Beach rock deposits; (a) Soverato, South of Italy; (b) San Vincenzo, Tuscany, (c) Playa de la Chapineta, Murcia (Spain).

Beach rock is formed by high evaporation, which causes upward movement of water and dissolved carbonates in the beach sand; they present as a layer of beach sand which becomes consolidated by secondary deposition of calcium carbonate (as calcite or aragonite) precipitated from groundwater in the zone between high and low tide levels and is mainly found on temperate. On Mediterranean coasts outcrops often include fragments of pottery from ancient civilizations, as it happens at La Punticella location within our test site, where it can consume the weak littoral current constituting a convergence pint. Where coastal emergence has taken place, while sea floor outcrops of beach rock are an indication of submergence (Bird, 2008).

Confirming previous studies on the San Vincenzo's coast, we can confirm that sub-unit A after the realization of hard structures and water regimentation works, responded with geomorphological trends dictated by site conditions. After 1959, all the further comparisons have highlighted the starting and increasing of erosive trends as the result of anthropogenic activities (i.e. hard structures, wetlands and backshore management Erosion rate reached the maximum value of 13 m/year between 1976 and 1977, when a first artificial nourishment was required downdrift in the harbor area. This has been the first soft intervention, after which several others followed during the enlarging phases of the harbor and the building of adaptive hard structures (last of which ended in 2015).

Past management plans focused on artificially stabilizing the shore by creating hard borders, with a controlled density of concessions. The surface area could be further used to host sustainable and removable businesses. They should maintain the low ISC while respecting the medium to low economic classes.

Sub-Unit B shows critical conditions and a residual resilience potential (ISMV=0.01). Water channels, sand bars, and part of the ancient dunes system are present. The beach covers a surface area of 73,225.420 m^2 (25 % of the whole Unit), 32.8 % of which is occupied by concessions, mostly in the form of resorts (74 % of the total concessions in the Sub-Unit). The economic class here is exceedingly high and coupled with the high occupation pushes the ISC to the highest value (0.74) within the whole Unit of San Vincenzo. Although hard defenses were built to face the refracted waves from the harbor entrance, the shifting of the erosive phenomena downdrift required the building of the submerged basin that isolated these sectors. The IMV was 1.43, and it represents a medium acceptable value in the anthropized conditions of the test site. Only 20 % of the sectors were classified with a linear variation factor of 3, and 10 % with factor 2 (see Table 1). Shoreline displacement was high in only two sectors directly affected by the reflected waves, and the resilience potential results were compromised by the ISC and CRI (0.37). The latter is comparable with the CRI of Sub-Unit A, although Sub-Unit B has more counteractors that are deemed to be considerably spoiled. Water channels are evidently inefficient as sediment providers; the submerged defenses are a further weakness which isolated that portion of the coastal zone, and the urban center bordering the backshore. Coastal narrowing restricts the coastal zone to an average distance from the shoreline of about 45 meters where the urban center is located; the distance is up to 200m where the Sub-Unit is bordered by the Natural Park, as in the southern part. Part of an ancient dune system confers a weak stability to the emerged areas there, while some sand bar systems acting between the isobath 3 and 4 m, involve part of the sediments trapped from the shore in longshore drifting. Sustainable designs for Sub-Unit B should comprise protection of the upper part through NBS and the planned retreatment for some concessions that could be shifted to other Sub-Units. In particular, the high cost of the services, together with the high density of concessions, expose the Sub-Unit to a risk of social injustice. Access to the area becomes hard because of both the high prices and the space available for different kinds of users. Most of the concessions are resorts that have an average cost of 183.8 €/day, and that comprises hard buildings over imposed on the coastal zone. They should be relocated at a greater distance, or at least the services' prices should be more accessible. The processes that could be supported are the ones related to water channels, which here also need to be managed at watershed scale, as well as the sand bars that should be preserved to avoid modification of the longitudinal profile of the beach.

Sub-Unit C obtained the highest values of ISMV (1.57), CRI (4.11) and IMV (1.84), while a very low ISC (0.2) compromised its resilience potential. In particular, the sub-unit covers a surface area of 180,592.812 m^2 (62 % of the whole Unit), all bordered by the Rimigliano Natural Park. Concessions occupy just 13 % of the Sub-Unit's area, but all of them belong to resorts. Attention should be paid to the fact that five concessions occupy a total surface area of 13,000 m^2; within Sub-Unit B, which is the most anthropized, 23 concessions cover a surface area of 21,041.3 m^2. Prices are the highest in the area (average value of 241.85 €/day), and the ISC is notably affected by it. On the other hand, an area of 49,184.120 m^2 is totally accessible for free; it would seriously increase the ISMV of the whole Unit if we calculated it to a Unit scale. Benefits of the strong rules adopted in the Natural Parks also consist in the low number of concessions, and the inexistence of coastal narrowing phenomena. The backshore here consists of ancient dune systems and reclaimed areas that leave the hard borders at over 200 m (except for the southern sectors). Other geomorphological elements that should be preserved are the sand bar systems on the active submerged beach, and the two channels flowing in this Sub-Unit. Even if they have been artificially canalized, the regenerative potential is exceedingly high. The ISMV is comparable with that of Sub-Unit A, considering the risk of social injustice (ISC). Index of Morphological Vulnerability (IMV) is the highest in the Unit; 37 % of the beach sectors had a factor of linear variation of 3, and 21.4 % of 2. Within this Sub-Unit, the longshore currents drift inversely (S-N), and the only channel on the southern part is canalized and defended as internal parking for boats. The indices also confirm the probability that the submerged canyon in the southern sectors has a trapping function on the sediment discharged (Bianco et al., 2020). The ecosystem in Sub-Unit C should be supported to maintain the resilience potential. It could also be increased by reducing the price of the services, or even issuing additional concessions inspired by NBS.

Additional notions in the management of coastal erosion and in the resilient action to perform should take account of the patterns related to Sea Level rise and tides.

The available information to the scientific community can be obtained within institutional databases, and for the present study have been extracted from the website www.psmsl.org/products/trends (Figure 6.9).

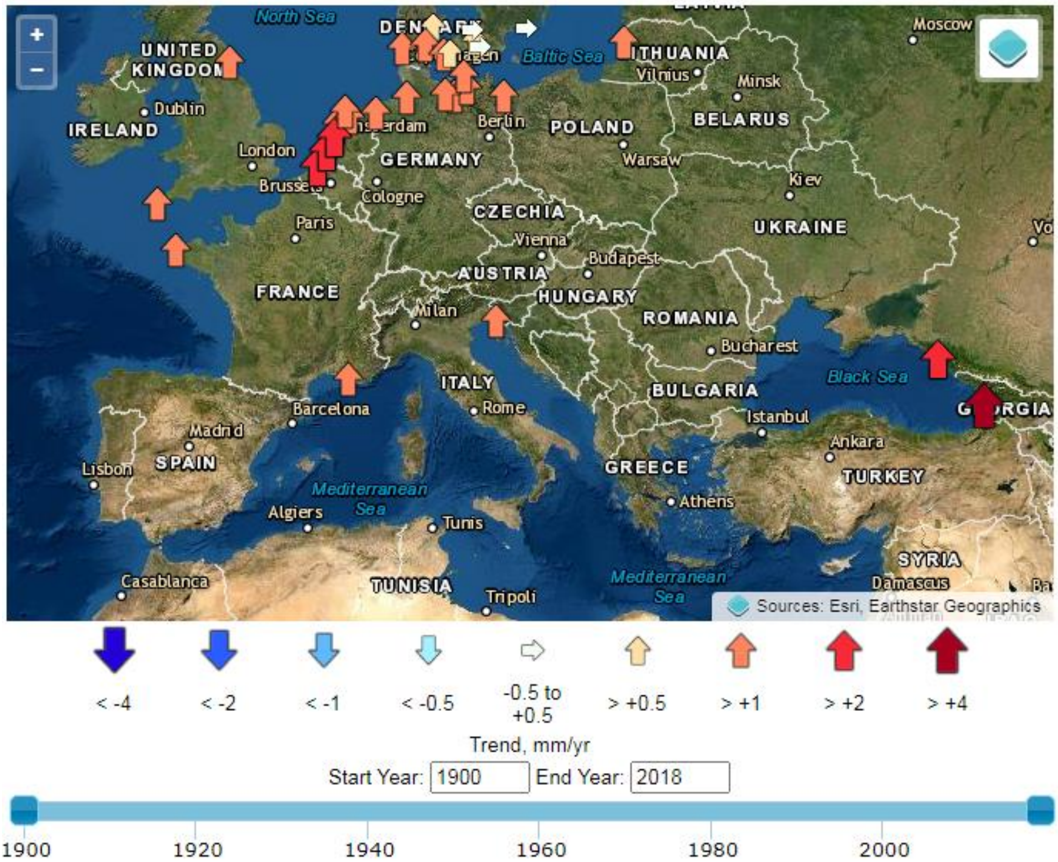


Figure 6.9 Plot map of SLR trends showing the European Mediterranean area www.psmsl.org/products/trends.

For the studied area trends, fitted using an Integrated Generalized Gauss Markov stochastic model from tide gauges have been extracted, and they are valid for the period 1900-2018.
The station of which they are referred is the Livorno site, where a Tidal Data Base is stored and managed by the Istituto Idrografico della Marina (Figure 6.10).

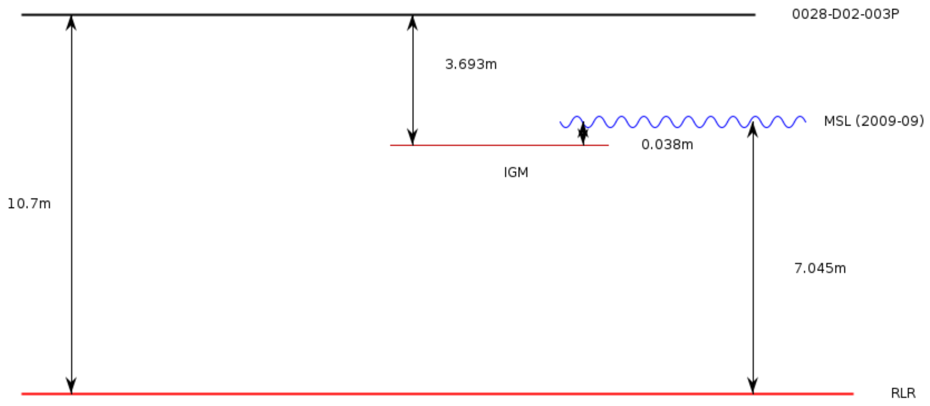


Figure 6.10 IIM, 2002. Tidal Data Base. Istituto Idrografico della Marina, Genova. Stazione LIVORNO https://www.psmsl.org/data/obtaining/rlr.diagrams/images/2080.png

The analysis of national procedures in Europe, as well as in several other parts of the globe was carried out. It was discovered that an almost generalized, and weak approach is followed to evaluate environmental assessments.

The charm of Tuscany, and the beauty of the Mediterranean landscape turned our coasts in one of the most anthropized of the country; results, as we saw during our field campaigns, pushed the touristic operators toward natural and before preserved areas, while weak national and regional normative allow coastal authorities to permit the fixing of the backshore line to the dunes' feet through seawalls, and to stabilize shorelines through sand replenishments.

Information on the geomorphology, geology, and hydrodynamics were represented for the first time, and provided tools from the normative supports to classify the coasts depending on the rates of erosion, as well as putting the basis to map the whole regional territory to plan decisions. Managers and stakeholders could be supported to extract usable values describing the real patterns of dynamism on sandy shorelines worldwide. These patterns were converted into indicators through our assessment model, that successfully indicated a very small difference between high anthropized areas and the natural one.

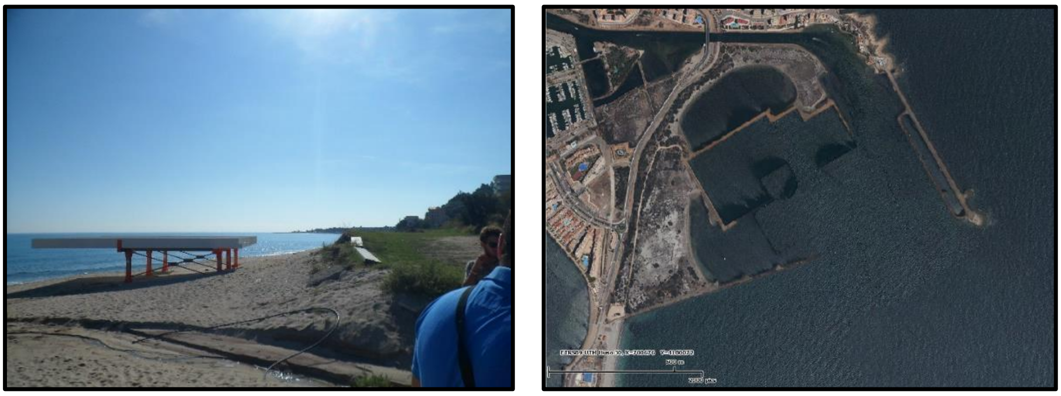
The modalities we used for the present study are here described clarifying about the concealing effects that classic methods provide.

San Vincenzo in fact was described as a stable coast even if studies since the '80 highlighted stressors on the vegetal associations threatened by the anthropic activities. For the purposes of the present thesis the features described are crucial since they create all together the delicate equilibrium we cited already. For coastal managers it should be clear that every time we modify, or even use one of these features, we are going to some way, modify all of them!

The sedimentary stock, that should be representative from the whole area within a coastal zone delimited as 200 m from the shoreline, at San Vincenzo does not consist of the urban center just in Sub-Unit C, where the Natural Park inland preserved this area from urbanization. In the other two Sub-Units the coastal zone is permanently occupied by buildings and infrastructures (such as a mass road and railway) that strongly reduce it. These features were considered for the calculation of the ISMV since they directly interact with the coastal zone, although at this scale of assessment they could not be considered in the management. Solutions regard just the sedimentary stock on which the active beach is over imposed physically and administratively.

Secondly, further than morphological, the economic value of the considered resource was very often considered the whole administrative (local, provincial, and even national) incomes tied to coasts. Sometimes economies comprised the GDP, the municipality or regional activities that are located even in the hinterland, but that rarely relate to the management of the sediment management. In fact, in the luckiest cases a watershed scale is used to perform sedimentary yield to coastal systems, and also when this happens, it is hard to find a complete management plan where, for instance, decisions are taken considering the morphodynamics.

What results from this common and accepted approach comprises a no-sense strategy, in addition to the overexploitation of spaces aiming to conquer new surfaces that do not belong strictly with the littoral zone. In the first case, *eco-monsters* and partial structures can be easily found within the Italian territory (Figure 6.11), while the invasion of the sea is a common practice followed in developing country and in some of the richest cities at the present time (Figure 6.12).



(a) (b)

Figure 6.11 (a) Abandoned embryonal touristic structures at Soverato (Calabria, South of Italy); (b) Abandoned embryonal harbor -Puerto Mayor- at La Manga (Murcia, South of Spain), source map: Sistema de Información Territorial de la Región de Murcia http://sitmurcia.es/visor/?

The structure in the picture 6.11 was abandoned during its realization, and never removed. Buildings like the one in the pictures almost always came from private ventures; similarly, self-realized defense structures were built to protect own properties without any permission or engineering competencies, such as blocks or seawalls.

Figure 6.12 (A) Archival photograph of Gu lf Hotel in Bahrain in 1969, image’ source www.ttnworldwide.com; (B) Gulf Hotel in 2020 from Google Earth; (C) Bahrain satellite view from Google Earth in 2020 with Gulf Hotel in the red box.

Differently, in the Figure 6.12 the case of Bahrain is pictured; the practice to build an artificial shelf is quite common in the Emirates. This strategy appears a rich one, mainly applied where countries invest to gain more space for buildings, that are not strictly made for recreational purposes.

The Gulf Hotel pictured was built in 1969 and protected by seawalls. After 50 years the hotel (that was directly jut out on the seaside) was completely bounded by further replenishment that today isolated it from the sea that is more than 2 Km far.

A further comparison has been made between Italians and Spanish sites interested by the building of harbors. Previous studies carried out by Garcia-Ayllon (Garcia-Ayllon, 2018) have already shown how these kinds of structures affect the shoreline displacement as well the quality of bathing waters.

A case is represented by the Region of Murcia (Southeast of Spain), and the Mar Menor area (Figure 6.13).

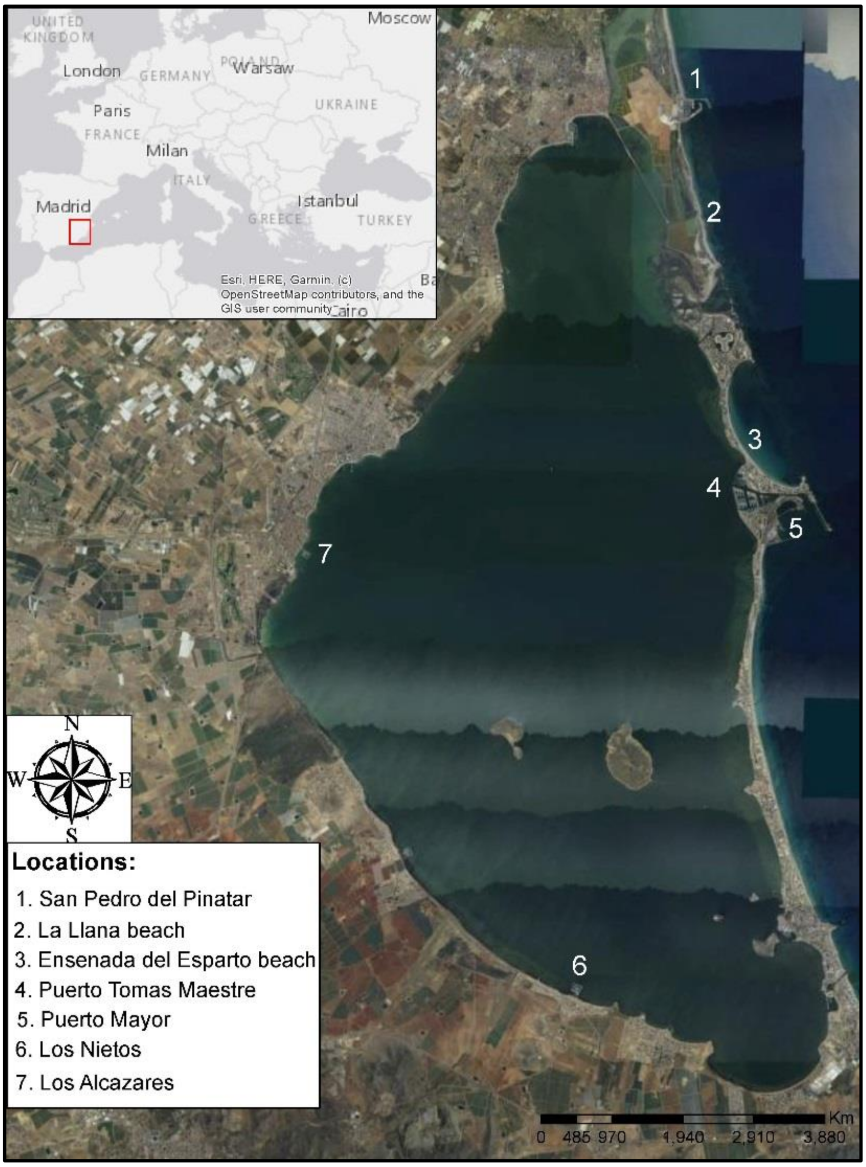


Figure 6.13 Geographical sketch map of the Mar Menor area (southeast of Spain).

It is a coastal lagoon separated from the Mediterranean Sea by a 20 km long dune cord. It hosts a high value environment threatened by incipient urbanization and intensive agricultural practices developed within the hinterland, that has been mainly registered during the last 50 years. Coastal structures can be divided into two mains categories of harbors. They are the ones built on the Mar Menor, and known as *island ports*, and the harbors realized on the Mediterranean coast of the same Region. Island ports have been realized paying attention to not interfere with longshore currents, such as the cases of Los Nietos (Figure 6.14), Los Alcázares (Figure 6.15), and Los Urrutias harbors, as well as the nautical infrastructures of Santiago de la Rivera. In a first stage they produced some tombolos, even if they had never reached the shape of salient. Although the shoreline within these portions of the beaches was not drawing back, the unexpected results concerned the sedimentation of finer sediments that have provoked serious issues to the quality of bathing waters (Garcia-Ayllon, 2018).

To avoid the current problems of accumulation of sludge which prevent bathing and that are produced by the generation of tombolos in island-type, such as Los Nietos, it should be studied the replacement of the current rigid breakwater structures of the docks of the port, by semi-permeable floating dock structures that did not hinder so much the sedimentary dynamics in the area.

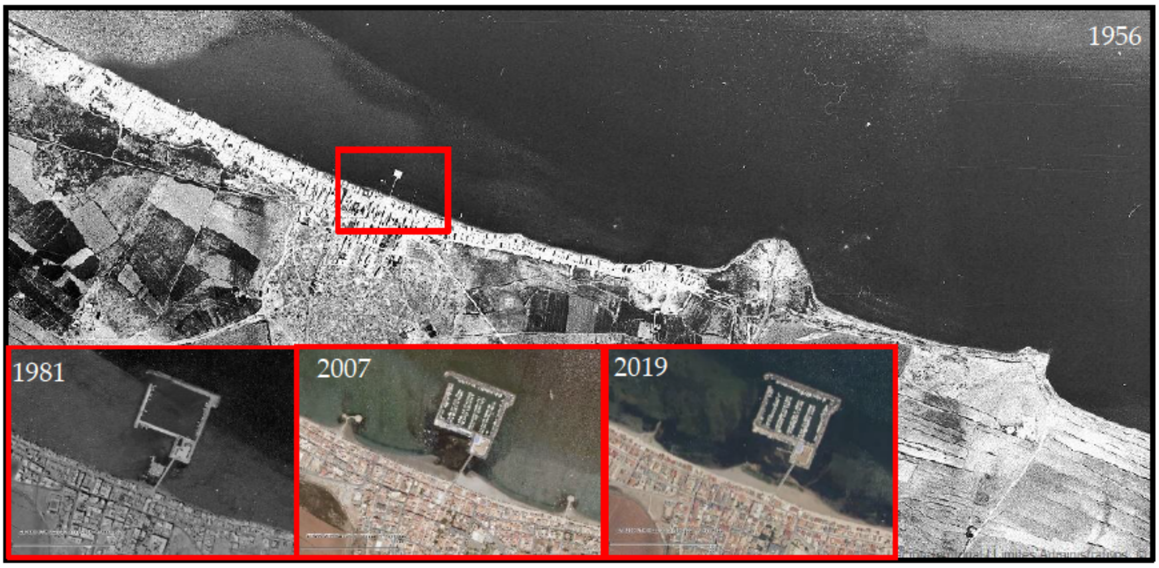


Figure 6.14 Los Nietos island port`s evolution from 1956 (big sketch map) to 2019; source map: Sistema de Información Territorial de la Región de Murcia http://sitmurcia.es/visor/?

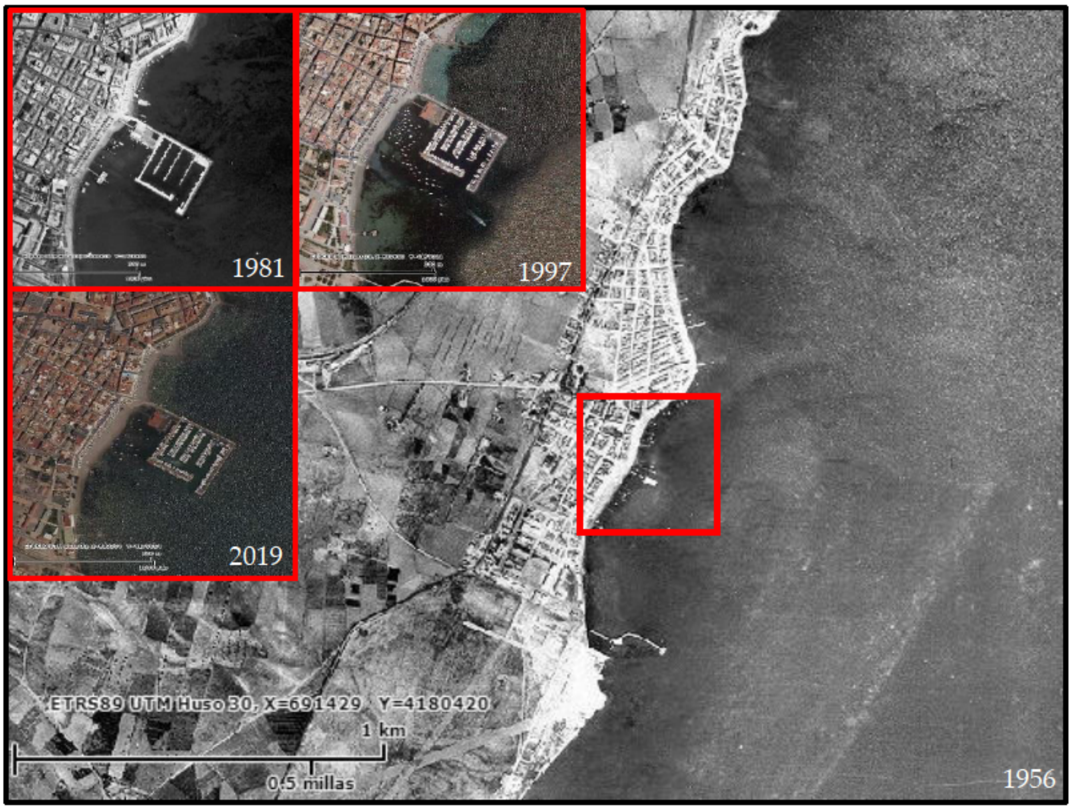
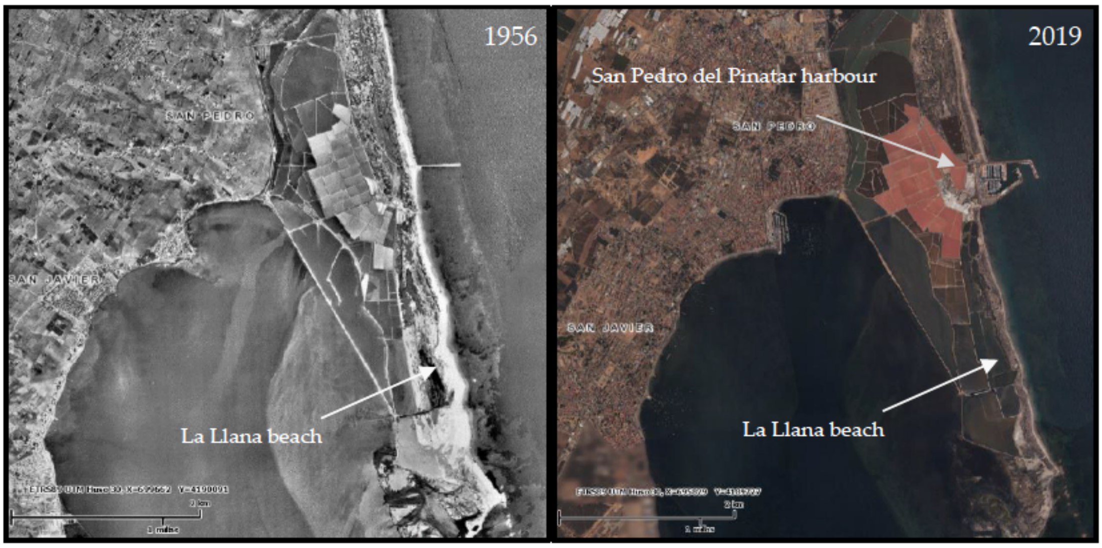


Figure 6.15 Los Alcàzares island port`s evolution from 1956 (big sketch map) to 2019; source map: Sistema de Información Territorial de la Región de Murcia http://sitmurcia.es/visor/?

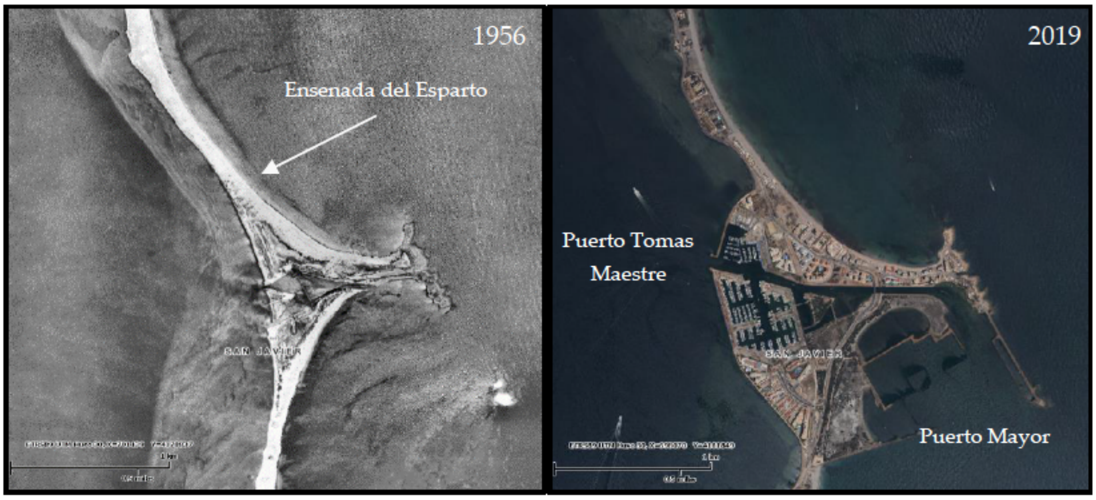
Differently, the Mediterranean coast of the Region assisted to more incipient modifications of the morphodynamics due to the realization of classical ports. They were accompanied by breakwaters and groynes built to face the erosive effects downdrift, but with weak results. A critical example is the San Pedro del Pinatar's harbor, that within the last 50 years caused a shoreline drawing back of 84 meters (Garcia-Ayllon, 2018), and the consequent disappearance of the La Llana's beach (6.16).



(a) (b)

Figure 6.16 Differences between the 1956 and 2019 situation on the Mediterranean coast of la Manga (Mar Menor) after the building of the San Pedro del Pinatar harbor; (a) the context in 1956 before the building of the harbor, with the wide La Llana beach individuated by the white arrow; (b) in 2019 the classical harbor was completed, and the La Llana beach almost disappeared; source map: Sistema de Información Territorial de la Región de Murcia http://sitmurcia.es/visor/?

Another case of bad practice related to the harbor's realization is represented by the dredging of la Gola del Estacio; it has been done to build Puerto Tomas Maestre and Puerto Mayor-the latter remained unrealized- and caused a shoreline's erosion of 25 meters (Garcia-Ayllon, 2018) and the drastic reduction of the Ensenada del Esparto beach (6.17).



(a) (b)

Figure 6.17 (a) La Manga site (Mar Menor) before the dredging of La Gola del Estacio in 1956, where the white arrow individuates the Ensenada del Esparto beach ; (b) La Manga site after the dredging of La Gola del Estacio and the realization the harbors Puerto Tomas Maestre and Puerto Mayor; the reducing of Ensenada del Esparto beach can be noted northern to the Puerto Tomas Maestre; source map: Sistema de Información Territorial de la Región de Murcia http://sitmurcia.es/visor/?

7. CONCLUSIONS

Coastal erosion is mostly increasing because of both, the lack of univocal and resolutive practices on coastal management, and the increasing of human pressure on coastal systems. A further criticality is due to the climate change, that depends mostly on the greenhouse production and the consequent global warming and ice caps melting.

Global change component is a big worry, and the previsions on its increase are not good at all.

In the present study an overview on each of the drivers of coastal erosion has been provided. Evidence has clarified that management and depletion of coastal areas by humans' activities represent the main issues to the loss of coastal systems, as well as for others transition environments, at regional and local scales.

High levels of urban pressure, and wrong management actions taken by administrators very infrequently follow the prescriptions and results of the assessments, and this creates wrong "habits" that directly affect the sediment availability on the active beach.

In this thesis we developed an index-oriented method that allowed us to perform a resilience assessment that take account of the potential of regeneration within littoral areas. We focused on the feedback that affect sedimentary stock as the space necessary to support coastal processes.

The work comprises different levels of assessment; the vulnerability as a classical way to measure the exposed areas to coastal erosion, and the risk of a social justice threat were used to condense humans' activities and natural processes. Although mostly conducted parallelly, some vulnerabilities were derived from the combination of others. For instance, through the analysis of the economies at a beach level a social justice risk index was derived and linked to the sedimentary stock limiting the businesses that are directly over imposed on the beach, thus interacting with the sedimentary stock. The latter was addressed as the main component within coasts that can support resilience, so we linked the geomorphological method to map the risk and calculate sediment availability, and the processes, or even activities, that reduce it.

The trends we found reflect the findings of the EEA, which in South Italy and Spain point to increase pressure, curbing the right of free swimming and access to the beaches.

Social justice has already been applied to environmental management, and in our case the risk of its arising came out from the small period managements. In fact, the sediment management, as usual in Italy, is never linked to the coastal system; actually, their borrowing from rivers' beds and land mines created other problems, such as the lack of sedimentary sources to coasts, and the exacerbating of environmental impacts. In this way the restriction of beaches drove the increase of prices on the beach establishments, and the always higher density of concessions released by the maritime domain authorities.

During the last 60 years in the majority of the sites upon which we have focused our research, as examples and even within our test site, managements show how they mainly used protection as a strategy to preserve infrastructures and buildings first, and to invade natural spaces later. Their usage has been adapted to the most peculiar conditions, converting classic coastal engineering in a continuous experimentation. New approaches were experienced widely, but they always pointed their attention to create usable spaces for tourism and economic interests. This fact represents the main problem of coasts' depletion, and moreover the reason why resilience assessment has never been considered by authorities and managers.

A resilience assessment should be conducted to compute the ecosystems' status that in coastal areas are regulated by a very fragile equilibrium. Sandy shorelines are globally the most impacted, due to their wide concentration in the most temperate and favorable climate situations. These conditions historically attracted humans to settle and invest within these areas, that today represent the greatest economies of the globe.

A representative, sandy, Italian coast was chosen to test the present research. The test site is in the San Vincenzo municipality, in the West Mediterranean coast of Italy (Region of Tuscany). Here, the modern tendency constrained touristic fluxes to concentrate even on the natural and "protected" areas, that cannot bear the increasing pressure.

Damaging activities have been legalized, and the messages of sustainability and respect of the environment crash in a funny way with the concrete-made structures that allow apparently "green" tourists to enjoy all the comforts of a swimming pool!
In fact, very rarely a 360° overview can be observed from vulnerability approach, that consider the risk only to humans' goods exposed, and never account of the risk to lose the main resource of the beach, that is the beaches in themselves.

Global change today becomes a popular challenge since its effects are always more incipient, and several parts of the society is starting to take care of it, creating new climate striker's movements very frequently. The possibility we have today to connect the whole globe through the web has created new and faster ways to promote and cooperate worldwide, also against global changes. Climate changes comprise an ample variety of phenomena, that basically produce an increase of the global temperatures and all the related consequences.
The development of urbans was very often exploited without precise rules during the second half of the '90s. The designing and urban planning suffered the wrong policies that political programs of which did not set in respect of sustainability and the natural resilience of the places.
To face this issue the environmental licensing of interventions should be homologated to define how much, and in which way human interventions impact the natural capacity of natural settings in coastal areas.
Hence, hard structures evolved from the status of defenses to a media of conquering. Of course, this strategy does not care about natural capacity to support human activities, and even about coastal tourism. In fact, in these places the main industry is represented by oil spilling that already represents a huge source of environmental impacts. Scarcely planned methodologies are sometimes the results of a complex bureaucracy that affect Italy, but in most of the cases they hide a complex tested method to preserve lobbies in the touristic industry.
This is for sure the case of Tuscany; it is indicative of this undeclared system that assures rich concessions to a favored and restricted class of investors, and that became legalized in several Italian regions. Here, the rules on the number of concessions to issue are not clearly stated in the normative. This cannot further be considered a case or a casual gap, but a strategy made on purpose!

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9. RESEARCH CONTRIBUTIONS OF THE PhD STUDENT RELATED WITH THE PRESENT THESIS

Bianco, F., Conti, P., García-Ayllon, S., Pranzini, E. (2020). An Integrated Approach to Analyze Sedimentary Stock and Coastal Erosion in Vulnerable Areas: Resilience Assessment of San Vicenzo's Coast (Italy). Water 12, 805. https://doi.org/10.3390/w12030805.

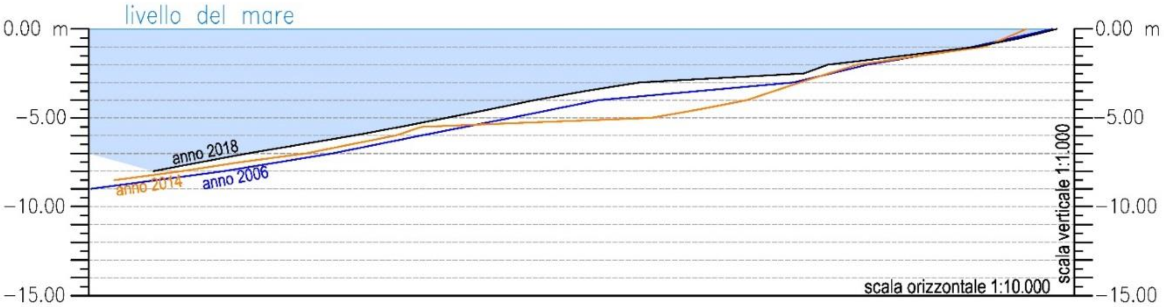
Bianco, F., Pranzini, E, Bonciani, F., Cinelli, I., Lanciano, C., Morandotti, M., Simoncini, D., Baldetti, A., Cipriani, L. E. (2019). Mapping Resilience, the Morpho Sedimentological Map of San Vincenzo (Tuscany, Italy). *Poster session of the CHEERS 2019 International Conference.*

Bianco, F., Dominici R., Lanciano C. (2018). Methodologies for the Validation Of X-Band Wave Radar Images as a Coastal Monitoring Tool. *Oral presentation at AIT 2018 - IX Conference of the Italian Society of Remote Sensing.* Published on-line at https://aitonline.org/?s=abstract+book.

Bianco, F., García-Ayllon, S., (2020). Coastal Resilience Potential as a Parameter of Social and Morphological Vulnerability: Indicator - Oriented Approach Applied in the Mediterranean Area of San Vincenzo (Italy). Estuarine Coastal and Shelf Science (Under review).

10. APPENDIX A. SUPPORTING DATA TO THE THESIS

10.1 CAD SECTIONS ON THE BATHYMETRIC FEATURES



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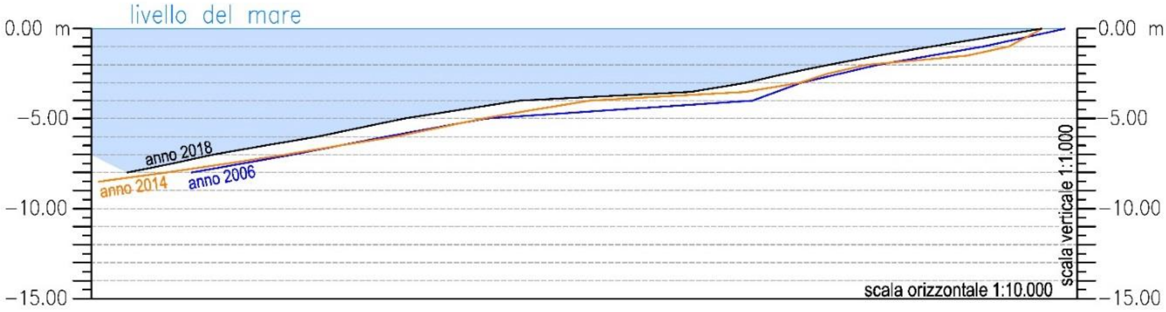

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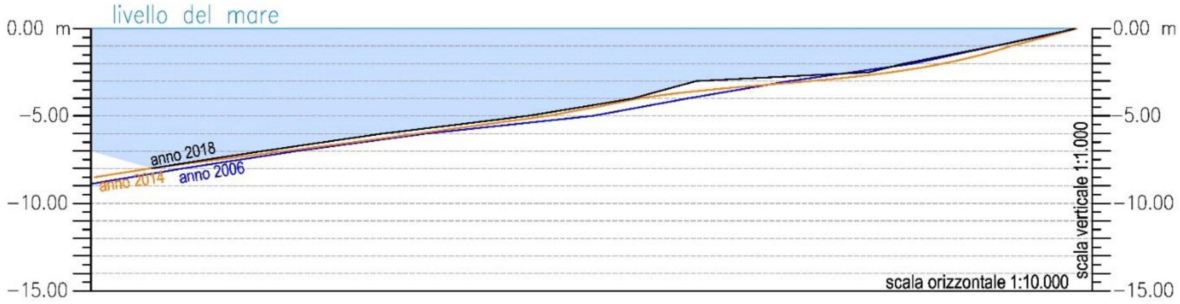

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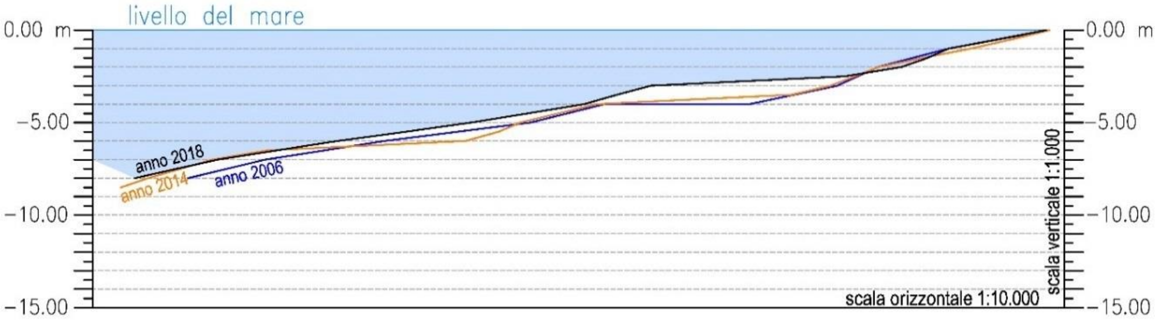

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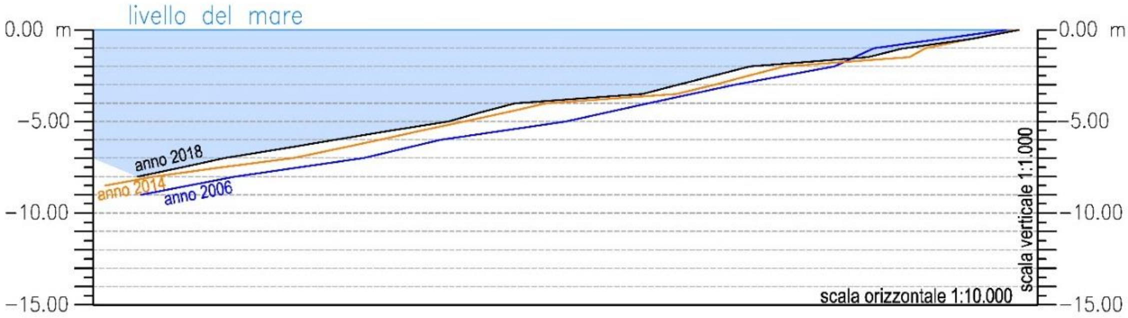
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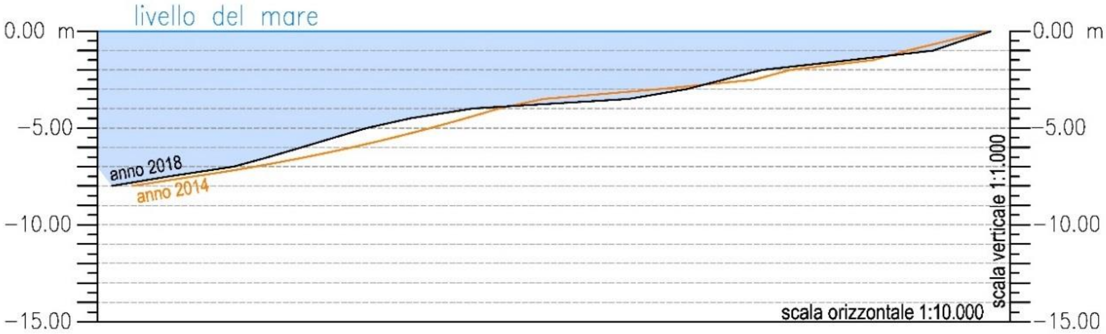
0.00 m
−5.00
−10.00
−15.00
anno 2018
anno 2014
anno 2006
scala verticale 1:1.000
scala orizzontale 1:10.000
0.00 m
−5.00
−10.00
−15.00

(e)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scala orizzontale 1:10.000
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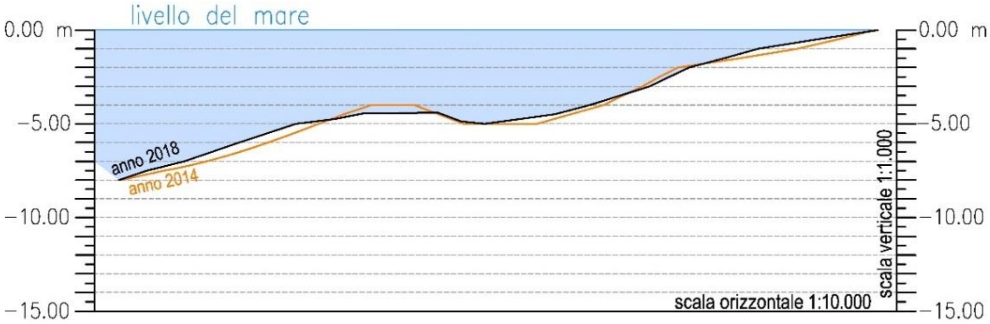
(f)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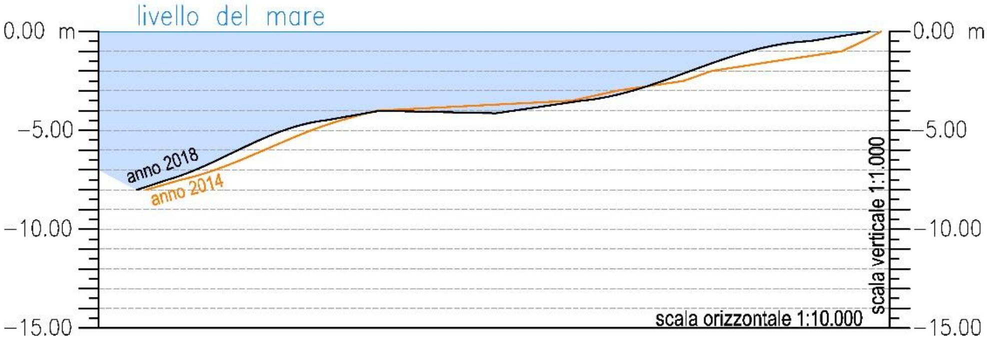
(g)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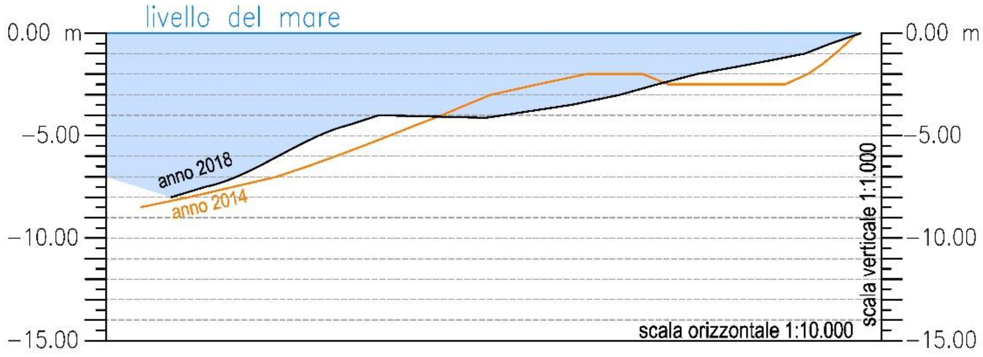
(h)



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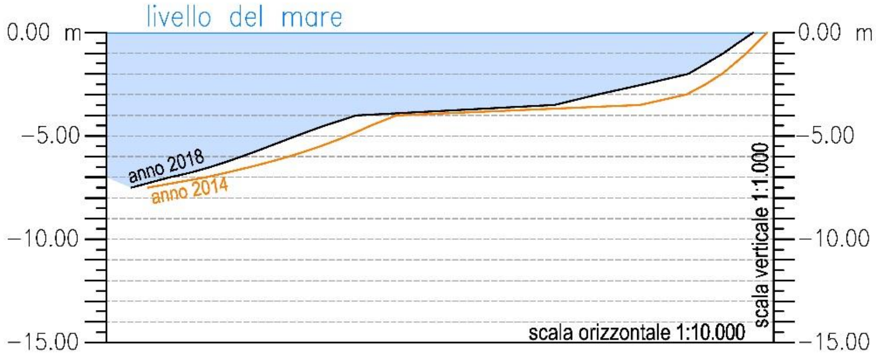
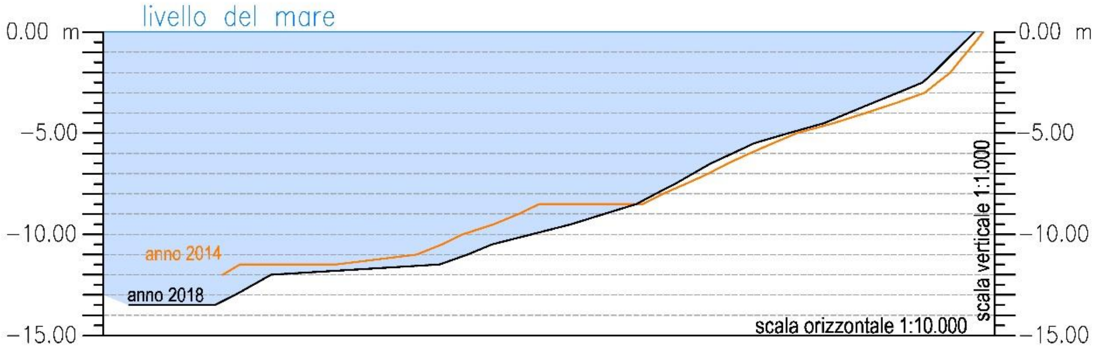


(l)



(m)

The ID of the sections corresponds to the sectors ID. a. S132; b. S133; c. S140; d. 142; e. 147; f. S150; g. S153; h. S157; i. S162; l. 168; m.174.

10.2 CONCESSIONS' FEATURES

N° Conc.	East	North	Surface (msq)	Denomination	Period	€/day x2	Price Source	Date	Sectors	Sub Unit
1	10.53940	43.11100	945	Holiday Beach	18 july/8 august	21.43	Av	nd	131	A
2	10.53930	43.11060	706.1	Villa Marcella	18 july/8 august	151.50	Ta	10th March 2020	131	
3	10.53930	43.11040	225.7	Hotel Villa Tramonto	18 july/8 august	170.71	Wb	11th March2020	131	
4	10.53930	43.11000	500	Santa Caterina	18 july/8 august	95.24	Wb	11th March2020	132	
5	10.53930	43.10960	200	Pensione Denia	10 july/1 august	153.00	Bk	7th March 2020	132	
6	10.53930	43.10870	1190	Hotel Lo Scoglietto	16 july/6 august	172.14	Bk	7th March 2020	132	
7	10.53910	43.10630	1916	Bagno Perla/La Perla del Mare	17 july/ 7 august	21.43	Wb	11th March2020	133	
8	10.53870	43.10510	766.93	Il Bucaniere	18 july/8 august	21.43	Av	nd	134	
9	10.53810	43.09730	220	Hotel Cacciatore	18 july/8 august	176.69	Av	nd	137	B
10	10.53830	43.09690	270	Hotel Stella Marina	18 july/8 august	176.69	Av	nd	137	
11	10.53830	43.09660	1101	Bagno Nettuno	18 july/8 august	30.81	Wb	11th March2020	138	
12	10.53840	43.09550	207.3	Ristorante La Triglia	18 july/8 august	30.81	Av	nd	138	
13	10.53850	43.09460	2171	Bagno Mediterraneo/Residence Mediterraneo	18 july/8 august	138.10	Wb	11th March2020	138	
14	10.53850	43.09510	35	Pantani Elsa	nd	0	nd	nd	138	
15	10.53850	43.09350	2355	Bagno Delfino/Hotel il Delfino	18 july/8 august	147.952381	Ta	10th March 2020	139	
16	10.53830	43.09220	2300	Paradisino	18 july/8 august	27 85714286	Wb	11th March2020	139	
17	10.53820	43.09160	36	Torzini Marisa	nd	0	nd	nd	140	
18	10.53810	43.09120	1640	Bagno Florida	18 july/8 august	32 38095238	Wb	11th March2020	140	
19	10.53810	43.09050	5	Soc. Il Delfino	nd	0	nd	nd	140	
20	10.53800	43.08750	990	Bagno La Lanterna	18 july/8 august	215	Wb	11th March2020	142	
21	10.53760	43.08680	1240	Hotel Sabbia D Oro/Aurora	18 july/8 august	242	Ta	10th March 2020	142	
22	10.53760	43.08640	269	Pensione Il Pino	18 july/8 august	134.5	Wb	11th March2020	142	
23	10.53750	43.08630	185	Albergo L Etrusco	18 july/8 august	190	Wb	11th March2020	142	
24	10.53750	43.08610	506	Hotel Kontiki	18 july/8 august	91.5	Ta	10th March 2020	142	

25	10.53750	43.08580	907	Albergo Coccinella	18 july/8 august	140.952381	Bk	7th March 2020	142	
26	10.53740	43.08510	1804	Hotel Bagno Venere	11 july/1 august	170.5714286	Bk	7th March 2020	143	
26	10.53740	43.08510		Bagno Venere	18 july/8 august	33	Wb	11th March2020	143	
27	10.53740	43.08500	600	Bagno Barcaccina	18 july/8 august	30	Ta	10th March 2020	144	
28	10.53690	43.08220	1200	Residence Euroturist	18 july/8 august	176.6904762	Av	nd	145	
29	10.53660	43.08070	3000	Hotel I Lecci	18 july/8 august	296.3333333	Bk	7th March 2020	145	
30	10.53620	43.07920	3000	Lazzi Vi.Tur (Riva degli Etruschi)	18 july/8 august	249.1428571	Bk	7th March 2020	147	C
31	10.53540	43.07540	3000			249.1428571	Bk	7th March 2020	148	
32	10.53550	43.07330	3000			249.1428571	Bk	7th March 2020	149	
33	10.53550	43.07100	3500	Garden Club Toscana	18 july/8 august	248.1904762	Bk	7th March 2020	151	
34	10.53414	43.06417	500	Residenza Cavalleggeri	18 july/8 august	213.6666667	Bk	7th March 2020	152	

Legend

Av Average price of the Unit

Ta TripAdvisor

Wb shop website

Bk Booking.com