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*Corresponding author

Milva Pepi, Stazione Zoologica Anton Dohrn, Fano Marine Centre, Viale Adriatico, Italy

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Review Article

Monitoring of Coastal Areas by Remote Sensing and Engineering Approaches

Silvano Focardi[1] and Milva Pepi[2*]

[1]*Department of Environmental Sciences, Università di Siena, Via Mattioli, Italy*

[2]*Stazione Zoologica Anton Dohrn, Fano Marine Centre, Viale Adriatico, Italy*

Abstract

Monitoring coastal regions is very important to protect the marine environment as a whole. Coastal erosion, sea level rise, coastal changes, flooding, and harmful algal blooms, are examples of challenges in coastal areas resulting from climate change. Furthermore, pollution from oil spills and agricultural activities that release large quantities of agrochemicals, organic matter, drug residues, sediments and saline drainage into coastal waters are further examples of coastal challenges and criticalities. All of these challenges require a high level of attention. Coastal monitoring through remote sensing approaches and possible models capable of predicting future developments can represent valid tools available to policymakers to develop interventions. Hard and soft engineering interventions can counteract the effects of coastal erosion, wave action, shoreline and flooding, thus restoring coasts and all associated activities. This mini-review describes remote sensing approaches for coastal monitoring, such as the use of unmanned aircraft, and possible hard and soft engineering interventions capable of mitigating coastal damage according to sustainability rules.

Introduction

Coasts represent complex and dynamic systems that change shape at different spatial and temporal scales in response to geomorphological and marine forces [1]. Coastlines are the boundary between land and water and are important and dynamic linear features [2]. When coastal landforms are affected by short-term disturbances such as storms, they often revert to their pre-disturbance landforms, thus reflecting an underlying morphodynamic equilibrium [3].

Coastal areas, estimated to be around 504,000 km worldwide, are home to a large and growing percentage of the world's population, with more than 10% of the world's population (600 million people) living along coastal areas that are less than 10 m above sea level, while about 40% of the world's population (2.4 billion people) live within 100km of the coast [4]. The concentration of the world's population in coastal areas leads to increased pressure on the environment and coastal ecosystems.

Coastal areas are exposed to the continuous action of various factors, both natural and of anthropic origin. Coasts are under intense pressure from urban growth, industry, agriculture, aquaculture and tourism [5]. Other factors, both natural and anthropogenic, such as reduced river sediment input, offshore bathymetric changes, altered wind and wave patterns, or a combination of factors, can have important impacts on coasts, such as coastal erosion [6,7].

Among the main anthropic factors there are maritime constructions and coastal defence barriers, such as ports, which interfere with the dynamics of the sediments; housing construction; industrial and recreational infrastructure; interventions in the management of river basins and in the regulation of watercourses for the supply of water resources for drinking use; irrigation in agriculture and the industrial use of water, causing changes in the level of vegetation; forest drainage [8]. Some of the most relevant natural factors influencing coasts are the height and direction of waves, wind, tide, sediment transport, sediment supply from rivers to the sea, subsidence, sea level rise sea precipitation, frequency and intensity of extreme weather events, including storms [9]. In the last century, the factors listed above, combined with population growth, urbanization and development activities, have begun to influence coastal processes and, consequently, the related services, causing the degradation of ecosystems, altering the dynamics of coastal areas, especially increasing coastal erosion and risks [10].

As cities expand, they can converge with coastal spaces. This can cause an alteration of the coastal morphologies such as beaches, deltas, dunes, and mouths, and there can be erosions, accumulations by sedimentation, and profile variations. Coastal vulnerability is currently rapidly increasing due to climate change. Vulnerability is manifested through increased levels of flooding, changes in beach profile, erosion, increase and changes in coastal landforms, changes in coastal transport rates, and coastal erosion. Ports can create coastal erosion by altering wave patterns. Changes in weather patterns due to climate change produce an intensification of the frequency of extreme marine events [11].

The main problem plaguing the world's coastline is erosion. Most of the erosion phenomena are caused by human activities that have analyzed the coastal dynamics by adopting an inadequate spatial scale. Therefore, the defence interventions to solve the erosion problems have induced erosion processes in other coastal stretches, even several kilometres away. Most coastal environments around the world are experiencing the effects of climate change. Its most relevant consequences are the rise in global sea level and the increase in the frequency and intensity of storms. In this regard, it is worth noting that marine flooding could amplify beach erosion and saline intrusion, thus increasing the susceptibility of coastal populations and ecosystems. These effects could be even more dangerous when combined with a high concentration of people and socioeconomic activities [12-14].

The impacts of climate change are quite evident in the coastal areas of the world which are subject to the effects of erosion processes, inundations, inundations and seawater intrusion, with serious consequences on natural and socio-economic assets. The rise in global mean sea level is one of the most evident and thoroughly studied consequences of ongoing global warming. The global mean sea level could rise by up to 1.10 m by the end of the 21st century [15], and this trend is expected to continue in the future. Over the past two decades, the global mean sea level has risen at a rate of 2.5 mm per year and this rate is four times faster in low-lying coastal areas, with an average relative increase in the sea level ranging from 7.8 mm to 9.9 mm, year^{-1} [16]. Many sandy coasts are already subject to erosion and nearly half of the world's sandy beaches could be considered close to extinction by the end of the century because of the action of greenhouse gas emissions. In the absence of coastal protection or adaptation strategies and considering the worst climatic conditions, by 2100 there will be a 48% increase in the world's land area at risk of flooding, threatening 52% of the population and 46% of global resources [17]. Climate change is altering mean sea levels, medium and extreme wave conditions, storm surges, extreme sea levels and river flows [18]. Changes in these climate-related drivers have potential associated impacts on the coast. It is important to note that even moderate increases in mean sea level could lead to a significant increase in the number of climate-related extreme retreat episodes [19].

Climate change is predicted to alter medium and extreme wave conditions [18]. Changes in medium waves could lead to increases or decrease in coast drift and changes in the amplitude and frequency of oscillation and/or rotation cycles at long inlet beaches [20]. Changes in extreme waves could cause more cases of erosion thresholds to be exceeded [19]. Storm surges are included among the significant features of extreme coastal climate that can contribute to rising water levels and exacerbate episodic coastal erosion. Due to these phenomena, extreme sea level rise could lead to an unprecedented frequency of extreme coastal erosion events in many parts of the world [21]. Large variations in river flows and associated solid discharge due to increased evapotranspiration, changing precipitation and snowfall are produced by climate change [19].

Coastal communities face severe socio-economic challenges posed by the disastrous impacts of natural hazards such as hurricanes. Such challenges are exacerbated by an increase in population over time coupled with the ageing of existing infrastructure, a rise in property value, and the expected shifts in the frequency and intensity of natural hazards due to climate change [22].

Monitoring of Coastal Areas

Coastal zone monitoring is characterized by complex dynamics and is of fundamental importance. Traditional measurement methods are commonly applied, but are time-consuming and may not provide the necessary spatial scale and local detail and/or completely cover the information [23]. Remote sensing techniques have been introduced, which use satellite images to measure the morphology and scale of sandbanks. The state of coastal erosion can be assessed using integrated systems to provide a comprehensive and comprehensive model for coastal erosion detection and monitoring and to promote a clear pathway that will serve for coastal decision-making and management [11].

Unmanned aerial vehicle (UAV) applications have become an ever-expanding area in remote sensing in recent years [24]. The advancement and easy accessibility of unmanned aerial vehicle technology has enabled the development of an alternative coastal monitoring technique that efficiently captures spatial and temporal requirements in a wide range of environmental applications [25]. This type of approach makes it possible to evaluate the spatiotemporal distribution of coastal changes; evaluate long- and short-term shoreline changes from data obtained from unmanned aerial vehicles, the most recent shoreline changes and beach-dune morpho-topography; evaluate the possible influence of such changes on the vulnerability of areas to coastal erosion and flooding [10] (Figure 1).

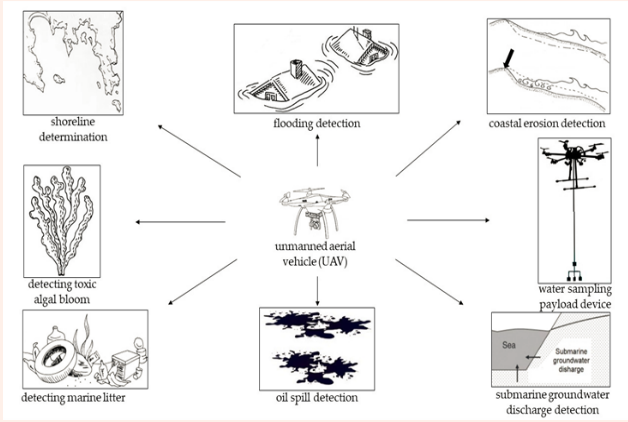

Figure 1: Monitoring of the coastal environment by using remote sensing in the form of unmanned aerial vehicle (UAV). The method allows the determination of coastal features including shoreline, flooding, coastal erosion, algal bloom, the realization of sampling, detection of marine litter, detection of oil spill, and revealing submarine groundwater discharge.

Surveying and monitoring the coasts, therefore, has considerable economic and social importance. The shoreline marks the transition between land and sea and is defined as the physical interface between land and water. To have a good coast survey method, it is necessary to evaluate the existing ones and to know their disadvantages so as to be able to propose better approaches. Coastal surveying can be achieved using several processes. Mapping the seabed using acoustic waves such as sonar is currently the only technique that can be used without depth limitations. However, storm conditions and tidal currents can make integrated operations difficult. Terrestrial surveys can be obtained using landmarks, Global Positioning System (GPS), terrestrial Light Detection And Ranging (LiDAR) or three-dimensional (3D) scanners [26]. In general, in situ, measurements are difficult to obtain. In this case, other survey methods such as remote sensing are recommended [27]. Remote sensing is the technique of obtaining information about objects or areas at a distance, typically from aircraft or satellites [28].

Unmanned aerial vehicles are increasingly used in coastal monitoring as they contribute to the completeness of radiometric information and allow automated or semi-automatic coastline extraction through image processing. In order to analyze coastal change, it is necessary to choose a shoreline indicator. Given the dynamic nature of this boundary line, the indicator to be chosen must take into account the coastline in a space-time sense and must also consider the dependence of this variability on the time scale. For the purposes of coastal management, it is necessary to know the evolution of the coast according to the relative time scale. To analyze these changes it is necessary to give a definition of coast. The definition of the shoreline which should theoretically represent the linear boundary between the maritime and land domains is very challenging due to the wide variety of indicators necessary to elaborate geomorphological aspects, tidal level or the configuration of vegetation [29].

Concerning the organization of the coastal environments, they include four general areas definable in a typical beach profile, extending from the cliff or dunes to the edge of the coasts. The coast profile can change and there is no indicator that can be used for all types of coasts. Therefore, the functional indicators depend on the coast profile and on the monitoring objectives. Coastal indicators must schematically and correctly represent the overall state of the coast from the point of view of its sedimentary evolution [30]. The indicators can include geomorphological reference lines, vegetation lines, instantaneous tide levels and wetting lines, tidal data, beach contours and storm lines. Indicators can be used in coastal surveying and monitoring, and they represent key points in coastal monitoring. These indicators should meet the requirements of being able to highlight changes in the coastal level, but should not be sensitive to the extent that they are affected by changes themselves [4].

The assessment of coastal erosion is extremely important and must take into account natural and anthropic causes, in order to design interventions aimed at contrasting erosion and enabling the sustainable development of coastal areas. Monitoring beach-dune systems and shoreline variations using traditional measurement methods, such as the interpretation of topographic maps and aerial imagery, can provide a complex and time-consuming system that may not provide the necessary information, such as spatial scale and local detail, and may not fully cover the most recent time intervals [23]. Today, these limitations in spatiotemporal resolution can be overcome thanks to access to large satellite databases and the development of various ad hoc technologies. This is largely due to the advancement and easy accessibility of unmanned aerial vehicle technology. This approach has enabled the development of an alternative coastal monitoring technique that allows the acquisition of spatial and temporal data information within different environments [10,25,31]. Coastal monitoring with unmanned aerial vehicles allows data to be obtained and methodologies that integrate computer vision algorithms for 3D and image processing techniques for analysis, combined with maritime information [11].

Unmanned aerial vehicles are becoming increasingly affordable tools and their use is spreading as environmental monitoring systems. Recent rapidly developing research shows that unmanned aerial vehicles are being used to detect man-made marine debris offshore and along coasts [32]. Coastal change sensing can be conducted using unmanned aerial vehicles, gaining knowledge about shoreline changes and coastal degradation in various areas. Monitoring by unmanned aircraft of shoreline changes that have occurred over a time interval can be useful for predicting future impacts in the coastal region. Compared with other methods, unmanned aerial vehicles can provide more accurate data as the minimum height they can fly is 10 m, especially along the hard-to-access coastal area, and one of the best tools to analyze changes in costs and other costs problems [33]. Very important is the monitoring of coastal areas with respect to pollution from oil spills. These accidents are caused by oil transportation, storage, a tanker truck accident, or the intentional drainage of oil into seawater. The spilt oil could greatly affect life in coastal regions. Unmanned aerial vehicles paired with artificial intelligence enable accurate, real-time detection of oil spills [34]. Oil spill detection using unmanned aerial vehicles needs to analyze collected images to enable intelligent control of oil contamination in the coastal region and prevent damage [34].

Blooms of floating macroalgae have been reported worldwide recently. While the seasonal outbreaks of blooms may provide important ecosystem functions in the open-ocean environments, they also bring multiple hazards to the coastal environments, tourism economy, vessel navigation safety, and even human health. Unmanned aerial vehicles are effective tools in monitoring algal blooms due to some characteristics of these tools such as a high temporal frequency, relatively low operating costs, and the ability to include lightweight sensors with the optical capability to detect algae in various wavelengths. The range of the detected waves is between 500 and 1400 nm (visible and near-infrared range). Traditional water quality monitoring relies on manual field sampling and laboratory analysis of chlorophyll-*a* (Chl-*a*) concentration, which is resource-intensive and time-consuming. The use of an unmanned aerial vehicle allows to quantitatively map the distribution of Chl-*a* in surface waters in coastal waters from low altitudes. This approach proved to be economical, robust and able to map the spatial and temporal variations of chlorophyll-*a* concentration during an algal bloom [35]. It is important to establish a long-term data record of bloom characteristics to help understand the mechanisms behind blooms, such as ocean warming or eutrophication. This will provide near real-time information on the location and quantity of floating macroalgae to aid countermeasures in response to these phenomena [36].

Engineering Approaches for Coastal Protection

The management of coastal areas has become essential to protect the coast, contain and reduce the degradation processes in progress and avoid the emergence of new crises. Erosion is the main problem affecting the coasts. This phenomenon is gradually worsening as coastal environments around the world are feeling the effects of climate change. The most obvious consequences are the rise in global sea levels and the increase in the frequency and intensity of storms. Furthermore, marine flooding amplifies the effects of beach erosion and saline intrusion, thus increasing the susceptibility of coastal populations and ecosystems. These effects can be even more dangerous in the presence of a high concentration of people and socio-economic activities [12,13].

This approach is also necessary to effectively achieve integrated coastal zone management [14]. Coastal engineering plays a key role in assessing the impacts of climate change along coasts and in offering adaptation solutions for the resilience of coastal systems. Meanwhile, populations in coastal areas continue to grow, highlighting the need to protect and preserve coastal systems in the face of intensifying climate change [14]. Hard engineering, also called "grey infrastructure", is a coastal management technique used to protect coastlines that rely on absorbing wave energy, thus managing to prevent erosion and flooding. Highly visible man-made structures used to moderate the intensity of some natural processes are included in this type of approach [37].

Hard engineering is widespread and particularly concentrated in North-Western Europe, East Asia and deltas or densely populated areas such as coastal cities [38]. There is no technological limit limiting the maximum height of a seawall, rigid protective structures do not provide a reliable long-term response to coastal hazards, as seawalls can exacerbate erosion, affect the seabed and nearby shorelines and diminish the ability of the coast to respond naturally to changing conditions. Hard protection includes dykes and static breakwaters which are effective in shoreline stabilization but cause erosion and can destabilize the beach; groins and man-made headlands which intercept sand transport along the coast and are effective in beach building upstream but induce run-off and erosion downstream; detached breakwaters and artificial reefs that reduce wave activity and energy along the coast and are effective in beach construction but can produce erosion downstream [39]. Sea-level rise caused by global warming increased from 1.2 ± 0.2 mm yr-1 from 1901 to 1990, to 3.0 ± 0.7 mm yr^{-1} from 1993 to 2010 [40]. Sea-level rise is accompanied by coastal erosion, both along sandy beaches and rocky coasts, representing major components with rocky coasts and sandy beaches constituting approximately 52% and 31% of the whole coastlines, respectively. The erosion of sandy beaches linked to sea level rise is set to increase in the future. Rocky coast erosion results from cliff recession, which is a consequence of individual cliff collapse. Coastal cliff collapses are classified into four types: flows, overturns, slides, and falls [41]. Basal erosion caused by waves forms a typical notch and this pattern is common to all collapse types, except flows. These collapses produced the fall of blocks about 10 meters in size. Therefore, the collapse of a rocky cliff produces a major shoreline change compared to the gradual change due to sandy beach erosion, although the frequency of rocky cliff collapse is relatively low. Man-made structures, such as metal bars inserted into cliffs for reinforcement, can be added to protect shorelines from erosion in hard engineering processes called cliff fixing [42] (Table 1).

Coastal barrage consists in partly submerged dam-like structures that control tidal flow (Table 1). Coastal barrage has an important impact on storm surges consisting of changes in water level driven by atmospheric forcing. A barrage may provide protection against coastal flooding from storm surges [43]. This approach originates a more consistent water level that can be used to create hydroelectricity. The kinetic energy present in marine and tidal currents can be converted to electricity using relatively conventional turbine technology [44]. Gabions consist of wire mesh bundles or rocks placed at bare cliffs, which are intended to reduce the impact of waves [45] (Table 1). The two main causes of flood failures are washout and the impact of debris against the bridge superstructure. Debris can also divert flows, causing increased scrubbing and increased horizontal pressures acting on the bridge piers and abutments. Percolation is the result of the erosive action of running water, which digs and carries the material away from the banks of streams and watercourses. Gabions have long been used as anti-erosion devices on bridge piers and abutments [45].

Groynes are structures which block the littoral drift partially or completely and consist of wooden fence-like barriers built at right angles at the beach (Table 1). Single groynes are used to create smaller sediment cells in which the beach can turn against the locally predominant wave direction. They are also often used as terminal structures which limit the amount of sediment deposited in tidal inlets and navigation channels. Groyne fields, meaning a series of groynes, are typically constructed on shorelines where erosion problems are generated by gradients in the longshore transport, in contrast to erosion problems caused by cross-shore transport. The groynes act by partially blocking the longshore sediment transport and as a result, the bed contours landward of the groyne tip tend to turn against the predominant waves [46].

Revetments consist of slanted structures made from concrete, wood or rocks along a cliff, preventing cliff erosion by absorbing the wave's energy (Table 1). The revetment needs maintenance works such as removing the visible part of the steel hook, treating the units that had a leg fracture for example by epoxy and replacing the fractured units with another one or adding extra units [47]. Rock armours consist of large boulders or rocks piled up on a beach in front of a cliff or sea wall. They absorb the energy of waves and help build up beaches (Table 1). These hard engineering structures need to control stability, in particular for highly nonlinear waves in shallow water. Such waves are characterized by a high and narrow crest and a wide wave trough [48]. A sea wall, also called a breakwater, consists of large walls constructed from concrete, steel, or stone located along the shoreline of the beach (Table 1). This hard engineering structure protects cliffs from upland erosion and is a barrier to flooding. It is a wooden or stone wall that extends from the shore into the sea and is built in order to protect a harbour or beach from the force of the waves [49].

These common hard engineering structures for coast protection can present some disadvantages as they can be expensive, can represent short-term solutions and can have a negative impact on the environment. Installing hard engineering structures in one coastal location can have detrimental effects further down the coast. Therefore, these structures and the environment around them require continuous monitoring.

Table 1: Common approaches of hard engineering for coasts protection.

Type	Definition	Advantages	Disdvantages	References
Cliff fixing	This procedure requests metal bars inserted in cliffs for reinforcement	The result is an improvement in the strength of the cliff and the prevention of rocks falling	This method can cause a metal mess	[42]
Coastal barrage	This procedure consists in partly submerged dam-like structures that control the tidal flow	This method creates a more consistent water level that can be used to create hydroelectricity	The intervention has a strong impact on the environment and is expensive to implement and maintain	[43,44]
Gabion	The method consists of bundles or rocks in metal mesh located at cliff bares	This approach reduces the impact of waves	This intervention consists of an inexpensive hard engineering structure, but not very effective or attractive	[45]
Groynes	The structure consists in wooden fence-like barriers built at right angles at the beach	This intervention prevents longshore drift, flooding and erosion, allowing beaches to build up	This approach can cause erosion further down the coast. It is unattractive and expensive	[46]
Revetment	The method consists of slanted structures made from concrete, wood or rocks along a cliff	This approach prevents cliff erosion as it absorbs the waves energy	The method is expensive to implement. It can cause a strong wave backwash	[47]
Rock armour	This approach consists of large boulders or rocks piled up on a beach in front of a cliff or sea wall	The method absorbs the energy of waves and helps build up beaches	This intervention is expensive to implement and maintain	[48]
Sea wall	The structure consists of large walls constructed from concrete, steel, or stone located along the shoreline of the beach	This method protects cliffs from upland erosion and is a barrier to flooding	The method originates waves that can erode the wall defeating its purpose and is expensive to implement and maintain	[49]

The negative impacts of hard protection on erosion and sedimentation patterns, as well as on ecosystems and the services they provide, led to a growing recognition of the benefits of soft protection. Dune rehabilitation and sand nourishment, including beach nourishment, allow the coast to respond dynamically to change. It was therefore presented a response defined as "building with Nature", a strategy that provides an effective response to protect beaches and coastal areas. Optimal beach and shore nourishment responses offer economic and social benefits and can reduce forced migration. Soft adaptation is mostly focused on beach nourishment, considered an environmentally friendly protection response for coastal ecosystems [50].

The conservation, restoration and use of vegetated coastal habitats in eco-engineering processes for coastal protection provide a promising strategy, giving important insights for climate change mitigation and adaptation [51]. Vegetated coastal habitats can therefore dissipate wave energy through flow separation. Seagrasses and other vegetated coastal habitats also provide protection by dissipating wave energy due to friction due to their presence which increases bottom roughness, reduces near-bed flow velocity, and elevates the lower boundary layer. Vegetated coastal habitats, with their particular stem density and flexibility, also provide a porous medium with a large energy dissipation capacity. Thus, vegetated coastal habitats act on all mechanisms that dissipate wave energy. Their contribution to bathymetric changes through sediment accumulation and shoreline accretion is critical to shoreline protection, as is direct damping of incoming waves [51].

The soft engineering approach works with nature to protect the coast, rather than trying to stop natural processes. It uses ecological principles and practises, therefore making less of a negative impact on the natural environment and are defined as "Nature-based solutions", expressing a concept to actively promote nature for climate mitigation and adaptation purposes. The definition from European Community is as follows: "Nature-based solutions" 'aim to help societies address a variety of environmental, social and economic challenges in sustainable ways. They are actions inspired by, supported by or copied from nature; both using and enhancing existing solutions to challenges, as well as exploring more novel solutions. Nature-based solutions use the features and complex system processes of nature in order to achieve desired outcomes, such as reduced disaster risk and an environment that improves human wellbeing and socially inclusive green growth' [52,53].

Coastal dunes are often important elements in the coastal response to storm waves and storm surge impacts on coastal lowlands. Afforestation of coastal dunes is a way to stabilize dunes by planting trees (Table 2). Vegetation cover, in turn, has profound impacts on coastal dune morphology and storm protection function; binds existing sediments, promotes accumulation of fresh sediments and thereby increases dune volume and dune crest elevation where a sediment-plant interaction occurs with vegetation growth attempting to overcome the vertical accumulation of sediments. This approach offers benefits by stabilizing the dunes, thereby minimizing sand drift and erosion [54,55].

The soft engineering approach of beach nourishment makes it possible to increase the distance a wave has to travel, thus slowing it down and preventing erosion (Table 2). Beach nourishment practices have evolved from focusing on maximizing the time sand stays on the beach to also encompassing human safety and water recreation, groundwater dynamics and ecosystem impacts [56]. Beach stabilization consists in planting dead trees in the sand to stabilize the beach (Table 2). This soft engineering approach widens the beach, therefore, slowing down waves and preventing erosion. Shoreline stabilization works may therefore not only help preserve fragile ecological conditions but further lead to sustainable growth in the local economy [57]. This approach is encouraging for increased use of eco-friendly practices for coastal protection [58].

Reef conservation and improvement include both the protection of existing coral reefs and the establishment of artificial reefs by placing environmentally friendly materials on the seabed (Table 2). Coral reefs reduce the height of wave energy and protect against coastal erosion. Reef restoration can be a useful tool to support coastal resilience [59]. It is noteworthy to highlight the search for innovative techniques and ecological engineering approaches in coral reef restoration programs [60]. Dunes act as a barrier and absorb wave energy reducing coastal erosion and protecting against flooding, therefore the dune regeneration procedure (Table 2) aims at the formation of new sand dunes or the restoration of existing dunes. Nature-based solutions can play a significant role in responding to climate change challenges in coastal areas and can provide viable alternatives to "grey infrastructures" [61]. During the soft engineering procedure of managed retreat (Table 2), some coastal areas, chosen on the basis of their low value, can be eroded and flooded naturally. The naturally eroded coasts thus favour the development of beaches and salt marshes. This is a low-cost process [62].

Mangrove conservation and planting are soft engineering approaches that require the planting of mangrove trees along the coast (Table 2). Restored mangrove ecosystems have important ecological, economic and social values for coastal [63]. Using mangrove trees, their roots hold the soil in place preventing erosion and help dissipate wave energy. Coastal wetlands such as mangroves and salt marshes have gained interest as important ecosystems for reducing the vulnerability of coastal communities. Mangrove restoration is considered a broadly applicable strategy to improve coastal security [64]. Soft engineering is less expensive to implement and maintain and can give more sustainable long-term solutions than hard engineering projects. Soft engineering aims to work with nature by manipulating natural systems that can adapt to wave and tidal energy to good effect and has the potential to achieve economies by minimizing the environmental impact of traditional engineered structures [65].

Table 2: Common approaches of soft engineering for coasts protection.

Type	Definition	Advantages	Disdvantages	References
Afforestation of coastal dunes	This approach represents a way to stabilize dunes by planting trees	The method offers advantages by stabilizing the dunes, thus minimizing sand drift and erosion	In the case of non-native tree planting, there can be impacts on the nutrients deposition of the soil	[54,55]
Beach nourishment	By applying this method, the beach is made wider by using sand and shingle	This approach increases the distance a wave has to travel, thus slowing it down and preventing erosion	In this intervention, sand and shingle need to be sourced from somewhere else (usually by dredging). This method requires a lot of maintenance and can be costly	[56]
Beach stabilization	The method consists in planting dead trees in the sand to stabilize the beach	This approach widens the beach, therefore, slowing down waves and preventing erosion	Similar to beach nourishment, in this intervention trees need to be sourced and require maintenance	[57,58]
Coral reef preservation and enhancement	The method acts to protect existing coral reefs from harm and create artificial reefs by placing environmentally friendly man-made materials on the seafloor	In this approach, coral reefs reduce wave energy height and protect against coastal erosion	In this approach, by constructing artificial reefs can cause pollution. The materials can result in new contamination and artificial reefs are not as stable as natural reefs	[59,60]
Dune regeneration	The method aims to create new sand dunes or restore existing dunes	In this approach, dunes act as barriers and absorb wave energy reducing erosion and protecting against flooding	As a disadvantage, dunes are a barrier to beach access and creating new dunes results in land loss	[61]
Managed retreat	In this approach, certain areas of the coasts are allowed to erode and flood naturally due to their low value	In this method, naturally eroded material encourages the development of beaches and salt marshes. It is a process at a low cost	This intervention requires to compensate people who lose buildings and farmland	[62]
Mangrove preservation and planting	The approach requests planting mangrove trees along the shore	By using mangrove trees, their roots keep soil in place preventing erosion and helping dissipate wave energy	During the process, non-native mangroves can become invasive to an area's natural plants	[63,64]

Conclusion

Coasts represent an important border area between land and sea, highlighting criticality and high sensitivity to anthropic contamination and changing environmental conditions. Coastal monitoring is strategic and different approaches can be adopted, from laboratory analyses to remote sensing surveys. The development of technologies such as unmanned aircraft has allowed for major improvements in monitoring procedures. In particular, coastal erosion was detected at the coastal level by adopting these monitoring tools combined with efficient processing of the data obtained combined with mathematical models. This information has made it possible to develop intervention procedures of an engineering nature capable of restoring the coasts. Hard engineering, also called "grey infrastructure" and soft engineering, also called "nature-based solutions", are important interventions that can be used to solve coastal problems and can improve environmental and socio-economic conditions. Future insights and research will have to include the improvement of engineering approaches at the coastal level, combined with an important monitoring activity both before and after any engineering intervention process, in order to carefully evaluate the environmental conditions and the effects of the interventions.

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