Overview of soft coastal protection solutions

Atlantic Network for Coastal Risks Management

ANCORIM
ATLANTIC NETWORK FOR COASTAL RISKS MANAGEMENT


Galicia (Spain)

Contents

INTRODUCTION

Rich and varied littoral but fragile and coveted

The littoral is a fragile and mobile area at the interface of the atmosphere, lithosphere and hydrosphere. The evolution of littoral environments depends on continental factors (geological structure), marine factors (variations of the mean sea level, processes brought about by waves, tide and induced currents) and atmospheric factors (subaerial agents). Varying combinations of these factors change shoreline position and coast morphology (beaches, dunes, cliffs, tidal marshes) on various time and space scales (diagram 1[1]).

Roughly 16% of the European population lives in coastal communities. This proportion is ever increasing. However, this human presence has clearly affected the littoral environment. In general, economic activities increase pressure on coastal zones (increase in number of buildings, beach sediment extraction, intensive tourist use of coastal areas, etc.). Residential, touristic and economic attractiveness is steadily growing on the European Atlantic coast. Coastal zones have large ecological, social and economic functions and it is advisable to define a coastal sustainable development plan including protecting people, property and activities, while also protecting natural environments and their functioning in the coastal ecosystem.

Beach, cliff and coastline erosion as well as receding shorelines and the risks of marine submergence are preoccupying subjects that are becoming more important for European shoreline communities (20% of the European Union coasts are affected by this phenomenon), because of increased stakes, and particularly economic stakes in zones affected by recurrent natural climatic hazards.

Galicia (Spain)

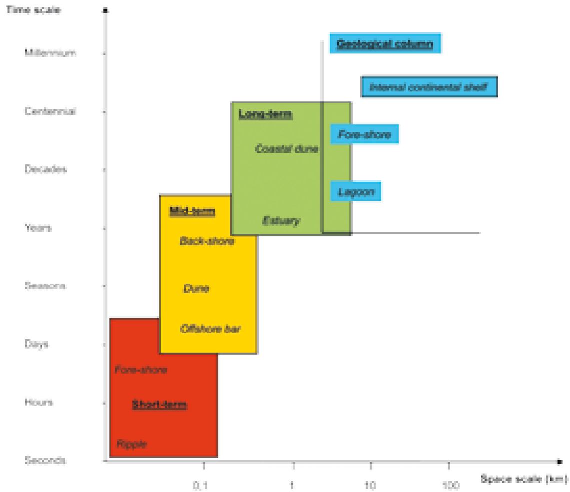


Diagram 1: Concept of time in littoral processes

[1] The different notions are expressed in chapter 1.

Some essential concepts

A hazard is the probability of occurrence of a potentially damaging phenomenon within a given time period and area. The coasts are mainly subject to risks such as erosion, marine flooding and landslides.
A stake is a group of goods, people, systems or any other element present in a risk area and which could be potentially lost.
Erosion hazard is, by definition, a group of external phenomena, which on the soil surface or at low depth change the topography by matter extraction. Erosion can be natural or anthropogenic[2].
Coastal erosion occurs when the sea gains ground on the land under the effects of factors such as wind, swell, tides, etc. This natural process has always existed and has shaped the European Atlantic coast throughout history. However, its current magnitude is undeniably linked to anthropogenic factors.
In many sites, solutions to mitigate this phenomenon, such as the construction of heavy protection structures, have aggravated erosion on areas requiring protection and neighbouring shorelines. These solutions are used less frequently with growing preference for soft solutions which are more favourable to the environment. In addition, the soft infrastructure represented by the coast, plays an important role in increasing and preserving biodiversity, which also contributes to coastal protection.
Besides, the marine submergence hazard is particularly damaging along coasts where the concentration of the stakes continues to increase.
In order to limit the inevitable phenomenon of erosion as well as marine submergence and thus preserve natural environments and their stakes, it is first necessary to understand the interest and role of natural littoral infrastructures such as dunes, cliffs and coastal marshes, and wherever possible, envisage "soft" solutions designed to work with nature by integrating natural coastal dynamics and the mobility of shorelines. Dynamic shoreline management is a continuous process which oscillates between observation and action and which lasts for as long as there are stakes exposed to coastal risks. A risk is in fact to expect losses (lives, injuries, property damage, etc.) due to a particular natural or human-induced hazard in a given area and reference period. The degree of vulnerability[3] and exposure of socio-economic or environmental systems to the hazard are key elements when considering the severity of potential risks.

[2] Anthropogenic: result of human activity on the natural environment.
[3] Vulnerability: refer to chap. III, A, 1.

How can coastal risk management be improved?

The European project, ANCORIM, aims to set up a public and scientific stakeholder network for enhanced prevention and management of coastal risks in the Atlantic Area.

The project is organized around three main issues:

1) shoreline erosion and stability,
2) coastal water quality and its impact on economic activities, and
3) rural and urban coastal development.

Three pedagogical tools and a glossary were thus developed within this project. Tool n°1 deals with coastal risks. Tool n°2 deals with natural littoral infrastructures and soft solutions to protect coastlines threatened by erosion. This document deals with this tool and is intended for decision-makers and managers. Tool n°3 deals with management and taking these risks into consideration for coastal development. .

This document initially discusses Atlantic coastal erosion, then goes on to present a range of soft solutions for coastal erosion. The document concludes with a discussion on coastal management (decision support tool).

Three kinds of typical European Atlantic coasts are discussed: sandy and rocky coasts and coastal marshes. This tool takes as geographical reference space the Atlantic space of the European continent, in particular the partner regions of the project Ancorim: Aquitaine, Brittany and Poitou-Charentes in France, North and Central regions of Portugal, Galicia in Spain and the Border, Midland and Western region in Ireland. Other limited examples from non-partner regions were also included as illustrative material.

Rocky coast

Galicia (Spain)

1 - ATLANTIC COASTLINE EROSION

The littoral is an ecologically rich and fragile area. It can experience reversible or irreversible developments under the influence of natural or anthropogenic external agents, in various temporal and spatial scales. Its dynamic balance is principally due to sediment exchanges and transfers at the interface between marine and continental environments (long-shore drift, cliff erosion, storage in dunes, etc.).

On the European Atlantic littoral, there are three types of shoreline: the sandy coast, the rocky coast and tidal marshes (wetlands including estuaries and lagoons).

Erosion is a natural phenomenon (hazard) created by the combined effects of:
- atmospheric agents: wind, rain, temperature;
- marine agents: swells, tides, induced currents, sea level (dependant on global warming, tectonic effects, subsidence[4], etc.);
- continental agents: in particular hydrology by feeding fluvial sediments. These agents are mechanical type processes (introduced by variations in temperature or variations in rock water levels) or physico-chemical processes (alterations). Precipitation (runoff or filtration) also contributes to the modification of littoral shapes;
- biological agents: possible erosive impact of flora and fauna on hard and soft sediment.

Sandy coastlines come from marine sedimentation or from the activity of organisms (algae and benthic fauna such as worms). On the Atlantic coastline, they include beaches and dunes (photo 1), directly linked from a landscape and functional perspective. Rocky coastlines are mainly characterised by coasts with cliffs, and wetlands are principally tidal marshes.

St Jean-de-Luz, Aquitaine (France)

The dynamic balance of the shoreline can also be impacted by sudden variations of the sea level (tsunamis, large storms, etc.). Coastlines, also presented as natural littoral infrastructures, are ecosystems that form an interface between the marine and terrestrial environment whilst providing better protection against coastal erosion. In Atlantic Europe, they each have their own identity depending on the type of coast and surrounding environmental conditions.
They participate in the coastal dynamic process and make up unique ecosystems with a high heritage added-value, contributing to the quality of natural resources, whether they are halieutic or terrestrial.

These infrastructures (mainly wetlands, cliffs and dunes) provide services that are indispensible for managing and developing the littoral and it is for this reason that they should be restored and treasured.
Europe's landscape is increasingly fragmented and this is a major problem for biodiversity. The term green infrastructure (European commission website) is used here because these infrastructures help reconnect existing natural areas (wetlands, dunes, etc.) and improve the area's ecological qualities. They also help maintain ecosystem services.

[4] Subsidence: floor level drop induced by tectonic movement.

Beaches

> Environmental presentation

Beaches are shoreline sediment accumulation zones (fine sand to blocks). Beach morphology (diagram 2) constantly evolves over time causing variations in sediment storage. Key dynamic agents are wind, waves, tide and the currents associated with them. There are beaches called "open" that occupy a large sandy coastline and are most often associated with dunes, "pocket" beaches fringe[5] rocky cliffs or are situated at the bottom of bays.
On the upper area, the beach ridge (or backshore) is affected by the sea only during exceptional events. The berm crest marks the transition from the backshore to the foreshore[6] (the tidal zone). The offshore (sub-marine shore), is always submerged. It is marked with accumulation forms (bars) formed when the slope is shallow and sediments are abundant. Further offshore, beyond the limit of storm wave action on the floor, the offshore gives way to the continental shelf. The rapid modification of beach forms and offshore highlights the adaptation of a shallow moving littoral environment with variable hydrodynamic conditions.

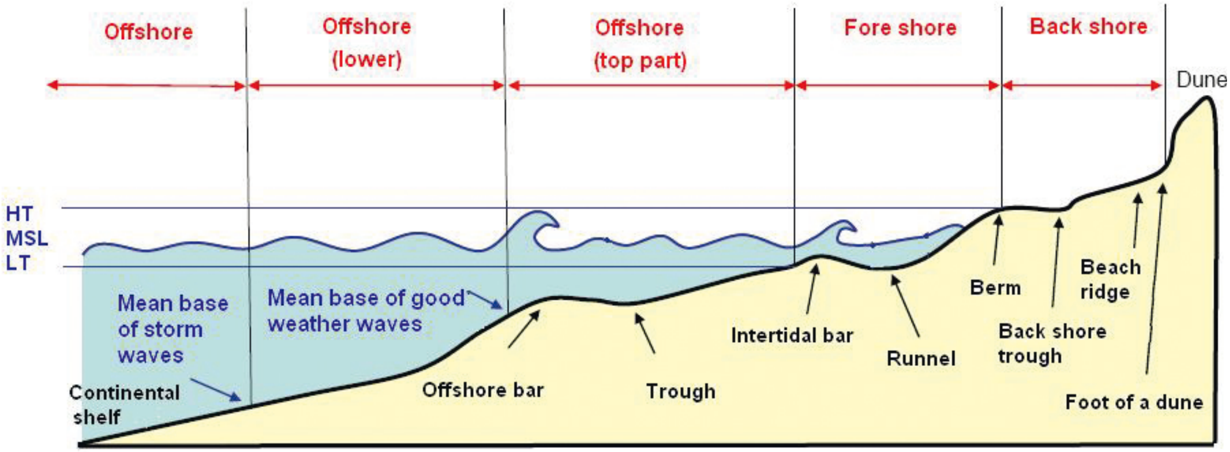


Diagram 2 : Beach morphology

The profile of a beach will vary according to the seasons. In periods of strong energy conditions (strong swells, strong currents, etc.), particularly in winter, the sedimentary stock transits from the beach towards the offshore leading to a reduction in the beach profile. On the contrary, during low energy conditions (weak swells and currents, etc.), particularly in summer, the sediments migrate from the offshore to the beach, raising the beach profile.
In addition, there are offshore swells propagating to the coast and creating waves of which the shape and action on the floor vary according to the geomorphologic shape (slope, continental shelf width, etc.. . .). When the wave propagation is oblique to the coast, a littoral drift is generated. This sediment transportation occurs on the foreshore and is oriented towards the shore. The tide plays an important role in the evolution of beaches as it continually moves the surf zone and transports sediments (mainly sand).

[5] Fringing beach: beach parallel to the shore.
[6] Foreshore: zone between mean low water and mean high water levels.

> Erosion and/or marine submergence phenomena

Maceda (Spain)

Firstly, the natural causes of beach erosion are a lack of sediments worldwide, as sedimentary feeding stemming from cliff matter that breaks down and continental erosion (transported by rivers) is very limited. The rapid succession of unfavourable climatic episodes (storms), through sustainable beach disintegration, can strongly impact its sedimentary balance. The rising sea level, consequence of global warming, causes permanent flooding in the coastal area as well as heightened beach and cliff erosion.

Beaches (when against a dune field) constantly exchange sediments with dunes: the beach feeds into the dune and the dune constitutes a sand reserve necessary for the beach's balance.

Dunes

> Environmental presentation

Dunes are created from beaches, with the assistance of wind and vegetation that slows sand movement and allows dunes to form. Wind is a construction agent as well as a dune remobilisation agent.
Dunes require sufficient aeolian dynamics, an available source of sediments and specific vegetation to exist. Dunes constitute reserves of sand for beaches should they be attacked by waves.
The dunal system is classified in the following way: the back-shore beach, the foredune (important for the beach's sedimentary balance), the mobile dune strip, the back-dune and the wooded dune (diagram 3). They do not have fixed limits; each ecological unit is differentiated by its shape and its vegetation.

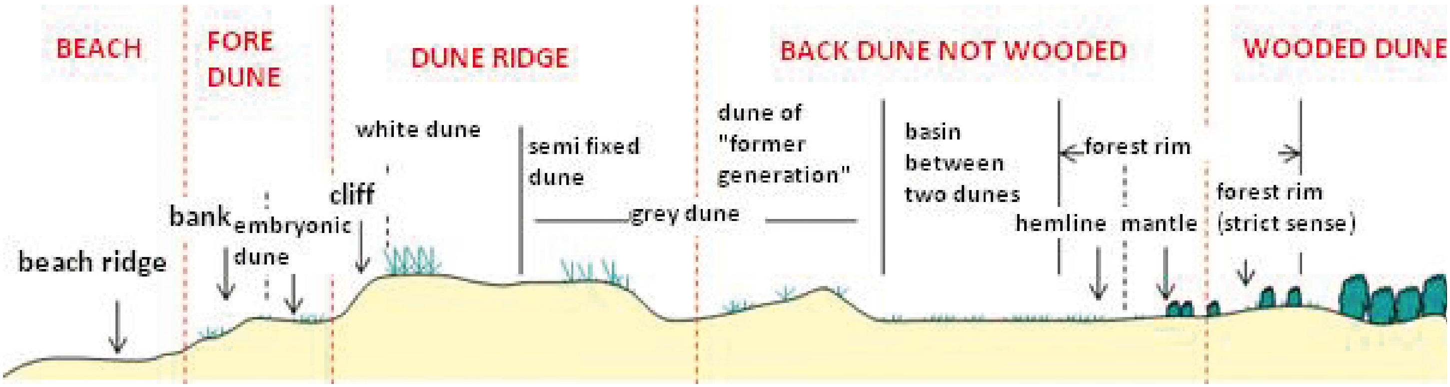
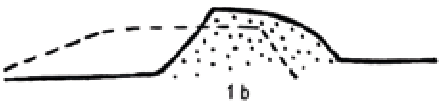


Diagram 3 : The dunal system

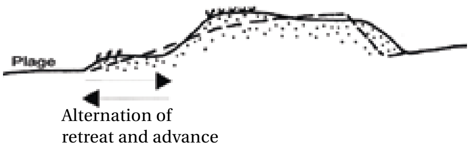
Beach / dune system typology

Littoral dunes are back-to-back with previous dunal systems, which, quite often, are much higher than sea level. There are three main types of situation:

1. on coastal sections with a sedimentary deficit, there are narrow dunes facing the cliff and their volume is usually decreasing;
2. on sections with a balanced or slightly deficient sedimentary budget, periods will alternate between erosion stages and rest stages when new fore-dunes will be formed, though they will remain unsettled;
3. on sections with a positive sedimentary budget, well-established and voluminous fore-dunes will be formed.



Sectors with a deficient sedimentary budget: "thin" beaches, a decreasing dunal volume and dune heads in cliffs.



Sectors with a slightly deficient or balanced sedimentary budget: global conservation of the dunal volume with strong fluctuations in shapes of the external slope.

Sectors with a positive sedimentary budget: rich sand beaches, natural formation of new fore-dunes.

Diagram 4: Beach/dune system typology

> Erosion phenomenon

These natural infrastructures are destabilised by natural processes (flooding, whistling wind[7], etc.), but also by anthropogenic actions (trampling, etc.) and by their conjunction. These processes can be considered to be favourable "in small doses" to the diversity of landscapes and shapes, however they can become extremely destructive if not controlled. 21thcentury worries stem from two root causes:

- on one hand, coastal erosion, an ancient phenomenon, which is accelerating and affects more and more people due to littoral development.
- on the other hand, the risk of submergence that is increasing with sedimentary shortage, linked with the global trend of rising sea levels caused by climate change.

Though marine erosion is a dominant phenomenon on mobile coasts, the risk of submergence itself only concerns coastal sectors in which a narrow strip seperates a low altitude inland region from the sea (breach risk).

Human causes of beach and dune erosion are countless, including excessive cleaning of beaches and intensive use of materials found in dunes, beaches and on the foreshore.

There is also the problem of urban planning which is often associated with deforestation. The main negative impact of construction is sedimentary blocking: constructions are artificial barriers which prevent sedimentary transit. These man-made coastlines, while curbing biological exchanges also limit natural ecosystems, leads to risks for property and equipment that have been developed (risks of silting-up occasionally linked to the rapid drop of the coastline).

Overcrowded beaches related to the boom in sea-side tourism are also a serious issue: trampling leads to deterioration of vegetation, which in turn causes sand to become mobile which the wind blows towards the land and is thus lost to the beach-dune system.

Dunes and beaches are the two main compartments of sedimentary cells. Waves and wind generate beach and dune shapes, which in turn, interact with the process. This results in a "dynamic balance" capable of absorbing storm effects through energy dissipation. Adaptation to changes (resilience[8]) is optimal when the system is not disturbed and has enough breadth to represent itself.

A major structural cause of marine erosion is the lack of a beach/dune sedimentary system. In the context where such lacks are aggravated by rising sea level, dune management should be adapted.

[7] Whistling wind: deflation (removal of the light particles and fine sand in the soil) which occurs when wind passes between two sections of dunes.

[8] Resilience: capacity of a system, community or society exposed to hazards to resist, absorb, accommodate and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions.

> Beach-dune system as littoral natural infrastructure

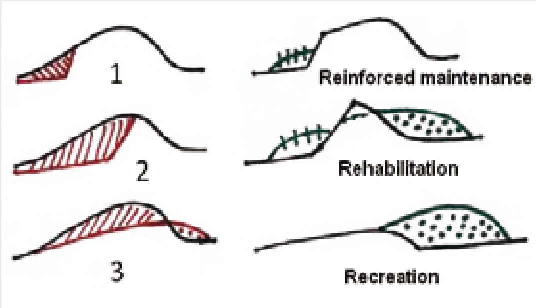
When dunes seperate low zones from sea, an uncommon situation in Aquitaine, but well known in other parts of the Atlantic Coast, they can also have a role comparable to dykes: dunes play a defence dyke role against submergence risks. Dunes have played a historical role: during several historical periods, and, in particular, towards the middle of the 19th century, men laid out littoral dunes to protect the land from sand encroachment: the role of "sand traps".

Making up part of the precious sedimentary stock, dunes play several roles in mitigating marine erosion and submergence risks:

- a soft absorption of marine energy (the beach/dune system is a natural way to dissipate energy);
- replenishment of a beach after storms;
- dyke and the first "warning fuse" in case of flooding, etc.

Flexible dunes management (cf. chap. II, B, 2) responds mainly to the issue of aeolian erosion and must be completed to respond to sea-related risks. Such measures are much more costly than those merely managing wind-related mobility.

Adaptation of dunal interventions to respond to new expectations, the "dune-dyke" concept
First of all, legally speaking, dunes are not considered to be dykes, however in some situations they are or will be involved in the logic of action plans aiming to protect the population from marine erosion and submergence risks. There are several different types of situation, illustrated and outlined below (diagram 12):



Case 1: Natural erosion grooves a cliff which does not affect the structure's stability.

Case 2: Very strong marine erosion that removes the capacities of the dunal strip to behave like a dyke.

Case 3: Marine erosion erodes the quasi-totality of the strip.

Diagram 5: Types of situation where dunes can intervene

Beyond rehabilitation works, a follow-up and warning process must be put in place: mapping of the state of the dunal strips which play a defensive role against risks of submergence, and sensitive zone measurement protocols to alert public authorities when work is needed to maintain the dunes' capacity to behave like a dyke.

> Ecological stake of dune ecosystems

The position of dunes on the interface between the earth and sea is a source of landscape and fauna diversity. Difficult conditions for flora and fauna (salinity, sand bombardment, etc.) result in extremely specialised species and a high level of endemism. We could, as an example, mention the small littoral common borage (photo 1) or toad flax with thyme leaves (photo 2), both endemic to the French coast. This linear ecosystem however is narrow, reducing its capacity to adapt itself to receding shorelines and increasing its fragility in the face of anthropogenic pressures. A high level of endemism[9] reflects the high heritage value of dunes. Non-wooded littoral dunes in Aquitaine (France) have several endemic species, such as the Yellow Alyssum, the Bayonne Milkvetch, Stone Pinks, etc.

In order to best perform its various "environmentally beneficial services[10]", the littoral/beach dune system must be able to expand to a sufficient width to express different processes and physiognomy.

Omphalodes littoralis

Linaria thymifolia

[9] Endemic: characterise the natural presence of a biological group exclusively within a delimited geographical area.
[10] Environmentally beneficial services: useful natural processes that are necessary for people without them having to do anything to achieve them.

Cliff

> Environmental presentation

Cliffs (rocky coast) constitute a particular case where cliff sides roll back parallel to themselves leaving a rocky platform gently sloping towards the sea. There are three types of cliffs: eroding cliffs (unstable) (regularly beaten by the sea causing its steep escarpment aspect), stabilised cliffs and dead cliffs (when they are no longer hit by waves, they have a similar evolution to continental sides).

Cliffs can be differentiated according to their morphology, their structure and by the speed of their evolution. The Atlantic European cliffs are characteristic of the wide diversity of geological environments (limestone, marly, granite, etc.), offering a great ecological wealth of varied environments and landscapes.

The nature of the rocks plays an essential role in cliff morphology: formations can be loose and thus fragile (sand, silt, clay, marl and chalk), or formations can be hard (limestone, sandstone, volcanic, granitic and metamorphic rocks) and so less prone to erosion, generally producing nearly vertical forms. In loose formations, slipping (or mud-slides) is present, whereas in hard formations, rockslides and block fall are most prominent.

Tidal currents influence the sedimentary deposit and the turbidity of water. In addition to the impact on the cliff, waves limit vegetative development (role of sprays). The hydrodynamic mode determines the dominance of one type of settlement over another.

Miramar, Biarritz (France)

> Cliff erosion

Cliffs are unstable due to the interaction of various factors, which include:

- on one hand, marine processes at the foot of the cliff by wave actions which bring about sub-maritime (foreshore) and aerial erosion (the impact of swells on the cliff). In addition to the impact on the cliff, these processes limit vegetation. These marine dynamics can lead to undercutting[11](photo 3). The ocean (swells and coastal currents) worsen this phenomenon of instability, by clearing away rock falls and by preventing a stabilising abutment from being placed at the foot of the cliff (photos 3 & 4).
- on the other hand, weathering processes (wind, rainfall, infiltrations, rock weathering, salt weathering[12], etc.) occur on the cliff side as well as at the top. These processes can lead to landslides through chemical, physical and mechanical processes, rockslides (photo 4), slumping, washout, etc. These processes occur because of the nature and/or the structure of the rocks.

Cliff erosion allows sediment feeding as a positive and necessary source for cell balance and the neighbouring beaches (e.g. the weathered rocks in the Basque Country (France) which can feed some pocket beaches). Cliff erosion, beach movement and erosion of the intertidal and submarine beach (foreshore planing) are inseparable phenomena (diagram 5).

St-Jean-de-Luz, Aquitaine (France)

[11] Undercutting: notch realized at the cliff foot by wave surf under an overhang.
[12] Salt weathering: process of rock disintegration linked to the crystallisation of saline solutions. Process of effective weathering in saline environments (coastal zones).

Erosion is accentuated by anthropogenic impacts:
- on the cliff top, the light, housing development type urban planning is accompanied by an increase in the ground water roof (watering gardens, etc.), heavy traffic on trails also has a destabilising effect;
- on the cliff slopes, building roads disturbs the natural cliff side balance by digging trenches and accumulating rubble;
- at the cliff foot, using pebbles leads to impoverishing the natural littoral strips that play a protective role for the foot of the cliff (see the case in Upper Normandy, France) and the creation of structures to protect the cliff, such as dams, disturbs littoral transit. On all the Atlantic coasts, the variability of rocky coasts is significant. The fragility of materials and contact with the sea lead to variations of forms, structures and vegetation in all areas, from the foreshore to the continental fringe.

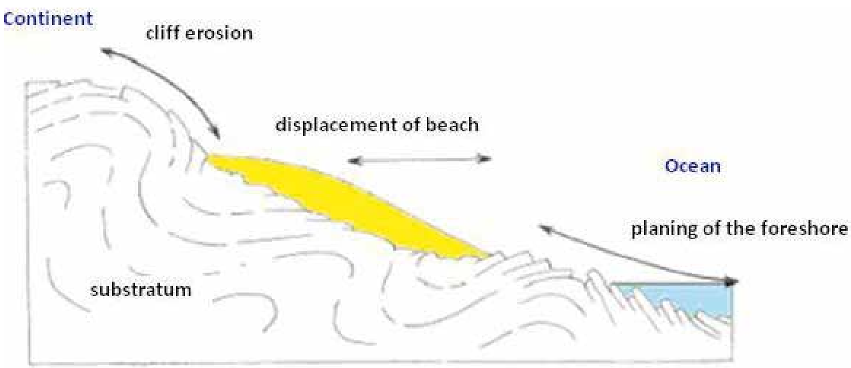


Diagram 6 : Link between cliff erosion, beach movement and erosion of the intertidal and submarine beach


Cliffs of Mohair (Ireland)

> Cliff as littoral natural infrastructure

Cliffs, because of their height, are natural barriers preventing risks of maritime submergence. On the other hand, the rocky coastal platform, dissipating mechanical wave energy, mitigates erosion at the foot of the slope. Moreover, material stemming from land movements (landslides, rockslides etc.) feed into the sediment for neighbouring beaches, which enhances accretion.

> Ecological stake of cliff ecosystems

Rocky Atlantic coastlines, despite their rugged mineral appearance, are very rich environments thanks to the presence of a myriad of habitats. Littoral settlement stepping is directly linked to hydrodynamic conditions: tides, tidal currents, waves and coastal exposure to swells.

The tidal phenomenon, through its amplitude, conditions the communities of littoral organisms, which are almost entirely of marine origin. Thus, in the supra-littoral[13] fringe, which the sea can only reach at high tide of spring tides, very few organisms can tolerate quasi permanent immersion conditions. A bit lower, in the intertidal zone, the substrate has a large population of organisms. Very low seawater level areas represent the sublittoral stage.

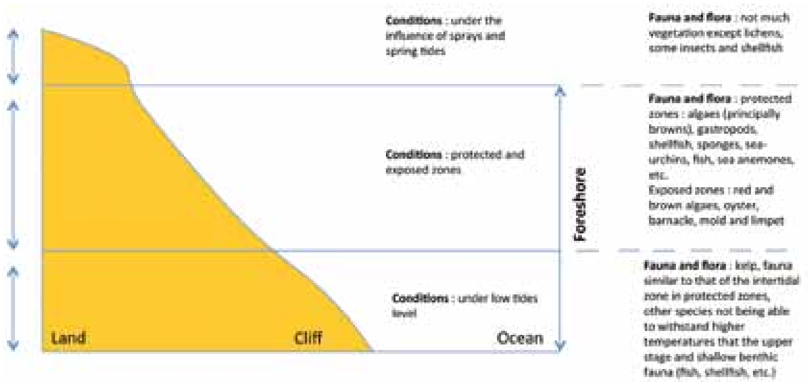


Diagram 7 : Rocky foreshore ecology

Morus bassanus (France)

The rocky foreshore has a key role in marine biological cycles. It preserves complex food chains of fish to molluscs, shellfish and seaweed. The presence of rocky elements of various shapes and sizes offer shelter for these benthic organisms. Cliffs, outside the supra-littoral lichen stage zone, generally do not have much vegetation, except on soft materials, or on their upper margin or in zones where there are cracks or benches that have been plugged by fine earth. On these zones, typical herbaceous vegetation called an aerohaline[14] lawn will grow with a high heritage value. It is on the areas behind the cliff (heath land made up of low-lying bushes followed by a forest), that we find a wide variety of fauna and flora. But the emblematic fauna found on cliffs is of course the avifauna[15]. On the rocky foreshore and on cliffs, many different types of birds, such as the Morus bassanus (France), take advantage of the food and shelter that rocky coasts offer (photo 5).

Rocky coastlines have a rich and varied environment, from their maritime stages up to peripheral terrestrial areas. The high rocky substrate quality on the foreshore allows abundant vegetation to grow which forms the base of many littoral food chains. Rocky cliff vegetation shelters a significant percentage of nesting littoral avifauna. Last but not least, littoral fringes, heathlands and forest are also extremely varied natural habitats and represent an interface between littoral settlements and "continental" species.

[13] Supra-littoral: situated over the high tide level area.
[14] Aerohaline: subjected to the saline wind.
[15] Avifauna: all the bird species in a given area.

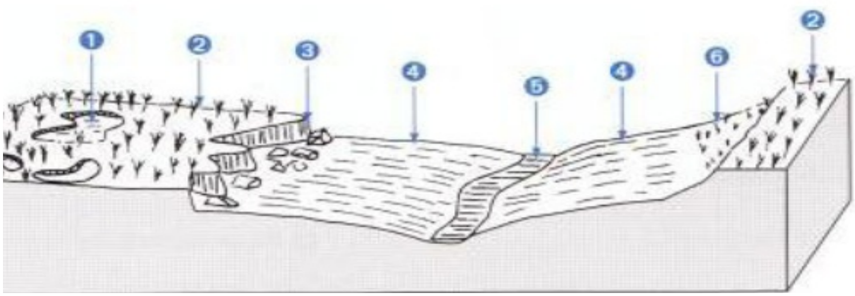
Tidal marshes

> Environmental presentation

Tidal marshes are wet areas with a strong marine influence. They develop when salt water and fresh water mix in sectors that are fairly well protected from swells. Wind-waves and storms can affect and erode tidal marshes. Well situated beneath the high water spring tide level, these spaces are rarely submerged by salt water as men have worked to annex these zones to the continent, particularly by embanking and containing them.

Marsh foreshores are lower zones made up of recent alluvia and are transfer zones between the marine and land environments: schorres and tidal flats. Marshes strongly depend on tide generated currents. The vegetated areas of land, which are only under water during equinoctial tides, are called schorres. This zone enjoys a wealth of vegetation, in particular "grassy" halophytic plants that mitigate currents while trapping fine particles in suspension and fixing them in place with their roots.

In the intertidal zone, tidal flats are strongly sedimented areas made up of fine sediment: silt (zones that are called Slikkes), tangue (calcareous mud with a high proportion of powdered mollusc shell material) or sand. In this document, the term tidal marsh, groups the entire functional coast together, from its foreshore up to the continental border (diagram 7).



1 Basin
2 Schorre
3 Microcliff
4 Mud Flat
5 Tidal channel
6 High mud flat

Diagram 8 : Morphology of a coastal marsh in a temperate climate zone

A marsh generally has a very gentle slope; it can be directed either towards the sea or towards the main natural drain channel. The marsh is thus called a "conform" marsh: it is mostly made up of fine clay sediment, brought in by a clarification process in calm waters. But the slope can also be directed towards the continental border. The marsh is called a "contrary" marsh: sedimentation occurs through more turbulent waters.

Arcachon Delta, Aquitaine (France)

> Erosion and marine submergence hazards

Tidal marshes, which are lower coastal wetlands, are naturally and regularly subjected to marine submersions of variable intensity and frequency (or return period). This hazard is to be taken seriously in many confined zones where previous or current agricultural activities and also sometimes urban communities are sheltered. This type of sensitive littoral is subject to an anthropogenic pressure linked to the development of housing, agriculture, fishing and hunting and to harbour and industrial activities. In fact, for agricultural needs (creation of polders[16]) and to limit the flooding of land, many protective dykes have been built, isolating the marshes from the sea (photo 6). Draining basins have been added in order to contain continental waters during flooding. But this structuring is questioned today, from an ecological protection point of view, as the limitation of water circulation leads to disturbances in biological flows.

Certes domain (France)

The conservation of these areas means a better management of the mosaic of natural habitats, in particular by allowing water to flow back into contained land, a technique which is called depolderisation.

> Tidal marshes as littoral natural infrastructures

These environments discharge a physical role in coastal protection. The presence of tidal flats and schorres mitigates wave action on these shorelines. Moreover, most marine marshes on the Atlantic have been confined. Dykes are an important rampart to combat marine submergence, but these structures must be well calibrated and well maintained. Coastal marshes also play an important filtering role for polluted water transiting from continental to marine environments.

> Ecological stake of tidal marsh ecosystems

These wetlands, vegetated according to their position in the estuary, are essential habitats for the biological cycles of many fish, crustaceans and birds.
These coastal marshes are also home to many human activities: shellfish farming, fishing, port activities, agriculture, etc. which have sometimes accelerated natural evolution and favoured aggradation, progression of salt pastures or shoreline erosion. Flora in these intertidal zones depends on tide levels, soil and the human activity. Harsh ecological conditions leads to limited biodiversity, however the lack of competition between species promotes a considerable wealth of individuals. These environments have one of the planet's highest primary production rates. Diatoms, monocellular algae, colonise the surface of the slikkes. Flowering plants colonising the lowest parts are Zostera, also called eel-grass (photo 7). They cover large spaces as monospecific herbarium. On high slikkes we mainly find Salicornia (photo 8) and Spartina.

[16] Polder: (dutch word) arable soil, reclaimed from the sea by embanking and drainage.


Ecological zostera marina stake of tidal marsh ecosystems


Salicorne

Numerous traditional agricultural activities use the resources of this foreshore (oyster farming, shellfish farming, shore fishing, collecting seaweed, etc).
On the schorre, flora diversifies (puccinelli, etc) and is favourable to numerous insects. Flora on the breakwaters is generally represented by the Tamarix and increasingly by the Senecio vulgaris, a very invasive tree. Fauna distribution depends on the submergence frequency and thus the water level (marine and fresh), salinity and the type of substrate. The most common species found in silty sediments are small detritivorous crustaceans whereas in sandy sediments the most common species are sandworms and Nereids. Shellfish are also very numerous in these sediments: cockles, soft-shell clams and venus clams; shellfish farming ensures the presence of mussels and cupped or flat oysters. In these environments, fish must adapt themselves to large variations in salinity and temperature. Coastal marshes, especially in their higher areas (confined marshes and schorres) are also home to many insects, amphibians, reptiles, mammals and especially birds. Many migrating birds use these environments as a necessary resting place between Northern Europe and Africa. The different stages of vegetation and the diversity of the environment, from channels and canals to contained marshes, the variation in water and salinity levels make these zones places which ensure the development or reproduction of many aquatic species (crustaceans, molluscs, fish, etc.) as well as terrestrial species (insects, birds, mammals, amphibians and reptiles). Survival of these species and ecosystems is linked to maintaining hydraulic functions, limiting aggradation and controlling human activity.

The littoral is an open system. Its balance must be understood by analysing its sedimentary assessment with a "sedimentary cell"[17].

[17] Sedimentary cell: portions of homogeneous coast, coherent in terms of morphology and functioning, independent from any administrative structure.

There is a large interdependency between the processes of the same cell (erosion, accretion[18], etc.). Sedimentary cells can be closed (or semi-closed), as in an open bay between two rocky points, but more often than not, there are exchanges between neighbouring cells. They are analytic units where a sedimentary budget can be drawn up: either between the cell and its neighbours or in the cell itself (eroded volume, volume transported by the long-shore drift, volume stored in the fore-dune and dune, volume exchanged between the beach and the dune, etc.). The sedimentary off shore budget can be explained by elements from the long-shore drift (breaking waves and tidal currents interact to move massive amounts of coastal sediments), rivers and cliffs and dune erosion but also long-shore drift and canyon losses benefiting the continental shelf and aeolian transport (diagram 8).

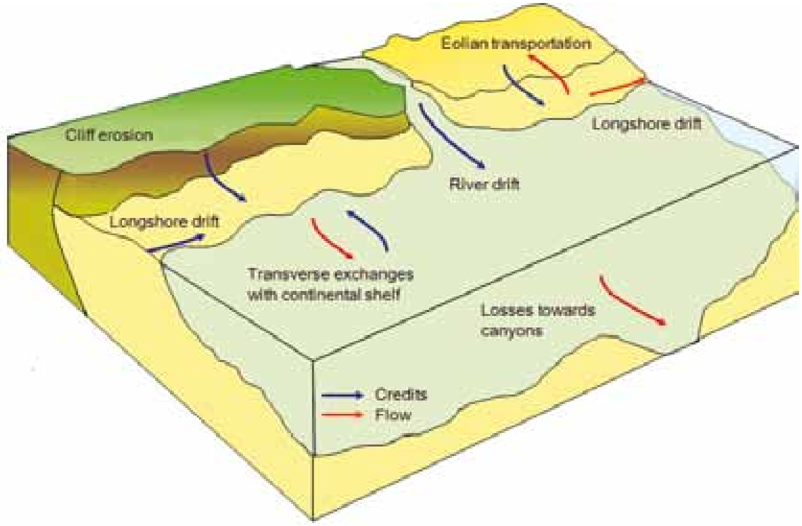


Diagram 9 : Flowchart explaining the notion of sedimentary budget

These sensitive coasts are subjected to strong natural and anthropogenic erosion. They must be protected if there are important stakes nearby. "Soft" solutions offer protection possibilities which are eco-aware and the use of which is increasing steadily.

Ireland

[18] Accretion: progression of the shoreline towards the land by accumulation of sediments.

St Jean-de-Luz, Aquitaine (France)

2 - SOFT COASTAL PROTECTION SOLUTIONS

Considering coastal hazards (erosion, marine submergence, earth movements) in the arrangement of the coast, with the particular aim of protecting stakes, can break down into four types of solutions (chap. III, A, 2): strategic retreat, non-intervention, limited intervention (use of soft solutions) and shoreline maintenance (use of hard and/ or soft solutions).

Among these solutions, two methods of protecting coastlines threatened by erosion distinguish themselves. One leads to fixing the shoreline, and it is called the "hard" or "rigid" method. The other is more ecologically minded and is known as the "soft" or "flexible" method. According to cases we have studied, it is however difficult to fix the limit between "hard" and "soft" solutions, and sometimes the solutions can prove to be complementary.
"Hard" solutions (groins, dikelets, water-wings, etc.) have the main role of fixing the shoreline and protecting immediate stakes. Although the structures or technologies used meet these objectives of protection, unfortunately, they do present several negative points in the midium-term. Indeed, these interventions modify the dynamics of environmental functioning, worsen coastal erosion near the protected area and are generally very expensive but they also have a higher lifetime expectancy.
"Soft" solutions are designed to "work with nature" by integrating the natural dynamics of the littoral and the shoreline's mobility (reloading the beach with sediment, work on revegetation, etc.). They have a limited life span, are reversible and depend upon their own characteristics and evolution of the environment on a global scale (climate change) or on a local scale (urban planning, traffic). The efficiency of soft solutions must be evaluated with respect to the intensity of coastal dynamic processes (wave climate energy, etc.) and lifetime performance.

Discussion on the limitations of "hard" and "soft" methods

It is especially important to remember that any structures put in place, whether rigid or flexible, negatively impact the surrounding environment (sediment transport and budget, noise pollution, increased traffic, interrupted recreational use, perturbation of littoral biodiversity, etc.). It is essential to know the real need (knowledge of the hazards and stakes) for protection and how the various techniques impact the environment. The answer in the face of risk can be also modulated over time, or be a combination of soft and hard solutions.
The distinction between "hard" and "soft" solutions is not simple. If we take the example of cliffs, intervening solely on an unstable zone using a "hard" technique or a geotechnical approach can be considered a "soft" method as it represents such a small percentage of the entire coastline. This, of course, is not valid for all sectors. It depends on the importance of the zone to be treated and also the importance of the cliff in the entire rocky coastline of any given region (this is also valid for beaches).
On cliffs, it is generally strongly advised to combine several geotechnical approaches and to associate them with another "soft" method, such as revegetation. Applying this method does not aim to fight against erosion but rather to accompany natural processes and increase safety. The nature of materials employed can also be taken into consideration, so that they integrate into the surrounding environment. Structure reversibility also allows a differentiation between "soft" and "hard" solutions. It is true that a "soft" technique (when applied to a small surface) remains an easily reversible technique (few consequences) as opposed to heavy structures, which generally greatly disturb the surrounding environment and are costly to dismantle (i. e. dykes).

The cost of these techniques are very variable (from a few thousand Euros to several hundred thousand) depending on technical and local variables. That is why a cost/benefit analysis is required before any action is taken (chap. III).

Vieux Boucau, Aquitaine (France)

"Soft"solutions

> Beaches

There are many protections against beach erosion. The difference between soft and hard methods comes mainly from the type of impact on natural sedimentary dynamics and equipment reversibility. These types of impact are characterised by the choice of materials used, equipment flexibility, spatial stretch, visual impact, etc. The next few paragraphs present a few solutions usually characterised as "soft" due to their advantages and disadvantages.

• Geotextile structures

Hydraulic piling, Cap Ferret, Aquitaine (France)

Description

They maintain sand and can be installed perpendicularly (e.g. groins when littoral drifts are dominant) or longitudinally to the shore, such as reinforcing the core of a dunal weather strip behind a beach. These are permeable fabrics made from synthetic fibres shaped as bags or coils. They are pressure filled with a sand and water mixture.

Advantages

The visual impact of geotextile structures is less obtrusive than others such as groins and breakwaters, etc., all the more so as they are often covered by sand. When laid to make partitions, bags can be useful to maintain sand by acting as an anchor (for example after having artificially reloaded sand onto a foreshore). They are reversible and those of the latest generation are permeable, flexible and UV-resistant, thus promoting the installation of vegetation. Installing structures of this type is rapid and less costly than heavy structures (in rip-rap for example). They do not disturb the littoral ecosystem very much.

Disadvantages / limits

They have the same disadvantages as heavy structures (e.g. groins, breakwaters), regarding sedimentary dynamics. Their role is to limit sedimentary transits so they lead to sedimentary deficits in unprotected neighbouring zones, accentuating erosion. Having a water circulation limiting role, they may lead to complications on swimming beaches, in particular, pollution. As in every type of work, those made from geotextiles require regular maintenance, especially for any damage caused by users (particularly in summer).

• Artificial reefs

Artificial reefs, Narrowneck, Australia

Description

Set on offshore or fore shore, artificial reefs reduce the wave energy liberated on the beaches behind them. They slow down the long-shore drift and favour foreshore growth, thus limiting erosion. They react in the same way as submerged breakwaters, and are often made up of coils or bags of geotextile, but other materials that can be used include sand, large blocks, concrete or pit run material.

Advantages

On a coast with a weak tidal range[19], they remain invisible and do not distort the landscape. In contrast to breakwaters, they preserve a restlessness of the water helping self-cleansing and thus maintain a bathing quality. They also contribute to enriching littoral biodiversity (fauna and flora).

Disadvantages / limits

Shorelines with high tidal amplitudes are not suitable for the implantation of artificial reefs. Indeed, for them to limit wave action during high tide, their structure must be massive and raised, generating a strong visual impact during low tide as well as having high costs. The ideal context is a microtidal coastline or beaches located in bay heads able to constitute sedimentary compartments by themselves.

• Hydraulic piling

Description

Hydraulic pilings are made of wooden rods vertically planted in the sediment (sand or mud) at regular intervals. They can be implanted perpendicularly or parallel to the shore on the foreshore, often for several tens of meters. These permeable piles allow the swell to be dispersed before breaking, limiting sedimentary transport and favouring beach stability.

Advantages

They are very permeable, the circulation of sediments, although modified, is maintained, limiting negative impacts on both sides of the works. They are relatively easy to implement and not expensive.

Disadvantages / limits

The efficiency of these structures cannot currently be guaranteed and depends on the type of beach. It is thus necessary to establish regular monitoring for a sufficient period of time to assess their effectiveness. In addition, they could become obstacles for people walking on the beach and dangerous for maritime navigation if destroyed and carried-out offshore.

windbreaks (France)

windbreaks (France)

[19] Tidal range: difference between the high tide and the low tide.

• Draining beaches

Description

A drainage system lowers the top of the aquifer ground water and water deposited by the waves (or swash zone[20]), thus creating a non-saturated zone beneath the foreshore surface near the shoreline. One or several filtration canals are installed at about one metre below the surface, parallel to the shoreline, they thus are able to gather water and transfer it using gravity to a well. From there a pumping station sends the water back to the sea or if possible, towards recycling stations. The objective is to drain the top of the aquifer ground water to promote sediment deposits; descending water partially seeps through and thus looses part of its energy. Another objective can also be to drain the swash zone (upper area of wave propagation) for certain types of beach morphology. In this way, the sea brings in more sediment than it takes away (diagram 10).

Advantages

This has no impact on the landscape (except during work) and the sand dries out faster, something that tourists appreciate when they are on the beach. The littoral ecosystem is hardly disturbed (except during work and less ground water can eventually modify the benthic[21] ecosystem). The draining system is efficient when continental water circulation (superficial ground water) participates in erosion. Energy costs can be mitigated by using recycled water (feeding from an aquacultural basin or a seawater pool, etc.).

Disadvantages / limits

However, using this type of structure remains limited to certain types of beaches. Sediment under the foreshore must be thick and permeable (between 0. 1 and 0. 5 mm) to allow pipelines to be installed and avoid clogging. Furthermore, a very slight slope is preferable (from 1/10 to 1/50). The zone must be moderately but regularly exposed to waves with weak seasonal variations (summer/winter) of the beach profile. The role of the surface water table must be dominant for sedimentary transport (thixotropy[22]) in comparison to other agents of erosion. Draining weakens one erosion process and does not solve the sedimentary deficit problem; thus it is better suited to bay head beaches (that make up a sedimentary compartment themselves). Attention must be paid to the pumping station's electrical system.

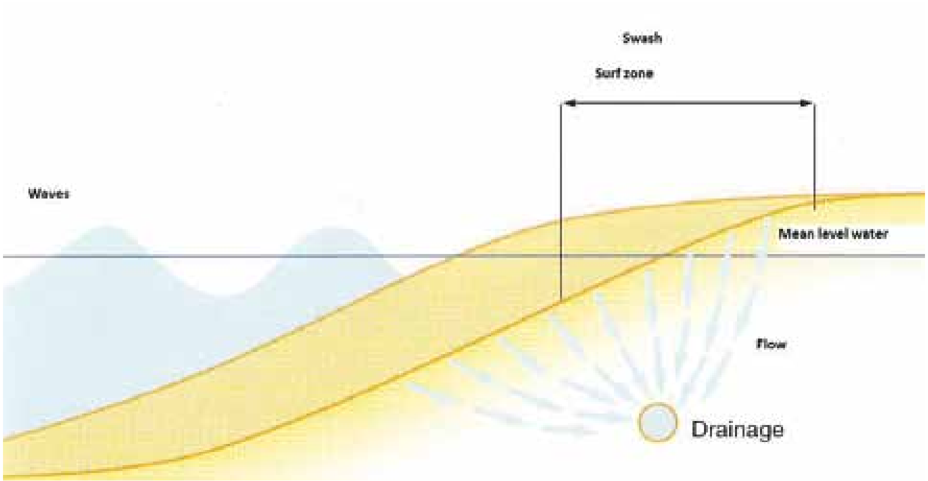


Diagram 10: A draining system on a beach

[20] Swash zone: superior limit of wave propagation on the beach.
[21] Benthic: organisms and processes linked to the bottom of the sea.
[22] Thixotropy: capacity of certain sedimentary substances to be transformed into liquids where the particles are in suspension (like running sand).

• By-passing

Description

By-pass systems, also known as sedimentary bridging, aims to re-establish long-shore drift blocking by artificially by- passing the sedimentary transit of a natural (a rocky headland, outlet, etc.) or anthropogenic obstacle (groin, port dykes, etc.) which it is confronted with (diagram 10). There are different ways to put this structure in place:

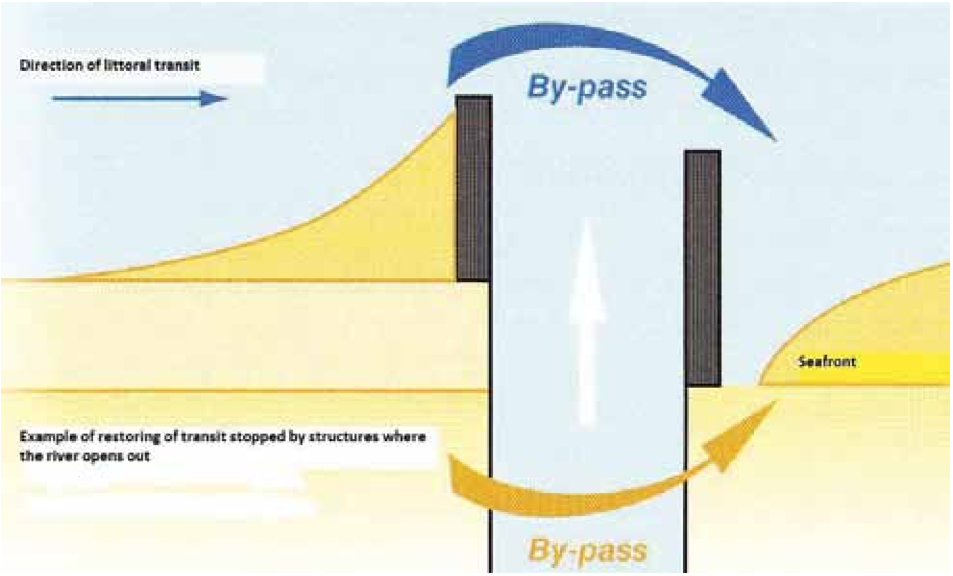


Diagram 11 : By-pass system

General advantages

The by-pass system re-establishes the natural dynamic of sediments. It can be easily operated if it is mechanical (by truck) and represents an interesting midium-term management solution. General disadvantages / limits By-pass systems can disturb littoral biodiversity (destruction of habitats, increase water turbidity etc.); dumping sediment on the beach can kill organisms living there (possible impact on benthic organisms). In the long term, this could affect a larger ecosystem (dune or near shore). In front of port zones, accumulated sediments may be polluted. In this case they must not be reinserted into the sedimentary chain.

Disadvantages / limits

By-pass systems can disturb littoral biodiversity (destruction of habitats, increase water turbidity etc.); dumping sediment on the beach can kill organisms living there (possible impact on benthic organisms). In the long term, this could affect a larger ecosystem (dune or near shore). In front of port zones, accumulated sediments may be polluted. In this case they must not be reinserted into the sedimentary chain.

- Hydraulic by-pass system

by installing a coning system with a mixture of sand and water in the deposit zone (upstream to the obstacle) and of expulsion downstream to the obstacle, in a hydraulic line. The system can be fixed (continuous operation) or mobile (activity adjustable in time and space).

Advantages

Restores the natural transport of sediments by balancing accumulation and erosion zones, without providing exogenous materials. The negative impact on the environment is low. The fixed system allows continuous use adapted to the seasonal cycles and needs.

Disadvantages / limits

Poorly adapted to pebble movements and high costs.

- Mechanical by-passing
by transporting by lorry sand and pebbles from one zone to another.

Advantages
Relatively low cost and easily mobilised technical resources.

Disadvantages / limits
Work leads to many environmental nuisances (such as acoustic) for those who live near the beach and the road; costs proportional to distances and feeding zones.

- Maritime by-passing
using nautical resources (e.g. dredgers). This consists of removing, transporting and piling sediments at high tide in shallow waters and on foreshores with a sedimentary deficit.

Advantages
This works with all types of sediment and periodic operations.

Disadvantages / limits
The site must be easily accessible and close to the zone to be treated (if not this could lead to high costs). Nautical manoeuvring is difficult in zones with high waves, and piling is especially difficult in zones with breaking waves.

• Artificial sand nourishment (replenishment of a beach)

Description
The objective of beach reloading is to compensate littoral imbalance caused by natural erosion and/or anthropogenic impact (presence of defence structures). The aim is to feed beaches with exogenous material (sand, pebbles) from the sedimentary cell by lorry, dredges, etc. These sediments are spread over the beach by earthworks machines. This is a widely used method in the United States, The Netherlands, the Adriatic Coast in Italy, the Spanish Mediterranean coast, etc. Replenishments can be occasional or regular, after each winter, for example. Before any intervention, data on the size of material, the bathymetry and settlements in low water, the swelling technique, littoral currents, etc. must be collected. The average annual speed of shoreline recession must also be determined. Digital models (example GENESIS[23] in the United States) and empiric methods (preferred in the Netherlands) help assess the volume of sediment to be used.


Beach feeding

Advantages
Replenishing a beach allows wide foreshores to be maintained, protecting against erosion agents such as storm waves ("buffer zone" effect), the maintenance of wide foreshores and consequently the conservation of uses (recreation activities) and stakes. There are no harmful consequences for neighbouring beaches as opposed to other methods, and input can take place indirectly by bringing in sediments. Sand reloading can also raise the beach's slope, in a preventive measure against the rise in sea level. The impact on the landscape is very low.

Disadvantages / limits
Material used must be near the beach and manoeuvring must be accessible. Moreover, the volume of the deposit must be sufficiently large for the input operations (regular reloading). It is important to have good quality sand or pebbles (no polluted sediments or those thinner than the reloaded beach). These methods are not suited to some configurations (due to large swells, difficult to access, sand granulometry, etc.). Pebble reloading is much less common because technical resources are more important and more costly. Dredging can disturb the littoral biodiversity of sample or deposit zones (destruction of habitats, increase in water turbidity, etc.).

[23] Generalised model for simulating shoreline changes.

Beach feeding

Notes

The Eurosion[24] 2004 study recommended identifying "strategic sediment reserves" which could be used to artificially feed beaches. These reserves can be located on other beaches (in relation to the littoral drift), inland (dunes, careers or offshore). The reloading profile is also important. It can be calculated using beach profile knowledge or by using a mathematical model (Dean, 2000).
Seasons must also be taken into account: replenishment must be done at the end of the winter. This is not a definitive method. It is often advisable to plan an initial massive replenishment followed by other smaller supplies after one or more seasons. The budget thus has to be planned over several years. Beach monitoring must also be carried out (topobathymetric analysis) during and after works over four to five years. This aims to characterise the shoreline mobility and to quantify the sediment volumes to plan for future replenishments.

• Case study : The by-pass system; Capbreton, Landes, Aquitaine, France.

Application Field

The rapid extension (roughly 200 m) of the beach located on the northern side of the Boucarot channel dyke corresponds to the sedimentary transit (approximately 100 000 m3/year) towards the South. Today, these sands by- pass the structure and clog the channel entrance. Consequences include increasing erosion (already present) of the beaches in the south. The reaction consists in initially reinforcing heavy structures (water-wings, groins, armouring the high foreshore). Between 1983 and 2007, 15 000 m3/year of sand was culled north of the channel by the Capbreton municipality in order to feed the southern beaches (routing by trucks).

Approach

A hydraulic by-pass system was put in place in 2008 to replace the terrestrial system (no environmental nuisance and the volume of sand transported increased) (diagram 11): sediments, when mixed with water (taken from the Boucarot channel) were mechanically withdrawn near the northern beach to be dumped on the southern beaches in a rigid underground conduit equipped with staggered outlet ducts to spread sand on the foreshores.

Results and outlook

The cost of this installation is estimated at 1. 2 to 1. 3 million Euros excluding taxes. The project plans an initial 100 000 m^3 sand input and annual reloading of roughly 75 000 m3 spread over a 12 to 15 week period in the months prior to the summer season (taken from R. Paskoff & C. Clus-Auby, 2007).

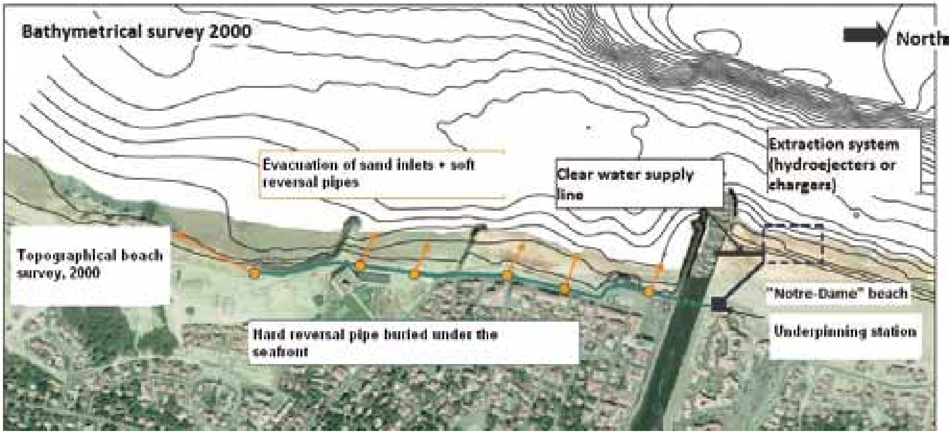


Diagram 12: The hydraulic by-pass system

[24] Eurosion (2004) Living with coastal erosion in Europe – Sediment and space for sustainability. Results from the Eurosion study. 21p

> Dunes

Here it is more a question of management than protection. Today dunes are no longer just considered as a source of risk, but also as a high heritage value landscape and soft protection for sandy coastlines. Management has a multi- functional objective: the inland region must be protected, a rare and original ecosystem must be preserved, and a limited sedimentary resource must be saved while at the same time contributing to erosion and submergence risk prevention.
Work to manage littoral dune mobility is based on knowledge of local situations and is a logical part of natural processes. This is flexible management.
The commitment to preserve typical, functional and diversified ecosystems means maintaining natural processes that contribute to the birth and functioning of these dunes (particularly a certain level of mobility), excluding reforestation of grey dunes and any introduction of exogenous species and an extremely limited use of mechanical remodelling techniques.
The objective of protecting the inland region, however, requires moderate inland region erosion to avoid a generalised new movement of the system that could threaten property and people (sanding up).
Dunes are mainly influenced by aeolian transport which can be controlled by soft protection methods. Efficiently playing the marine erosion mitigation role means maintaining a transversal solidarity between the dune and the beach. Dunal dynamics are dependent on marine dynamics which they also can impact. Part of the sedimentary input for beaches is ensured by withdrawals at the base of the dune. A flexible choice means being able to transfer towards the inland region should marine erosion become chronic. This possible recession can be done without damage if the dunes, without urban stakes, are sufficiently large: a 300 to 500 minimal width is required.
The closer the ecosystem objective to natural trends, the less energy is required to maintain it, which in turn leads to much lower costs. Experience shows that regular maintenance is much less costly than significant periodic restorations.
The action plan depends on a reference ecosystem. For Atlantic littoral dunes, it corresponds to the most complete succession possible of ecodynamic facies[25]. This landscape myriad gives the dunes a better resilience against disruptions (natural or anthropogenic) and generates attractive and varied landscapes.
Soft management means reducing wind speed and creating favourable conditions for the development of local species plant ground-cover. The basic techniques of this type of management are brush wood covers, windbreaks and plantations.

However, this present method has limitations: a sharp impact on plant ground-cover, a drastic reduction in geodiversity[26], a lack of adaptation to different dynamic contexts, etc. Currently remodelling is reserved to special situations where a soft choice is no longer possible, in particular in front of urbanised areas.

Les Cantines, Aquitaine (France)

[25] Ecodynamic facies: parameters allowing the characterisation of an ecosystem and its dynamics or evolution over time.
[26] Geodiversity: geologic (rocks, mineral, fossils), geomorphologic (relief forms) and pedologic (soil) diversity, generated by the dynamic processes.

Pyla, Aquitaine (France)

• Plant debris cover

Description

This causes an accumulation of sediments. The two most popular types are flat covers of thin branches (Genista shrubs, besom heather, etc.) which are manually put on the ground and mechanical covers of large branches (Maritime Pine, Holm Oak, etc.).

Messange, Landes (France)

Cap-Ferret, Aquitaine (France)

Materials

Most plant debris and branches are efficient as wind-breakers. However, the concern to preserve a natural looking environment, reduces possibilities. The following materials must be excluded:

- green branches that could bud;
- branches introducing unwanted exogenous species (garden debris, e.g. Yucca);
- large branches and trunks that do not have optimal performance (hard edges) and create environmental nuisance.

Advantages

Branch covers strongly reduce wind speed at ground level, which mitigates - or cancels - aeolian erosion. In sandy transit zones, they provoke an accumulation so that depressed zones can be filled in and aerodynamic profiles can be rebuilt. Moreover, this input of organic matter favours the recovery and development of plant communities (nutriments and humidity).

Branch covers can also have a deterrent effect, limiting dune use and trampling.

Disadvantages / limits

This technique is efficient in any erosion situation (deflation[27]) or deflation-transit. Accumulation zones do not have to be covered; their dynamics will be managed by upstream eroded zone treatment. Extension of these covers, however, must be absolutely limited (either for environmentally beneficial reasons (covers are a source of ruderalisation[28], transport by machines leads to deterioration, etc.), for landscape reasons, or for economic reasons.

[27] Deflation: removal of light particles and fine sand in the soil.

[28] Ruderalisation: damage of a natural environment under human influence (being translated by a nitrogen drift essentially), favorable to ruderal plants (which prefer grounds rich in nutriment elements) and unfavourable to the original plants.

• Windbreaks

Description
They limit wind speed near ground level, which mitigates deflation and promotes the deposition of transported sediment. These are vertical obstacles with variable permeability and height. The use of windbreaking curtains in the struggle against aeolian erosion is historical, with quite diversified material. Windbreaks are light, made out of plant palisades (besom heather, chestnut tree boards, etc.) or plastic grids. The natural materials used are biodegradable such as chestnut tree ganivelles, or nets made from coconut fibres. Windbreaking curtains are operational in sand transit zones where they can quickly fill with sand. It is mainly in the frontal zone, when marine erosion has decreased, that using windbreaks is frequent and efficient.

Advantages
Moreover, this technique is well-adapted to fill in depressed zones that need to be raised.
Installing windbreaks can be associated with other techniques, for example branch covers in a depressed zone when the desired height has been obtained, or planting Beachgrass (and/or Agropyron) to complete and "naturalise" windbreak actions.

Construction examples
The use of windbreaks is most frequent in frontal zones, in coast sectors which alternate between maritime erosion and stages of respite.

Disadvantages / limits
This choice must be avoided in different situations such as:
- dominant deflation zones; covers are more efficient;
- narrow wind blowing areas: heaving by the bottom and at extremities;
- chaotic sectors: difficult installation and partial heaving;
- sectors with many visitors: maintenance difficulties;
- steep slopes: difficult installation, and deflation dominance;
- proximity to shoreline in chronic marine erosion sectors, etc.

• Plantations

Description
On regularly maintained dunes without excessive visits, natural dynamics generally suffice to ensure a satisfactory plant ground cover not only in superposition but in diversity. Outside of rehabilitated sites, plantations are uncommon.

Advantages
The vegetation can fix sediments to plant roots, limiting sediment loss caused by wind. This method can be combined with other techniques (see windbreaks p.31).

Disadvantages / limits
The number of plant types used is small; the most common is Beachgrass (also called Gourbet in Aquitaine), (graminal) cespitose[29] true grasses, able to adapt to the environment: a strong resistance to silting-up, tolerance to blowing sand and a moderate salinity, etc. In Portugal, the studied plant is lichen.
Other indigenous plants can be planted or sowed on dunes (Sagebrush, Pearly Everlasting, etc.); however the plant that has recently developed the most is the Agropyron (Agropyronjunceum). This graminaceous plant is characteristic of the foredunes and very saline resistant, and adapts better than Beachgrass on the external side of dunal strips.

[29] Cespitose: which forms a dense tuft at its base.

• Flexible management practices modulated according to the geographic and dynamic context

Description

On regularly maintained dunes without excessive visits, natural dynamics generally suffice to ensure a satisfactory plant ground cover not only in superposition but in diversity. Outside of rehabilitated sites, plantations are uncommon.

Intervention strategies must be adapted to local conditions. It is mainly the sedimentary budget on different coastal sections that imposes these different modes of intervention:

- in sectors of strong and constant recession: limitation of the spreading of sands inward. This modification of the processes allow the plant communities of the back-dune to adapt gradually to the new conditions;
- in sectors with alternating phases of marine erosion and respite: a common occurrence along the Atlantic Coast. During the phases of respite of the marine erosion, works can be committed to store a part of the sand in closer to its source to favour the development of fore dunes and aerodynamic external slope;
- in sectors with a notable accretion (quite rare): new dune ridges develop in front of the ancient white dunes[30] which stabilize gradually. These sectors offer an opportunity to let develop without obstacle the wind dynamics. Eliminating or significantly reducing pedestrian traffic on the sites facilitates natural regeneration and greatly reduces the need for further interventions in many cases.

Proper dune management may not be isolated from beach management: the continuous energy exchange between these two compartments is at the very core of the vitality and efficiency of the beach/dune system. A breakdown in these exchanges will lead to the loss of all or part of the services provided, which shows the importance of sediment management programmes, promoted by "Eurosion" (2004).

All of these beach management actions must take into account the many roles beaches play: a constantly adjusted sedimentary accumulation to absorb occasioned energy, a place where very original types of fauna and flora live, etc. For example, foreshore and intertidal bar systems play an important role in the dissipation of wave energy along the coast. Intimately linked with beach ridges and dunes, intertidal bars must be preserved if a natural protection against erosion is required. Extraction of sediment must be avoided when cleaning beaches; the impact of cleaning can be curbed by developing selective cleaning programmes that leave organic material in place, etc.

Arcachon, Aquitaine (France)

[30] White dune: zone of strong sandy accumulation (strong presence of vegetation), obstacle between the beach and the back-dune.

• Case Study : Algarve, Quarteira Sector Cacela, southern coast of Portugal

Location and natural context

The coastal sector Quarteira - Cacela is located in the south coast of Portugal between the urban seafront of Quarteira at the extreme west of the sector and the Manta Rota beach at the extreme east of the sector. It has a total longshore extension of about 63 km, most of it a barrier island system, Ria Formosa. The sector's natural backshore changes from the western to the eastern extremities: a red cliff, followed by the sandy dune system of the Ria Formosa islands and peninsulas. The embayment system is located behind the barrier island and comprises salt marshes, sand flats and a complex network of natural and partially dredged channels, all included in a Natural Park Area. The barrier island system comprises five islands and two peninsulas, separated by six tidal inlets: two artificially repositioned (Ancãoand Fuseta), two artificially opened and maintained with fixed coastal structures (Faro-Olhão and Tavira) and two natural inlets (Armona and Lacém).

Noticed disturbances

A large extension of the western part of the sector has been subjected to an erosion process for several decades. This phenomenon has been accelerated with the construction of the long jetties in the Vilamoura marine, which, followed eastward by the fishing harbour jetties and the groin field constructed to protect the Quarteira seafront (photo 18). A group of hard cross-shore structures interrupt the littoral transport, causing sediment starvation eastward of Quarteira and consequently the cliffs are retreating. Further east, another area of local erosion due to anthropogenic causes can be observed: on Faro beach. The construction of advanced infrastructures and subsequent limitation of the natural expansion of the beach profile have caused the beach width to decrease, the shoreline to retreat and frequent episodes of dune overwash during maritime storms. In the eastern part of the sector, which comprises the eastern part of the barrier island system, the major areas of erosion are localised eastward of the jetties which were built to fix the two inlets: Faro-Olhão and Tavira. The natural migration process of the inlets together with sediment starvation due to the upwave retention by the inlet jetties cause dune front weakening. Consequently, in recent maritime storms, the dune front did not resist episodes of overwash and sometimes were breached.

Forte Novo - reloading the Garrão foreshore, 2010 (Portugal)

Quarteira fishing harbour and groin field, eastward of Vilamoura marine (Portugal)

Pressures and management actions

The Southern Portuguese coast is a major area in local tourism industry and the country's economy. Therefore, the retreat of the cliff and dune systems, decrease of beach width and sometimes destruction of infrastructures require coastal management actions by the local authorities. Despite the current strategy being to preserve the present shoreline position (and avoid cliff retreat and dune overwashing and degradation) in significant stake areas (with either natural or economic value, such as resorts), it was also decided to let the shoreline retreat in certain areas. This decision was taken despite the enormous pressure by the local population who do not want to relocate (in many cases the dunal system is occupied by illegal infrastructures) and their request for coastal protection using hard structures. Facing this pressure, the local authorities have implemented beach protection and rehabilitation measures. The most recent protection interventions are based on beach nourishment of the foreshore area in front of the cliffs (photo 19) or the reinforcement of the barrier islands' dune system. The sources are offshore seabed sediment and sediment dredged from the embayment system channel's maintenance. Other dune system maintenance measures, such as planting vegetation, are also being implemented based on projects which aim to promote the natural processes of dune recovery.

> Cliff

In order to reduce eroding rocky cliff instabilities, two types of action are possible (combined methods). The first action concerns protecting the foot of the cliff using geotechnical methods that limit marine erosion and stabilise the base of the slope (e.g. rip-rap strips). Geotechnical methods and solutions can be passive (they do not prevent instability but prevent it from affecting stakes or limits its impact) or active (they directly prevent the movement from occurring or modify it in a preventative way).
The other type of solution consists of stabilising slopes against continental actions. It is possible to implement "hard" structures or "softer" solutions (e.g. revegetation).
Cliff stabilising methods are put in place on the cliff slope. They take into account the type of instability (characterisation of events by their volume, frequency, and concerned materials "rocky" or "loose",. . .), the nature of the stakes to protect, access conditions, cliff geometry, hydraulic behaviour and mechanical forces applied to the cliff.

It is essential to note that cliff stabilisation opposes the natural behaviour of eroding cliffs, which is to recede (through progressive erosion or earth movement). Furthermore, these incidents allow a stabilising foot to be created at the bottom of the cliff or filling by the ocean allows surrounding beaches to be reloaded. It is thus preferable to only treat cliffs where socio-economic stakes are high, to limit as much as possible the disruption of the sedimentary transit. The geotechnical methods used are not "soft" solutions, but their limited use and their combination with "soft" methods (vegetation) limit negative impacts.
Also, we must not forget that an effective method cannot be defined without detailed geotechnical studies (causes of cliff instability) or previous analyses (financial constraints, the best strategy in terms of safety and cost/efficiency studies, environmental impacts). Moreover, a single method is often not sufficient; generally several geotechnical methods are needed to achieve the expected results.

Cliffs of Mohair (Ireland)

• Revegetation

Description

The roles vegetation plays in stabilising rocky environments are well-understood and multiple. It is well-adapted to loose cliffs. Managing the existing vegetation, using its potential to regain damaged areas, are often sufficient to heal environmental alteration scarring (moderate extent of instabilities and frequency not high) and reduce regressive erosion. The vegetation is planted on the cliff to limit the risk of starting instabilities (roots retain soil). This approach can be applied by creating forested berm (manual, mechanical machine, etc.), waste water draining ditches, etc. In mobile facies, the roots of very specialised plants (fast-growing and deep-rooted species) grasp the substrate and prevent rock movement; in more stable sectors the continuous plant ground-cover generates a pedological profile that works as a type of protective "skin".
Plants also slow down the speed of continental runoff water and promote the accumulation of fine sediments. They limit erosive phenomenon and water seepages in favour of evapotranspiration[31]. Stabilisation structures are necessary, environmental engineering limits interventions using rolling out techniques that are much less costly than actions undertaken by civil engineers to resolve the most broken down situations.
Last but not least, these soft techniques, whose environmental and landscape impacts are generally weak and fleeting, have a very positive image with littoral users.

Advantages

This is not a costly procedure. It also has the advantage of being "natural", however attention must be paid to the type of vegetation used (no invasive species, favour local species), as this depends on the soil, the rock surface and the site being studied.

Disadvantages / limits

This soft technique can only be used on small plots. This is a non-sustainable solution (replacement of dead or destroyed trees). Potential ditches have also to be maintained. The roots system growth can cause a swing effect (rock fracturing thus created, and can lead to destabilization).

[31] Evapotranspiration: Moisture transfer towards the atmosphere from plant evaporation.

• Reloading littoral strips (sand/pebbles) at the foot of the cliff

Description

The objective of littoral strip reloading is to compensate littoral imbalance caused by natural marine erosion and/or anthropogenic impacts (presence of heavy structures). Reloading littoral strips at the foot of a cliff takes place following the same rules as those for sandy beaches (see Artificial sand nourishment p.26). It generally concerns foreshores with insufficient littoral transit.

Advantages

This method, which does not impact the landscape, limits erosion at the foot of a cliff caused by maritime actions (reduction of swell action efficiency) and has a stabilising effect for the foot of the cliff.

Disadvantages / limits

Disadvantages and remarks remain the same as those concerning sandy beaches (see Artificial sand nourishment p.26).

• Cliff reshaping (a geotechnical solution)

Description

This is a method suited to loose cliffs. Earthworks and reshaping can shore up a cliff; this however requires deep knowledge of the geological structure and water infiltration conditions. This method consists in enhancing the general stability of the cliff by giving it a more adequate geometry (slope) and even eliminating any instable or dangerous blocks. In some cases terraces (stepped[32] or tiered) can also be created at different levels (diagram 13).

Advantages

The cost of this programme remains low if the earthworks are not large. Project studies are relatively simple. This is a sustainable solution. Potentially important volume areas can thus be treated.

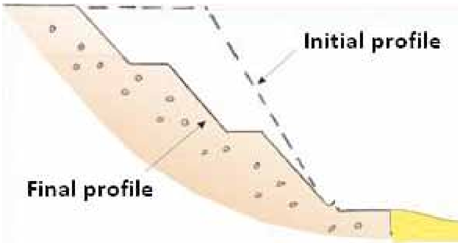


Diagram 13 : Drawing showing cliff reshaping

Disadvantages / limits

This method can provoke a more or less important recession at the top of the cliff, thus there should not be any urban areas or stakes present (near the cliff ledge) and a controlled management. This procedure may disturb littoral biodiversity (mainly habitat destruction). Sufficient room is needed between the foot and the top of the cliff (not adapted to rocky cliffs because "hard"). This technique cannot be employed for all cliff types (for high slopes which are sloped strongly). The visual impact is more or less important depending on the works.

[32] Stepped: layout of terraces each one upon the other at intervals.

• Draining systems (a geotechnical solution)

Draining consists in eliminating superficial surface runoff and infiltrations on the upright cliff or lowering groundwater level. There are different procedures; some are put in place to limit surface runoff, infiltrations and control superficial ground water; others concern deep water catchment.

Drain ditch system

Description

The drain ditch system (bitumen, plastic film, etc.) involves gathering and evacuating surface runoff water before infiltration. This system leads to building ditches at the top and/or on the slope of the cliff. This method is suited to phenomena with limited volume, rocky instabilities or slipping favoured by superficial runoff.

Advantages

This is a low-cost method which slows rock deterioration.

Disadvantages / limits

It must however be noted that on an unstable slope, this will be a fragile process (drain ditch system) requiring continuous up-keep. Landscape impact depends on the type of material used for these drains and also on the way they are distributed over the entire cliff.

Draining system procedure with sub-horizontal drains

Description

Some formations contain ground water aquifers which play an important role in rock deterioration. Methods allow intervention on these ground water aquifers by deep catchments.
In the case of a permeable environment, this will be in the form of sub-horizontal drains. These are small diameter tubes (metal or plastic) leaning towards the exterior in order to allow water gathered on the site to drain-off (diagram 14). They are put in place on the slope surface by drilling and inserting draining tubes or perforated metallic tubes. Every ground water has one or more drains.

Advantages

This has a weak impact on the landscape. Project studies are generally simple, although specialised contractors must be called upon. This is a sustainable solution. This system is suited to huge slipping areas to avoid using "heavy" techniques (rigid inclusion).

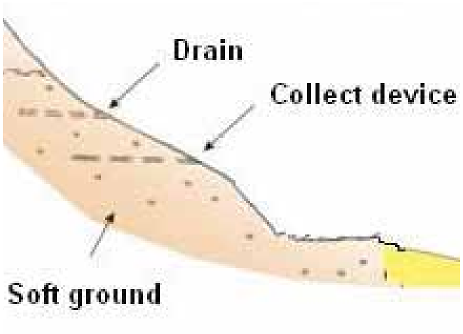


Diagram 14: Schema showing the draining system procedure using sub-horizontal drains

Disadvantages / limits

The disadvantage of this type of procedure is the risk of clogging in the long term; regular maintenance is thus necessary (blowing method). This method anticipates a noticeable activity reduction but not necessarily a stop in every area.

• Anchors and rock bolting (a geotechnical solution)

Description

This technique improves the stability of loose cliffs vis-à-vis identified rocky masses with relatively limited volume. They are not suitable for rockslides, unless the face is nailed or stabilised with an analogue method. These methods are used to protect downstream stakes and if there are wall head instabilities. The principle involves anchoring unstable rock elements using bolts or tie-rods (diagram 15).

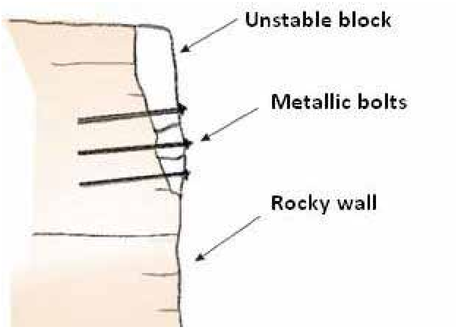


Diagram 15: The anchoring procedure using metallic bolts

Advantages

This is a sustainable solution which needs regular inspections to control the condition of the inclusions. It is possible to treat overhangs.

Disadvantages / limits

It is only adapted to isolated stabilisations and for limited volumes. This technique may only be used for small to medium-sized rockslides and medium to large rocks. Implementation can be complex and thus quite costly. This method requires regular up-keep. This is not a technique that can be used on all cliff types.

• Reinforced geogrid (a geotechnical solution)

Description

This procedure superficially stabilises the side using a reinforced polymer grid. The grid is attached to the side with short anchors. The main interest in this type of technique is to avoid heavy works (diagram 16). It is generally used for crumbly scarps with an overall limited height.

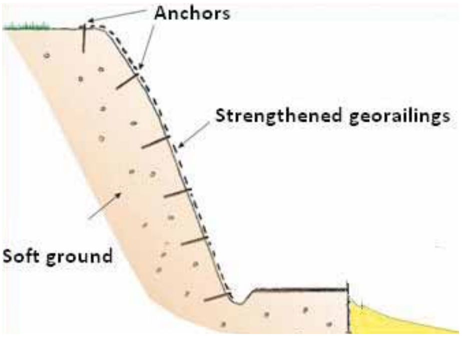


Diagram 16: The reinforced geogrid procedure

Advantages

This method encourages vegetation and constitutes an alternative to harder methods and thus limits costs. Preliminary project studies are simple; however specialised civil engineering contractors must be employed. This is a sustainable solution.

Disadvantages / limits

This solution is not suitable for deep slides, only small superficial slides. It requires regular monitoring to check the condition of the system. Large blocks must be eliminated.

• Pinned net (a geotechnical solution)

Description

This is a technique for maintaining unstable blocks. These methods are used to protect downstream stakes. These nets or grids are pinned to the side using short anchors and wrap unstable elements together to prevent rockslides. Only limited volume rocky instabilities are treated.

Advantages

This sustainable solution can treat some overhanging rock problems. Fixing a compartment can help prevent a more substantial cliff pane from destabilising.

Disadvantages / limits

Preliminary studies can be complex and specialised contractors must be employed. Inspections must be done regularly. Landscape impact remains strong despite localised intervention. It does not avoid major instability problems.

• Rip-rap strips

Description

These are percolated rip-raps which can be concrete (stabilising abutment) at the foot of the cliff, on the slope base. This action also mitigates sea erosion at the foot of the cliff (diagram 17). This method is similar to the offshore bar filling method (see Reloading littoral strips p.35). A stabilising abutment can thus be built at the cliff base.

Advantages

Preliminary project studies are simple and traditional civil engineering firms can be employed. This is a low-cost and sustainable solution. However, the simplicity of studies and costs can vary according to the site.

Disadvantages / limits

More often than not, this technique is employed to mitigate plane shallow slips on slopes with a medium inclination and can be used for limited rockslides on the lower part of the cliff. This method does not suit instabilities on the higher part of the cliff. The rip-raps must be sized according to storm conditions. This method can halt sedimentary input caused by cliff recession. Periodic monitoring must be performed. Landscape impact remains strong and excepting limited interventions in the area, this method must be considered as a "hard" solution (p.21).

• Concrete or masonry buttress (upright on undercut rocky zones) (a geotechnical solution)

Description

This is a reinforced concrete or masonry support installed upright on undercut rocky zones that, in time, could cause instabilities (diagram 17). This process can be set up in the cliff (undercutting by differential erosion) or at its base (marine erosion).

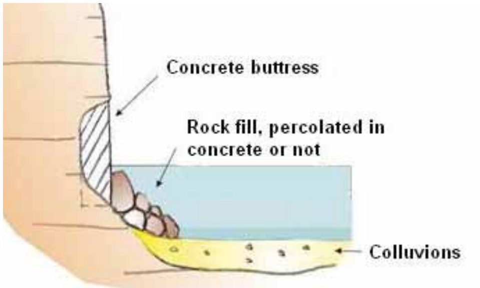


Diagram 17: The combination of two geotechnical solutions rip-rap and concrete buttress

Advantages

The intervention is simple at the foot of cliff but delicate on the slope. However in some cases, specialised contractors must be called on. This is a sustainable solution.

Disadvantages / limits

It does not suit crumbly instabilities. Suited to small to medium-sized rocky compartments. The landscape impact remains strong despite localised intervention and this technique requires regular maintenance.

Stabilisation techniques, costs and maintenance remain high which means that priority must be given to cliffs with critical issues such as those on urban littorals. These techniques are only employed for sites presenting an exceptional interest (probably disappearance and impossible to relocate).
Due to their height, cliffs are natural barriers preventing maritime submergence risks. On the other hand, the rocky coastal platform that dissipates mechanical wave energy, mitigates erosion at the foot of the slope.
All cliffs recede, the method of strategic receding or simply "doing nothing" (chap. III) is thus preferred.

• Case studies

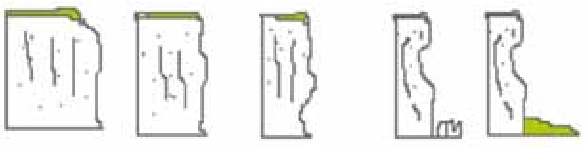
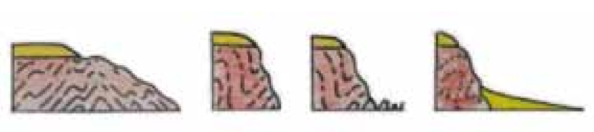
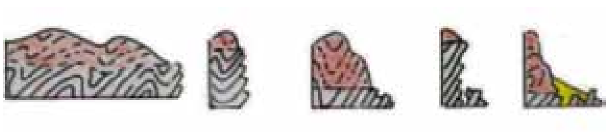
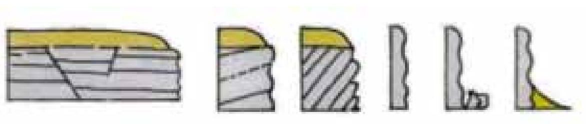
The following case studies take place in France and are aimed at characterising hazards and "soft" solutions envisaged for each main cliff type in Atlantic Europe. This is why we have chosen chalk and marl cliffs for loose rocks and for hard rocks we have chosen flysch and limestone cliffs.

Côte d'Albâtre, Haute Normandie / chalky cliff (France)

Biarritz, Aquitaine / Marly cliff (France)

Saint-Jean-de-Luz, côte basque, Aquitaine / Flysh and weathered rock cliff (France)

Pointe Saint Martin, Biarritz, Aquitaine / Limestone cliff (France)

Morphology of cliff types found in the Atlantic Europe	Type of hazards and solutions	Examples of location and stakes
White chalk cliffs (lines with shingle bar)		
	Hazard : 1 Solution : K & B possible	Côte d'Albâtre (Haute Normandie, France) Socio-economic stakes medium density urban zone (many houses along the cliff edge)
Marly cliffs (alluviums at the top)		
	Hazard : 2b Solution : H & J	Marbella beach (Biarritz, France) Socio-economic stakes : medium density urban zone (camp sites and beach tourism close by)
Marly calcareous flysch and weathered rock cliffs		
	Hazard : 2b no solution but could place preventive signs, rip rap, etc.	« la pile d'Assiettes » Cliff (Saint-Jean-de-Luz, la côte basque, France) Socio-economic stakes : sports trail development
Limestone cliffs (alternation of limestone bars and sandy marls, with alluviums on the top)		
	Hazard : 1b Solution : 1	Pointe Saint Martin (Biarritz, France) Socio-economic stakes : low density urban zone (public gardens, lighthouse)

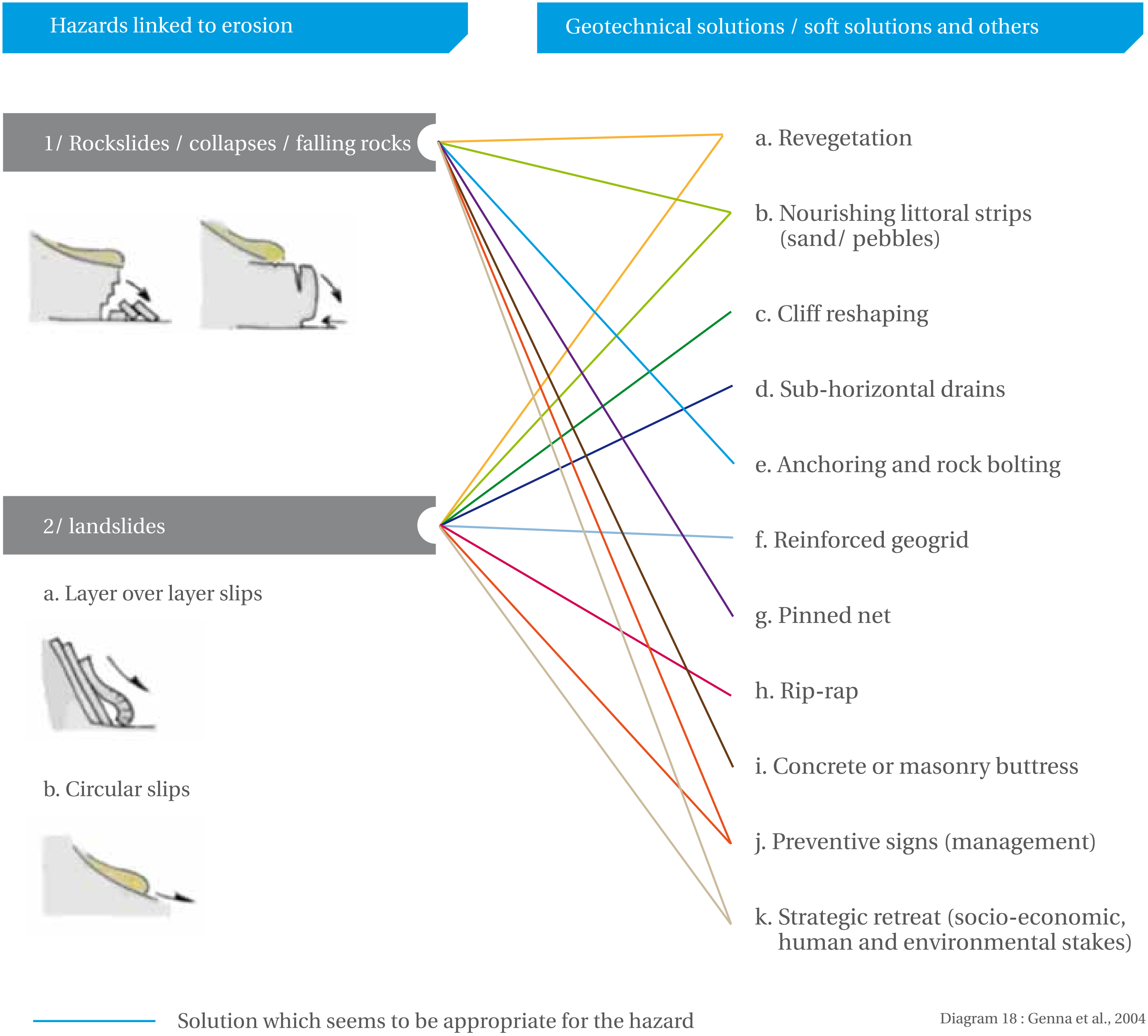


Diagram 18 : Genna et al., 2004

Mayo County (Ireland)

> Tidal marshes

Maritime marshes, as natural infrastructures, present a strong contradiction in their role of coastal protection.
The fight against erosion on littoral fringes is conditioned by the existence of obstacles opposing swells (coastal mudflats disperse wave energy), whereas the protection of biodiversity is conditioned by preservation of hydrodynamic conditions (wave energy, etc.) and limitation of aggradation (important sedimentary accumulations, mud and fine sand).
The vast majority of these sites have been protected by sea dykes parcelling off confined marshes often employed in agriculture. The main issue concerns maintenance of these dykes after strong storms and managing these structures faced with the current rise in sea level.
The rise in sea level leads to multiple consequences (indirectly) such as a modification of waves and current directions which could have geomorphological consequences, and lead to hydrogeological modifications to ground water runoff. These are serious consequences in regions with polders and marshes. Marshes have many environmentally beneficial and socio-economic stakes, and contribute to protecting urban environments from flooding. There are thus many defence methods that can be employed according to each case:

- elevation and reinforcement of sea dykes and restoration of unused dykes;
- rehabilitation of structures (runoff to the sea);
- pumps to ensure draining.

Methods that can be controlled, however, remain expensive. Moreover, wetlands represent a major ecological stake in maintaining many animal species, are a natural passive barrier against marine submergence and contribute to filtering continental waters (sometimes polluted) in their transfer towards a maritime environment. This is one of the reasons why the method of partially or totally returning reclaimed land to the sea (depolderisation) as well as returning land in submersible zones is becoming increasingly popular. Soft solutions to protect these littorals are thus increasingly moving towards an environmental approach through sustainable management of the many natural environments stemming from the foreshore to confined marshes.

• Depolderisation

Description

The depolderisation technique varies in accordance with the objective to be achieved. There are many alternatives to the total destruction of a dyke. This phenomenon is becoming increasingly popular today. Depoldering modifies the natural environment as it resalinises it while also rebuilding the maritime ecosystem (destroyed by the former confinement), slikke and schorre, which allows the creation of new habitations for the avifauna, to favour the hydraulic circulation and drainage, the elevation of schorre zones useful in the fight against marine erosion and submergence, and the increase in biodiversity on the various facies of these environments. For example, the schorre, because of its halophyte vegetation, allows sediments brought in by the sea, essential for its expansion, to accumulate. This phenomenon thus leads to an increase in topography thus slowing sea erosion.

Depolderisation includes four main objectives:

- environmental (an objective often linked with others): depolderisation of abandoned polders (totally or for a long period) in the framework of fragile littoral agriculture;
- legal: depolderisation in compensation for maritime marsh surfaces lost due to works (e.g. constructing dykes);
- defensive: depolderisation to recreate marshes that play a protective role against the sea (a new technique of adaptation to the rise in the sea level);
- touristic: depolderisation to promote local development favouring environmental and landscape interests.

A successful depolderisation depends on carrying out a preliminary study "external and internal physical parameters of the sites to be returned to the sea", as well as research on socio-economic aspects. It must be followed-up by monitoring (topobathymetric, ecosystem, risk, etc.).

Advantages

Allows a low-cost improvement in the environmental state of ecosystems as well as a "soft" response to the hazard of marine submergence.

Disadvantages / limits

Requires strict management of water levels in waterlogged zones. Limited action on the submergence hazard. Requires considerable consultations with users and potential residents behind the area.

• Restoration of maritime marshes

Description

The restoration of marshes allows an effective protection of internal defences against the sea. Wave energy is absorbed when it crosses an area of schorres. This limits erosion and thus limits submergence (sedimentary accumulation). It also has the advantage of increasing biodiversity and the production of organic matters which feed the littoral marine environment. This restoration thus includes managing tourist flows and limiting fishing, hunting activities etc. to permit the proper development of the vegetation in these zones.

Delta of Arcachon, Aquitaine (France)

Advantages

It allows a sustainable low-cost improvement in the environmental state of ecosystems as well as a "soft" response to the hazards of marine submergence and erosion. It improves water quality. This method encourages increased biodiversity and organic matter production supplying the littoral maritime environment.

Disadvantages / limits

Limited action on the submergence hazard.

About thirty years ago, general awareness of the ecological, patrimonial and landscape value of these environments developed, gradually bringing about a collective management directed towards sustainable development, combining ecosystem preservation and traditional trade preservation.

• Case study : Essex estuaries, England (eurosion, 2004)

Location and natural context

The County of Essex is in the south-east of England. The coastline around its southeast edge is deeply indented, but flat, due to several river estuaries enclosed between those of the river Stour to the North and the river Thames to the South. The coast is a big source of wealth with considerable economic and industrial activities, but also extensive areas of salt marshes, mudflats, salt meadows, etc. Much of these areas are protected from flooding by the sea by earth, sea walls and concrete embankments. Seaward of the seawalls are large areas of salt marsh which flood at high tide and provide a form of protection from wave attacks. Essex is one of the most threatened areas regarding coastal flooding in England. For the whole country, over 1, 8 million homes and 180, 000 commercial properties are considered to be at risk, potentially 5 million

Cudmore Grove Country Park salt meadow (England)

people, and 1, 4 million hectares of agricultural land including 61% of the total of grade 1 land in England and Wales. The total value of the assets at risk is estimated at over 350 billion Euros for England. All the estuaries show signs of erosion and from the North to the South there appears to be a general decline in beach levels. This is most noticeable in the salt marshes: in the North this is attributed to the poor supply of material from the north with the approaches to Harwich Harbour forcing the material seawards. The loss of salt marshes in south east England has been subject to a considerable amount of research (due to enclosure and subsequent use for agriculture). Beside its exposure to coastal erosion processes (either nature or human driven), Essex has to face another threat. Its coast lies in an area where sea level is rising relative to the land. A well-known effect of the sea level rise is the depletion of salt marshes, which provide a high level of safety by absorbing wave energy during storms. Some estimates suggest that without a fringing salt marsh a sea wall needs to be four times higher and could cost ten times more to construct than one fronted by an 80m wide salt marsh.

Current shoreline management strategies

The loss of habitat, changing perceptions of the implications of the rising sea level and the cost of maintaining hard defences have all contributed to moving away from 'protect at all costs' to a 'realignment' policy which accepts that some land will be lost to the sea. This is combined with the use of 'softer' engineering options (beach recharging). However, it does not imply that the policy supersedes all locations where coastal protection may be in place. Indeed there are several large towns and villages where protection is desirable and cost effective because of the assets they protect. The identification of the most sustainable approaches to manage risk along the shoreline over the next 50 years has been supported by the elaboration of the Shoreline Management Plan (SMP) at the level of each coastal sediment cell, recommended by the Department for the Environment, Food, and Rural Affairs (DEFRA) and the Environment Agency.

It is clear from the analysis of the situation in Essex that the rising sea level imposes severe restrictions on the capacity of the 'Hold the line' option to be sustainable in the medium to long term. Recent flooding events in Europe suggest that whatever is spent on capital and maintenance of coastal protection features, extreme events will always overcome the defences. It is too early to tell whether the long term realignment of the coast will achieve the aim of securing a more sustainable and cost effective approach to coastal defence. It is already clear, however, that the re-creation of mudflats and salt marshes is possible and that considerable benefits are derived for nature conservation. The main purpose is to ensure the natural resources of the coast, both on sea and land, in order to continue supporting business (tourism, maritime activities, agriculture, etc.), wildlife, and the sustainable development of coastal populations and nature areas.

• Case study: beach-dune systems as natural protection, a land planning dilemm from Co. Mayo, Ireland

A Coastal village

Louisburgh is a rural village (pop. 314) located 1km from the coast. It is expected to double in size by 2022. The local economy is sustained by a small factory, with some agricultural, commercial and retail activity. Most of the village's inhabitants commute out of the area to work. Holiday homes add to the economic activity during the summer months. It is expected tourism will be central to the area's future development.

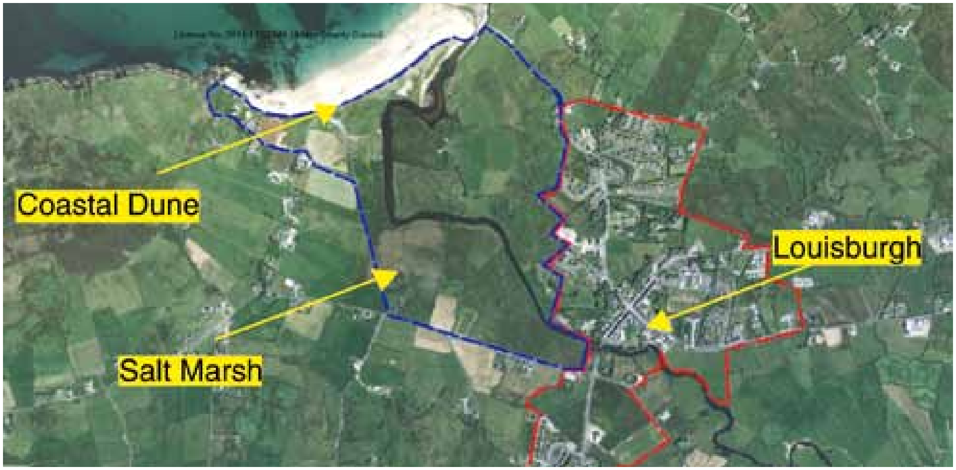
A sheltering coastal environment

While the influence of the tide extends up the Bunowen River to the village, flooding is not currently considered a problem. This situation, however, could change if the coastal environment were to alter. The village is protected on its seaward side by a coastal dune complex at the coast, with a salt marsh occupying the low lying land in between. During storms this environment is a buffer against elevated water levels reaching Louisburg. While recent efforts to manage and stabilise the dune complex have been concerned with conserving biodiversity, land planners feel that it may be prudent to include this land in future development plans - due to its function as a natural protection against coastal flooding. Unfortunately this may be counter-productive.

A coastal land planner's dilemma

Scenario 1 - If the land is not included in the local area plan (red boundary on map): The area is currently proposed as a Natural Heritage Area. This would give it some protection from development but may not guarantee the protection required. This scenario would consolidate development around the core of the town.

Scenario 2 - If it is included in the local area plan (extending to include the Blue Boundary): This would give recognition to the role the dune system and marsh have in protecting Louisburgh from flooding. There is, however, a danger that the area could be zoned inappropriately: the final decision on zoning is made by elected representatives - opening the possibility for local politics to play a role in land zoning.



> Summary table of solutions

Type of coast	Soft solutions	Advantages (+)	Disadvantages(-) / maintenance
Beach	Structures made from geotextiles	Preservation of sand behind the structure, reversible, permeable, flexible and uv-resistant structure, thus promoting the installation of vegetation	Fragile, regular maintenance, sedimentary impact is identical to hard solutions, water circulation limiting role, sedimentary deficit of unprotected neighboring zones
	Artificial reefs	Lowers the wave energy, does not distort the landscape, enrichment of biodiversity, preservation of a restlessness of the water	Regular maintenance, does not suit coasts with a strong tidal range
	Hydraulic piling	Dispersal of swell, equal distribution of sand retained on each side	Obstacles for walkers, dangerous for maritime navigation if destroyed by erosion, regular maintenance, limited effectiveness according to the site
	Beach draining	Lowers top of water table thus less erosion, no landscape impact, appreciated by recreational activities, costs can be mitigated by using recycled water	Limited to certain types of beach, regular maintenance of system
	By-pass system	Re-establishes long-shore drift blocking , fixed or moving systems	The site must be easily accessible and close to the zone to be treated, regular maintenance, costs depend on type of system, disturbs littoral biodiversity
	Artificial sand nourishment (beach refilling)	Compensates littoral imbalance, no landscape impact,recreational activities on the seaside have sufficient space, prevention measure against marine submersion, no harmful consequences for neighbouring beaches	Several re-sanding operations must be planned, leading to a costly budget, numerous studies, regular maintenance, possible impact on ecosystem
Dune	Plant debris covers	Provokes an accumulation of sediments, reduces wind speed which mitigates or cancels aeolian erosion, a deterrent effect limiting dune use and trampling, developing plant colonies, sustainable solution	Extension of these covers must absolutely be limited, regular maintenance
	Windbreaks	Promotes the deposit of sediment transported by wind, simple installation, can be associated with other techniques, biodegradable, sustainable solution	Do not use in sectors with heavy traffic, steep slopes, chaotic sectors, etc, regular maintenance, synthetic materials are pollutants if destroyed by erosion
	Plantations	Common plant is beachgrass,strong resistance to silting-up, tolerance to blowing sand, moderate salinity, etc and cost amortised, sustainable solution	On regularly maintained dunes without heavy traffic

Type of coast	Soft solutions	Advantages (+)	Disadvantages(-) / maintenance
Cliff	Revegetation	Decreases ground erosion (rain wash), environmental and landscape impact is generally low and not costly	Can only be used on small plots, non-invasive species, non-sustainable solution, roots system growth can induce a swing effect, regular maintenance
	Nourishing littoral strips	Compensates littoral imbalance, no impact on the landscape, a stabilising effect for the cliff base	Several re-sanding operations must be planned, leading to a costly budget, numerous studies, regular maintenance
	Cliff reshaping	Enhances the general stability of the cliff, project studies are relatively simple, sustainable solution	Any urban areas or stakes (near the cliff ledge) and a control management, not adapted to rocky cliffs because "hard", regular maintenance, costs depend on type of reshaping (landscape impact), disturbs littoral biodiversity
	Drain ditch system	Eliminates superficial surface runoff and infiltrations on the vertical cliff, low-cost method which slows down rock deterioration	Fragile process, requires continuous up-keep, landscape impact depends on the type of material used but also on the way they are distributed over the cliff
	Draining system procedure with sub-horizontal drains	Eliminates superficial surface runoff and infiltrations on the vertical cliff, project studies are simple, sustainable solution, low impact on the landscape	Risk of clogging in the long term, regular maintenance, a noticeable activity reduction but not necessarily a complete stop should be expected according to the area
	Anchoring and rock bolting	Improves the cliff stability, sustainable solution, possible to treat overhangs	Implementation can be complex and thus quite costly, regular up-keep, cannot be used on all types of cliffs (rocky), rocky masses and limited volume
	Reinforced geogrid	Improves superficial cliff stability, vegetation can grow through this geogrid, simple project studies, sustainable solution	Not suited for deep slides, only small superficial slides, regular surveillance, big blocks must be eliminated
	Pinned net	Maintaining unstable blocks, sustainable solution can treat some overhanging rock problems	Studies can be complex and specialised contractors must be employed, thus costs can be high, regular inspections, landscape impact remains strong, does not avoid massive instability problems
	Rip-rap strips	Improves cliff stability, disperses wave energy, project studies are simple, low-cost and sustainable solution	Does not fit instabilities in the higher part of the cliff, can halt sedimentary input due to cliff receding, regular surveillance
	Concrete or masonry buttress	Improves cliff stability, simple intervention, sustainable technique	Landscape impact remains strong in spite of a localised intervention, not suitable for crumbl instabilities, regular maintenance
Tidal marsh	Depolderisation	Allows a low-cost improvement to ecosytem environmental state as well as a "soft" response to the risk of marine submergence	Requires strict water level management in waterlogged zones, limited action on submergence risk, requires many consultations with users and any residents behind the area
	Restoration of environment (schorre)	Allows a low-cost improvement to ecosystem environmental state as well as a "soft" response to the risks of marine submergence and erosion, improves water quality	Limited action on the submergence risk


Arguin, Aquitaine (France)

3 - DECISION-MAKING TO ELABORATE A COASTAL EROSION MANAGEMENT STRATEGY

Mayo County (Ireland)

The littoral is an environment impacted by many specific hazards (especially coastal erosion) and the presence of socio-economic, human, and environmental stakes generates vulnerability.

Every action has a cost; this is the reason that, in a context of integrated coastal zone management, each approach considered must be fully thought through beforehand (scope of the phenomenon, stakes of zones to be preserved, etc.). The approach will vary depending on the different situations (rural land that could flooded should the dyke break, urban land exposed to risks, beach with strong touristic potential, etc.). In a given situation, opting for one type of structure, or for a combination of two or more structures, is always a compromise between the specificity of the problem being solved (persistent erosion at the shoreline, flooding of low-lying areas, etc.), the morphological conditions (the shoreline type and the beach-profile type), the land-use (residential, recreational, agricultural, etc.), and the anticipated impact of structures on coastal processes" (das Neves, 2011).

Managing coastal protection

> Defining hazards, stakes, vulnerability, risks and preliminary studies of an area

• Definitions

The choice of techniques to mitigate erosion and marine submergence issues partly depends on risks which are expressed by the combination of hazards and stakes (introduction). The stronger the hazard and stakes, the stronger the risk. The "erosion" hazard is determined by a sedimentary budget study of the littoral and shoreline or sensitive area long term evolution.
The "marine submergence" hazard depends, on one hand, on a historical study of littoral flooding, and on the other, a frequency analysis of oceanic parameters, (mainly the sea level). The "earth movement" hazard, from cliff erosion, is based on a historical study of movements recorded on the cliffs. Consequently a frequency analysis of mechanical and physico-chemical parameters is drawn up along with the study concerning the cliff's intrinsic factors (geology, geomorphology). Earth movements concern landslides, rockslides, falling blocks, etc.

A potentially dangerous event, or hazard, is a major risk if it applies to a zone where human, socio-economic or environmental stakes are present.

Reflection on these stakes must highlight the differentiation between current and future stakes. There are three main stakes: human stakes, socio-economic stakes and environmental stakes. They concern more particularly urban development (population and infrastructures), tourism, fishing activities, navigation, culture, the economy and the environment (natural heritage). The littoral zone has always been a zone of heavy human activity while also having environmental specificities. For the current stakes, risk management measures are considered (prevention, surveillance, pointing out dangers, prohibiting access, etc.). For future stakes risks must be reduced as far as possible. To do this, the zones (prevention) where infrastructures may be constructed (risk level, etc.) must be studied.

Vulnerability assessment is a stage that must precede the choice of management intervention. This assessment consists of drawing up a vulnerability report using indicators (hazards, stakes, risk perception, policies and management measures taken). This report measures damage that would be caused by the hazard should it take place. It depends on the stakes involved.

• Preliminary studies

Technical studies

The implementation of any shoreline management solution must be followed up by studies which assess the relevance of the work carried out and its environmental impact. Gathering data in situ is an important stage in order to understand site dynamics. Information gathered generally does not suffice and can be completed by physical or digital modelling.
The objective of preliminary studies is to supply a regional synthesis on knowledge of the chosen sector and detection of vulnerable zones, to propose a diagnostic at a local scale and to indicate the technical and economic feasibility of envisaged solutions. Fieldwork allows the site to be examined and a better understanding of expectations concerning the study and protection solutions. Data collection, initially carried out at a regional level, should include:

- Hydrometeorology;
- Sedimentary characteristics;
- Structures influencing sedimentary dynamics;
- Submarine bed morphology;
- Inventory of rare fauna and flora species.

An obligatory technical study must describe this phenomenon on a regional scale. Then, a detailed analysis of hydro- sedimentary mechanisms will lead to a diagnostic of malfunctions and solutions will be able to be drawn up. Should the subject be complex, it will allow critical sectors and those lacking knowledge to be identified.

Local risks memory

A detailed analysis of past events in the selected site, incorporating relevant data already collected for various purposes, enables us to learn from past experiences (by tapping local risk memory). Sharing data with other stakeholders, who may be engaged in monitoring or follow-up activities, is highly commendable and cost effective.
Including the public in the decision process using communication programmes (websites, conferences, etc.) is therefore important. Thus the "collective risk memory" must not be neglected to improve public awareness and prevent risks.

Economic evaluation

An economic evaluation of development projects is necessary. This consists of identifying functions and services provided by littoral ecosystems and assessing effects linked to erosion, whether positive or negative. This data must be integrated to development related expenses to obtain an estimate of the economic profitability of the development solution.

Flexible or hard techniques

Using "flexible" and reversible techniques (chap. II) (rather than hard structures), changes the role of the follow-up (an integral part of the solution). Implementing a littoral monitoring system (on a long-term basis) consists of assessing the techniques and management systems put in place, modifying them whenever necessary, estimating or compensating impacts, and enriching knowledge necessary for scheduling future interventions.

> Shoreline management axis

Four shoreline management axes are possible:

No intervention:
if the stakes do not justify an intervention or if there are no stakes involved, natural evolution will be followed while trying to limit anthropogenic impacts. This is the best solution in some cases as erosion does not always constitute a risk. No action is envisaged on the littoral. To limit future stakes (not planning any construction near the zones which present risks) and let nature take its course, we must control the land, e.g. classifying the zone as a "non-constructible" zone; it could also be classified as a green space with high added tourist value (in this case, signs will have to be installed in order to inform users of probable risks and limit access). It must be noted that property management must be accompanied by a follow-up in cliff or shoreline recession, in order to monitor the evolution of the erosion phenomenon and to adapt management strategies.

Advantages:
no spending and conservation of existent natural functionalities.

Disadvantages:
risks on littoral stakes subjected to the erosion; need significant communication with the population and concerned users.

Strategic retreat:
if stakes do not justify an intervention (zones where the costs/advantage analysis does not justify a defensive intervention technique), if the stakes are low or if this is the only option to ensure the protection of a population. Natural or developed defence structures can also be considered. There are three types of retreats: 1) moving equipment for beach areas (situated on the front line, they must be relocated inland according to the coastline evolution), 2) evacuation of rarely used public service equipment and 3) evacuation of privately owned property (camping and residential areas, stores). Evacuation can be definitive or can be done with a relocation to backshore territories[33] or if it concerns a definitive evacuation, this can be relocation and urban reorganisation (very difficult to implement).

Advantages:
restoration of natural infrastructures and return to natural functioning of the littoral.

Disadvantages:
complex, expensive and long implementation; need major communication with the population and concerned users.

Limited intervention:
if the stakes require an intervention but are not exposed to a high risk, intervention must take place by using "soft" methods which accompany natural processes of shoreline mobility. This solution is not always practicable as only some environmental conditions lead to considering decelerating shoreline evolution. On natural sites that are visited by the general public, it is essential to have a management plan aiming to mitigate the impact of trampling on weakened sectors (creeping back from cliffs, etc.), and excessive beach cleaning (absence of anchoring for sediments), etc. Communication and educational training can be carried out to inform on erosion phenomena, to limit anthropogenic impacts, to prevent risks, etc.

Advantages:
weak interventions (reversible), conservation of existent natural functionalities, anticipation thanks to follow-up, possibility to manage public visiting, limitation and prevention of risks to people and properties.

Disadvantages:
risks on littoral stakes subjected to erosion.

[33] Backshore territories: movement of the properties to land situated beyond the marine erosion hazard zone.

Maintain the shoreline:
if stakes are significant, these zones should be protected by using "soft" and/or "hard" techniques.

Advantage:
preserve the essential socio-economic stakes.

Disadvantages:
behaviour or reinforcement of artificial littoral, possible erosion on zones close by, regular maintenance and loss of natural functionalities. These disadvantages don't concern replenishing beaches.

These strategies can be combined within an action plan over years or decades and also in space.

> Choosing a method of intervention

The three following phases are realised to define the mode of intervention against coastal erosion.

1/ A list of hazards and stakes which characterize the coast. (chap. III, A, 1, a)
The different studies involve the characterisation of hazard levels (null, weak, medium, strong) of a given area which correspond to the susceptibility of the affected area to earth movement, marine submergence or coastal erosion (marine and eolian). It is also necessary to evaluate the stakes at of being impacted and the vulnerability degree of the concerned zone. Shoreline management also requires a deep understanding of the morphodynamic functioning of the given zone (EUROSION project). This must be based on:

- Preliminary studies on coherent sedimentary units: here we are talking about scheduling long term global interventions by integrating the interactions involved in the coastal processes to the scale adapted to sedimentary cells;
- Integration of the coastal resilience concept;
- Identification of strategic sedimentary reserves (they can be withdrawn without jeopardising the natural balance) as well as management of available sedimentary stocks.

2/ The choice of an option for the littoral can perform a preliminary cost/advantage analysis (CAA). This approach is key for economic assessment. This analysis allows interventions to be streamlined by comparing the expected advantages to expenses, to costs generated and to alternative uses that the ear-marked budgets could have had. The CAA is especially useful to estimate losses or modulate investments and budgets (preservation and restoration of ecosystems). This analysis must take environmental, economic and social aspects into account. It also reports on externalities between uses or activities. In the present case, erosion impacts natural and specific resources on littorals (beaches, dunes, cliffs or marshes) that make up public heritage resources for littoral communities. The implementation of a CAA involves three stages:

- identification and characterisation of all uses, functions and services provided by the ecosystems as well as their contribution to local heritage and legacy;
- evaluation of effects and losses (material or not, positive/advantages or negative/costs) linked to erosion;
- integration of data at the same time as information concerning expenditures following the synthesis protocol specified by the costs/advantages analysis. The objective is to obtain an estimation of the economic profitability rate for the work being carried out. (MEEDDM, 2010)

3/ A multi criterion analysis can be done after cost/benefit analysis. It concerns management mode feasibility and the acceptance of risk. The management mode can be defined by the administrators using acquired knowledge from preceding phases.

Decision-making tree

Generally speaking, specialised companies or contractors must be called upon to choose the solution that is the best adapted to coastal erosion, marine submergence or land movements.

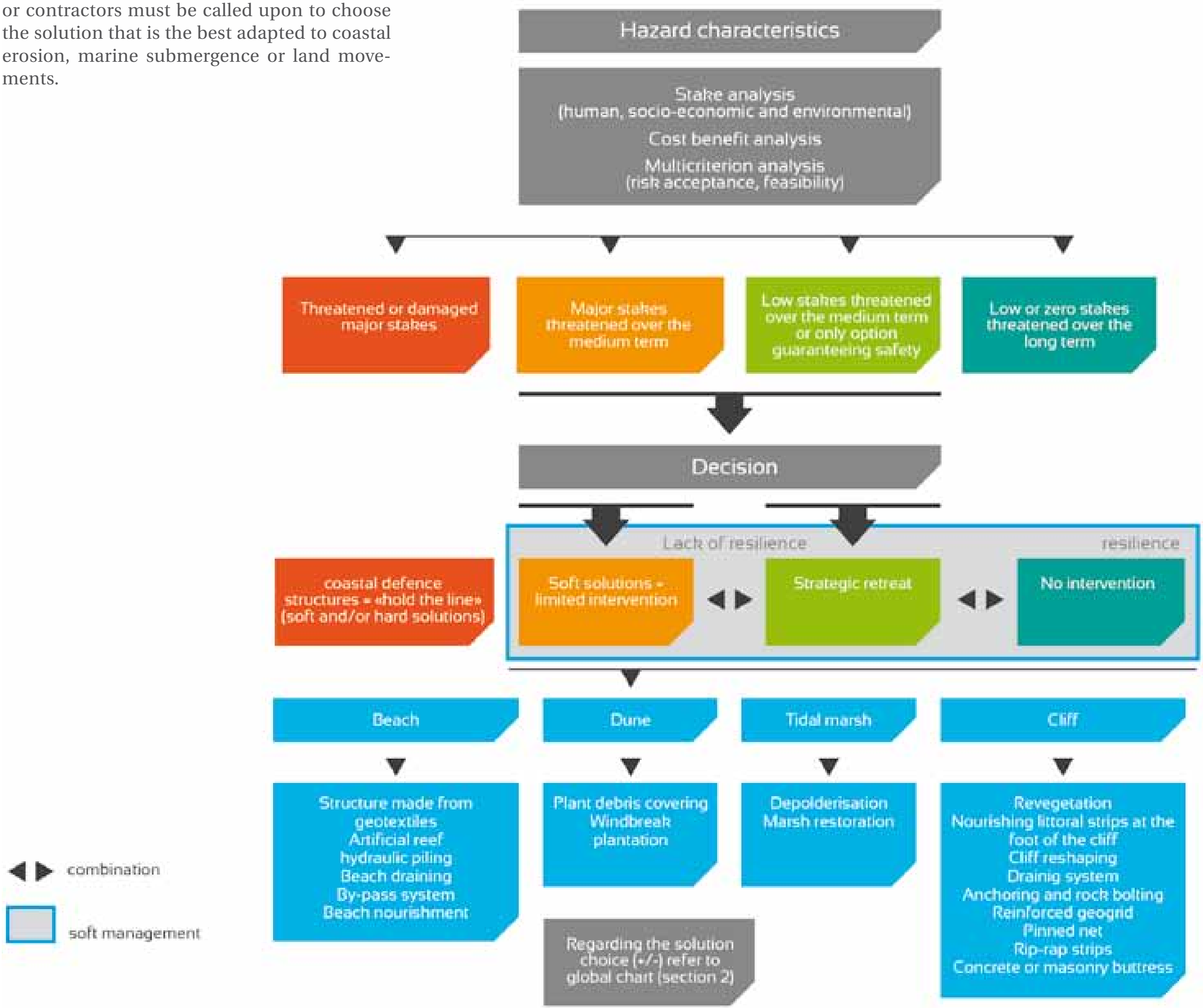


Diagram 19 : Decision-making tree

Conclusion

Coasts provide a lot of services. In some case, coasts are naturally protected by their shape. In addition, the biological diversity leads coasts to provide various natural coastal equipment. However, efforts must be made in order to improve the resilience of littoral spaces by better sedimentary management and by preserving sufficient space for coastal processes. The idea that there is a definitive way to manage erosion must be abandoned; on the contrary a cycle alternating periods of observation and action must be integrated. The only definitive mid-term and long-term action that can be considered remains the strategic retreat from zones threatened by risks of erosion. If there are no important stakes, it is useless to fight against erosion processes. In some cases, these processes can be positive to the ecosystems (ecological functions of wet areas such as marshes, maintaining identity landscapes).

This didactic tool intended for administrators, offers a sample group of solutions and geotechnical methods to limit coastal erosion and advances the importance of «soft» solutions as much as possible, with their advantages and disadvantages. "Soft" solutions are often not definitive and can be combined with "hard" solutions in order to protect threatened stakes in the short term. However, in the long term, it is a mistake to believe that the shoreline can be definitively fixed without significant environmental damage and heavy economic costs.

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