Service contract B4-3301/2001/329175/MAR/B3

"Coastal erosion – Evaluation of the needs for action"

Directorate General Environment

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A guide to coastal erosion management practices in Europe

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TABLE OF CONTENT

INTRODUCTION

This Shoreline Management Guide has been undertaken in the framework of the service contract B4-3301/2001/329175/MAR/B3 “Coastal erosion – Evaluation of the needs for action” signed between the Directorate General Environment of the European Commission and the National Institute of Coastal and Marine Management of the Netherlands (RIKZ).

It aims to provide coastal managers at the European, national and - most of all - regional and municipal levels with a state-of-the-art of coastal erosion management solutions in Europe, based on the review of 60 case studies deemed to be representative of the European coastal diversity. It is however important to mention that this “guide” is not a “manual” of coastal erosion management. The reason for this is threefold:

(i) Such manuals already exist, even though they mostly focus on coastal defence and may therefore suggest that coastal erosion is necessarily a problem to be combated. EUROSION particularly recommends two particular manuals: (i) the *Code of Practice Environmentally Friendly Coastal Protection* (1996) elaborated with the support of the Government of Ireland and the LIFE Programme of the European Commission in the framework of the ECOPRO initiative; and (ii) the *Coastal Engineering Manual* (CEM) published by the United States’ Corps of Engineers in 2001.

(ii) Beyond theoretical principles which may be explained in more or less simple terms to non coastal engineers, coastal erosion management is a highly uncertain task as knowledge about coastal processes is still fragmented and empirical. Trying to summarise such sparse knowledge in a new manual would lead to excessive simplification and would tend to minimize the important role of coastal engineers in the design of tailor-made coastal erosion management solution.

(iii) Finally, the notion of a successful coastal erosion management depends on the objectives assigned to it, which may greatly vary from one site to another according to the local perception of the problem and subsequent expectations. *In that perspective, the reader will probably be astonished to realize that very few of the case studies can be rated as successful.* Drafting another manual would inevitably result in adopting specific point of views – as it is the case for coastal protection manuals – which may not reflect the local expectation and social acceptability of solutions designed.

The approach preferred by the project team was therefore to provide a condensed description of the various case studies reviewed, the physical description of their environment, the known causes of coastal erosion and their current and anticipated impact on social and economical assets, the technical specifications of the solutions proposed as well as their positive and negative results from the perspective of local inhabitants. The review as such do not pass judgement on the success or failure of coastal erosion management solutions implemented. It tries however to highlight which objectives were initially assigned to such solutions and how far such objectives have been reached. *Again, the readers will probably be surprised to see that very few case studies have clearly defined their objectives for coastal erosion management.*

It is assumed that, with such an approach, the coastal manager, specialist or not of coastal engineering, will be in a position to understand the major obstacles he/she may encounter in deciding which coastal erosion management design fits the best his/her area, by tapping into a wide range of European experiences.

The shoreline management guide is composed of the following elements:

- an introduction to the criteria used to select the case studies reviewed during the project and the methodology adopted to collect information on these case studies.

- An extensive summary of the major lessons learned from this review, which also stand for the major elements any coastal manager should keep in mind before undertaking coastal erosion management projects

- An analysis report, organised by regional seas and assessment levels, which is an attempt to compare the various approaches highlighted by the review of the 61 case studies and to find common patterns among them.

- 60 condensed reports related to the cases studies reviewed, organised according to a standard review structure

The shoreline management guide is accessible both in printed copy and on digital format via Internet or – upon request - as a CD-ROM.

Introduction to the cases

60 case studies were chosen for this project to discover common successful strategies to manage effects of erosion. For choosing the cases, eight selection criteria were used. These criteria, listed in table 0-1, have generated a selection of cases with valuable experiences throughout Europe.

Applying these eight criteria ensures an optimized selection of cases throughout Europe, this will be further explained in the following sections of this Introduction to the cases. Table 0-2 at the end of this introduction presents a list with the entire selection of case studies. In the cases various coastal erosion management issues can be recognized. The Eurosion web site (http://www.eurosion.org) works with the same table, besides that a searching tool is available on the web site too.

The physical types
Covering Europe's large coastal diversity was one of the challenges in selecting the cases. By using every different coastal type of a comprehensive coastal typology the selection is made representative. Not only a distinction between coastal types (hard/soft rock or sedimentary coast) is made, but also between formations (e.g. shingle beach, saltmarsh, delta) that exist within these types.

The policy options
In the cases examples of all five generic policy options can be found. The option *Hold the Line* is by far the most used one while *Move Seaward* and *Managed Realignment* is rather seldom found. Some examples of *Do nothing* and *Limited Intervention* can also be found.

Social and economical functions
Functions in the coastal zone vary a lot. In the Mediterranean tourism is one of the most important functions. Also industry, harbours and flood defences are common functions of the coastal zone throughout Europe. The selection of cases represents the existence of many different functions in the coastal zone. The selection of cases does not represent eroding sites with very little interests involved because of the first selection criterion that demands that there has to be an erosion problem.

Governance
The responsibility for protection of the coastal zone can be leading for the choice of a management solution. In selecting the cases, finding examples for responsibilities at national, regional and local level was one of the goals. In some cases, responsibilities could not (yet) be clearly identified. In others, private parties took on responsability for protection against local erosion.

Willingness
Data and information on the case studies often had to be delivered by local contact persons from government, universities and/or private enterprises. Willingness to provide information is a key criterion for selecting sites.

Technical solutions
This guide aims to provide the most up-to-date overview of coastal engineering practices and management solutions in the coastal field. The sites have been carefully selected in including the most innovative solutions.

Geographic distribution
The selection also tried to cover all European countries and regional seas in a well-balanced way.

Methodology of collecting the information

The large diversity within the sites potentially provides a lot of new information whereby valuable comparisons can be made between cases. Consistent methodology was utilized in assessing the information. Since the erosion problem never is merely a technical one, the methodology aims to present the adverse effect of erosion against the physical and socio-economic background of the site. The methodology requires at least four main components:

General description of the area	(coastal type, physical processes, user functions)
Problem description	(why is erosion a problem here?)
Solutions and measures	(what was done to solve the problem?)
Effects and lessons learnt	(did the solution work?)

Limitations

The required information was supplied by different investigators throughout Europe. Some case studies were performed by local coastal managers, others by academics of universities. This explains the variety in exhaustiveness of the information. In gaining information on coastal erosion there are limitations in its interpretation and sometimes consistency, for example, availability of existing documentation, differentiation in monitoring programs and the effect of expert judgment on the analysis of the information. All cases have been reviewed by the consortium. The review guarantees a level of consistency in analysis of the sites. However, for some cases the cause of erosion remains undecided and therefore discussion can still occur. Also, the answer to the question whether erosion is a problem or not still is an issue for personal discretion.

The collected information is available at the Eurosion web site. It would be helpful for coastal managers if new experiences are shared in the same way by updating case studies and providing the web site with new ones. The Eurosion website provides a platform for sharing experiences in managing coastal erosion.

Table 0-1 Selection criteria for case studies

CRITERIA	GOALS FORESEEN
Erosion problem	All selected sites have to face an erosion problem which justifies the needs for action
Physical types	Selected sites have to be representative of the major physical types of coasts, including (i) rocky coasts, (ii) beaches, (iii) muddy coasts, (iv) artificial coasts, and (v) mouths.
Policy options	Selected sites have to be representative of the 5 major policy options available to manage erosion : (i) hold the line, (ii) move seaward, (iii) managed realignment, (iv) limited intervention, (v) do nothing
Social and economical functions	Selected sites have to be representative of the 5 major socio-economical functions of the coastal zones: (i) industry, transport and energy, (ii) tourism and recreation, (iii) urbanisation (safety of resident people and investments), (iv) fisheries and aquaculture (exploitation of renewable natural resources – including aquaculture), (v) nature (conservation) and forestry.
Governance	Selected sites have to highlight respective responsibilities of the different level of administration, namely : (i) the national level, (ii) the regional level, (iii) the local level.
Willingness to participate	Willingness of local stakeholders to provide information is a key criteria for selecting sites
Technical solutions	Selected sites have to be representative of existing shoreline management and coastal defence practices including pioneer and innovative technical solutions
Geographical distribution	Geographically distribution of the selected sites has to cover all the European Union member states.

Figure 0-1 geographical distribution of case studies

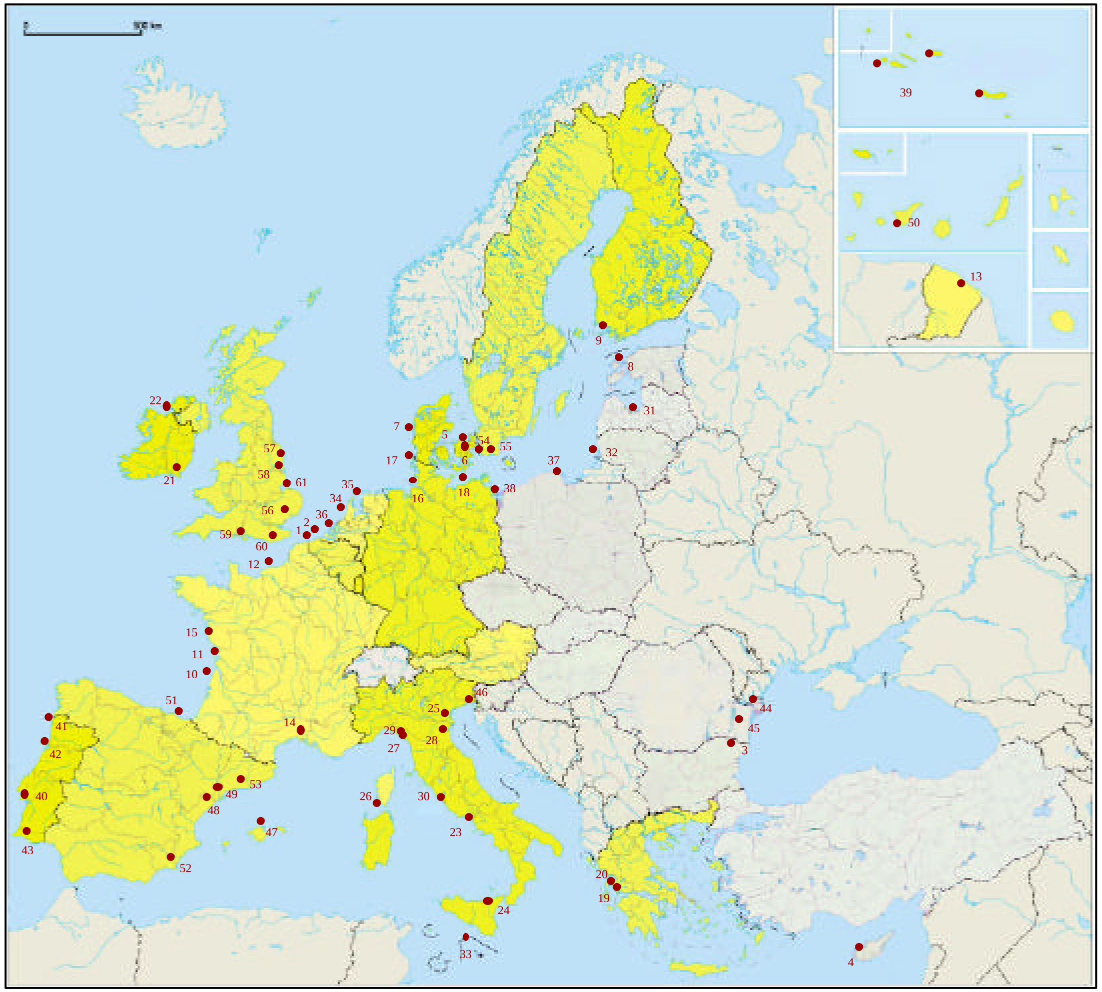


Table 0-2. Overview of the 60 case studies

Number	Country	Case study	Coastal type	Policy	Measure
1.	Belgium	De Haan	Sedimentary macrotidal *(Sandy beaches and dunes)*	Hold the line	Seawall / Nourishment
2.	Belgium	Zeebrugge-Knokke Heist	Sedimentary macrotidal *(Sandy beaches and dunes)*	Hold the line	Seawall / Groynes / Harbour breakwater / Nourishment
3.	Bulgaria	Shabla-Krapetz	Soft Rock Sedimentary microtidal *(Sandy beaches)*	Hold the line / Managed realignment	Seawall / Dyke
4.	Cyprus	Dolos-Kiti	Sedimentary microtidal (Shingle beaches)	Limited intervention / Do nothing	Harbour breakwater / Groynes / Detached breakwater / Revetment
5.	Denmark	Hyllingebjerg-Liseleje	Soft rock Sedimentary microtidal *(Sandy beaches)*	Hold the line	Slope protection / Groynes / Detached breakwater / Nourishment
6.	Denmark	Køge bay	Sedimentary microtidal *(Sandy beaches and dunes)*	Move seaward / Hold the line	Groynes / Dyke / Filter tubes
7.	Denmark	Western coast of Jutland	Sedimentary microtidal *(Sandy beaches and dunes)*	Hold line / Managed realignment / Do nothing / Limited intervention	Groynes / Detached breakwater / Revetment/ Nourishment / Dune protection
8.	Estonia	Tallin	Soft Rock Sedimentary microtidal *(sandy & shingle beaches, narrow vegetated shores, artificial coastline)*	Hold the line / Limited Intervention	Revegetation forestry / Nourishment / Seawall / Slope protection
9.	Finland	Western coast of Finland	Soft Rock Sedimentary microtidal *(sandy & shingle beaches, saltmarsh)*	Do nothing	None
10.	France	Aquitaine coast	Sedimentary macrotidal *(sandy beaches and dunes)*	Hold the line /Limited intervention	Revegetation / Seawall / Revetment / Groynes
11.	France	Chatelaillon	Sedimentary macrotidal	Hold the line / (Move seaward)	Seawall / Groynes (past) Nourishment

Number	Country	Case study	Coastal type	Policy	Measure
			(sandy beach)		
12.	France	Haute-Normandie	Soft Rock Sedimentary macrotidal *(shingle beaches)*	Do Nothing / Hold the line / Managed realignment	Groynes / Nourishment
13.	France	Rémire–Montjoly (French Guyana)	Hard Rock Sedimentary macrotidal *(sandy beaches)*	Do nothing (Limited intervention-future)	Future: Breakwater / Nourishment
14.	France	Rhône delta	Sedimentary microtidal *(delta, sandy beaches and dunes)*	Hold the line / Do Nothing / Limited intervention	Groynes / Seawall / Breakwater / Revetment / Nourishment / Wind trap Sand ripping
15.	France	Sables d'Olonne	Hard Rock Sedimentary macrotidal *(sandy beaches and dunes)*	Hold the line	Seawall / Beach drainage
16.	Germany	Elbe estuary	Sedimentary macrotidal *(estuary, saltmarsh)*	Hold the line	Dyke / Revetment / Saltmarsh creation / Polder / Groynes / Saltmarsh Drainage
17.	Germany	Isle of Sylt (Isles Schleswig-Holstein)	Soft Rock Sedimentary macrotidal *(sandy beaches and dunes)*	Hold the line / Managed realignment	Revetment / Seawall / Rif Enhancement / Groynes / Nourishment
18.	Germany	Rostock	Soft Rock Sedimentary microtidal *(sandy beaches and dunes)*	Hold the line / Limited intervention	Groynes / Revetment / Seawall / Revegetation / Nourishment
19.	Greece	Lakkopetra	Sedimentary microtidal *(sandy beaches)*	Limited intervention	Detached breakwater
20.	Greece	Mesollogi lagoon area	Sedimentary microtidal *(sandy beaches and dunes, saltmarsh)*	Hold the line	Groynes
21.	Ireland	Rosslare	Soft Rock Sedimentary macrotidal *(sandy beaches and dunes)*	Hold the line	Groynes / Revetment / Nourishment
22.	Ireland	Rossnowlagh	Soft Rock Sedimentary macrotidal	None (Locally Hold the line)	Revetment (Future: dune nourishment)

Number	Country	Case study	Coastal type	Policy	Measure
			(sandy beaches and dunes)		
23.	Italy	Cirqaccio-Ciracciello (Isle of Procida)	Soft Rock Sedimentary microtidal *(sandy beach)*	Hold the line	Beach drainage / Breakwater
24.	Italy	Giardini-Naxos (Isle of Sicily)	Hard Rock Sedimentary microtidal *(sandy beach)*	Hold the line	Groynes / Seawall / Detached breakwater / Nourishment
25.	Italy	Goro mouth- Po delta	Sedimentary microtidal *(delta, sandy beaches and dunes)*	Limited intervention / Hold the line	Nourishment / Groynes / Revetment / Dune rebuilding
26.	Italy	Lu Littaroni - La Liccia (Isle of Sardinia)	Hard Rock Sedimentary microtidal *(sandy beaches and dunes)*	Do nothing	None
27.	Italy	Marina di Massa - Marina di Pisa	Sedimentary microtidal *(sandy beaches, artificial coastline)*	Hold the line	Seawall / Groynes / Detached breakw ater / Submerged breakwater / Nourishment
28.	Italy	Marina di Ravenna-Lido Adriano	Sedimentary microtidal *(sandy beaches and dunes)*	Hold the line	Seawall / Submerged breakwater / Detached breakwater / Groynes / Jetty / Nourishment
29.	Italy	Marinella di Sarzana	Sedimentary microtidal *(sandy beaches)*	Hold the line	Groynes / Detached breakwater / Jetty / Artificial island / Nourishment
30.	Italy	Vecchia Pineta	Sedimentary microtidal *(sandy beaches and dunes)*	Hold the line	Submerged breakwater / Nourishment / Beach Drainage
31.	Latvia	Gulf of Riga	Sedimentary microtidal *(delta, sandy beaches and dunes, narrow vegetated shores)*	Limited intervention / Hold the line	Forest plantation / Seawall / Revetment / Nourishment
32.	Lithuania	Klaipeda	Soft Rock Sedimentary microtidal *(sandy beaches and dunes, narrow vegetated shores)*	Limited intervention	Forest plantation / Nourishment
33.	Malta	Xemxija	Soft Rock	Do nothing /	Revegetation

Number	Country	Case study	Coastal type	Policy	Measure
		Ghajn Tuffieha	Sedimentary microtidal *(sandy beaches)*	Limited intervention	
34.	The Netherlands	Holland coast	Sedimentary macrotidal *(sandy beaches and dunes)*	Hold the line	Nourishment / Groynes
35.	The Netherlands	Wadden Sea islands	Sedimentary macrotidal *(sandy beaches and dunes)*	Limited intervention / Hold the line / Do nothing	Groynes / Revetment / Nourishment / Cross-shore dam
36.	The Netherlands	Western Scheldt estuary	Sedimentary macrotidal *(estuary, saltmarsh)*	Hold the line / Move seaward	Nourishment / Revetment / Groyne / Pier protection
37.	Poland	Hel peninsula	Soft Rock Sedimentary microtidal *(sandy beaches and dunes)*	Hold the line	Groynes / Seawall / Nourishment
38.	Poland	Western Coast of Poland	Soft Rock Sedimentary microtidal *(sandy beaches and dunes)*	Hold the line / Do nothing	Seawall / Groynes / Nourishment / Revegetation
39.	Portugal	Azores (Azores Islands)	Hard Rock	Hold the line	Harbours / Marinas / Slope stabilisation
40.	Portugal	Cova do Vapor	Soft Rock Sedimentary macrotidal *(sandy beaches and dunes)*	Hold the line	Nourishment / Groynes / Seawall
41.	Portugal	Estela	Sedimentary macrotidal *(sandy beaches and dunes)*	Limited intervention	Dune nourishment / Sand ripping / Wind trap / Sand bags
42.	Portugal	Vagueira-Mira	Sedimentary macrotidal *(sandy beaches and dunes)*	Hold the line / Managed realignment	Groynes / Jetty / Nourishment
43.	Portugal	Vale do Lobo	Soft Rock Sedimentary macrotidal *(sandy beaches and dunes)*	Hold the line	Revetment / Nourishment
44.	Romania	Danube delta	Sedimentary microtidal *(delta, sandy beaches and dunes)*	(Hold the line) Do Nothing	Jetty / Groynes / Nourishment

Number	Country	Case study	Coastal type	Policy	Measure
45.	Romania	Mamaia	Sedimentary microtidal *(sandy beaches and dunes)*	Limited intervention / Hold the line	Detached breakwater / Nourishment
46.	Slovenia	Slovenian coast	Hard Rock Soft Rock Sedimentary microtidal *(shingle beaches, saltmarshes, artificial coastline)*	Hold the line / Limited intervention / Move seaward	Seawall / Submerged breakwater / Dyke
47.	Spain	Can Picafort (Isle of Mallorca)	Sedimentary microtidal *(sandy beaches and dunes)*	Limited intervention	Nourishment
48.	Spain	Castellón	Sedimentary microtidal *(sandy & shingle beaches, dunes)*	Hold the line	Groynes / Detached breakwater / Nourishment
49.	Spain	Ebro delta	Sedimentary microtidal *(delta, sandy beaches and dunes)*	Limited intervention / Hold the line / (Managed relignment)	Dune nourishment / Wind traps / Revegetation / Beach Drainage
50.	Spain	El Médano (Canary Islands)	Sedimentary macrotidal *(sandy beaches and dunes, narrow vegetated shores)*	Do nothing / Limited intervention	Dune nourishment / Revegetation
51.	Spain	Gross	Hard Rock Sedimentary macrotidal *(sandy beaches)*	Hold the line	Jetty / Nourishment
52.	Spain	Mar Menor	Sedimentary microtidal *(sandy beaches and dunes)*	Hold the line / Limited intervention	Groynes / Nourishment
53.	Spain	Sitges	Hard Rock Sedimentary microtidal *(sandy beaches)*	Hold the line	Groynes / Detached breakwater / Seawall / Artificial island / Nourishment
54.	Sweden	Falsterbo peninsula	Sedimentary microtidal *(sandy beaches and dunes)*	Do nothing	Seawall / Groynes(Future: revegetation / nourishment)
55.	Sweden	Ystad	Sedimentary microtidal *(sandy beaches and dunes)*	Hold the line	Groynes / Seawall / Dune plantation / Geotextile

Number	Country	Case study	Coastal type	Policy	Measure
56.	United Kingdom	Essex estuaries	Sedimentary macrotidal *(estuary, saltmarsh, shingle beaches)*	Hold the line / Managed realignment / Do nothing	Seawall / Revetments / Embankment / Groynes / Polder / Nourishment
57.	United Kingdom	Holderness coast	Soft Rock Sedimentary macrotidal *(sandy and shingle beaches)*	Hold the line / Do nothing	Groynes / Seawall / Revetment
58.	United Kingdom	Humber estuary	Sedimentary macrotidal *(estuary, saltmarsh)*	Hold the line / (Managed realignment)	Embankment / Revetment / Seawall / Tidal flat recreation
59.	United Kingdom	Luccombe-Blackgang (Isle of Wight)	Soft Rock Sedimentary macrotidal *(shingle beaches)*	Managed realignment / Hold the line / Do nothing	Seawall / Revetment / Groynes / Nourishment / Slope stabilisation
60.	United Kingdom	South Downs (Sussex)	Soft Rock Sedimentary macrotidal *(shingle beaches)*	Hold the line / Managed realignment	Seawall / Groynes / Nourishment

SECTION 1
LESSONS LEARNED FROM THE CASE STUDIES

Lesson 1

Human influence, particularly urbanisation and economic activities, in the coastal zone has turned coastal erosion from a natural phenomenon into a problem of growing intensity. Adverse impacts of coastal erosion most frequently encountered in Europe can be grouped in four categories: (i) coastal flooding as a result of complete dune erosion, (ii) destruction of assets located on retreating cliffs, beaches and dunes (iii) undermining of sea defence associated to foreshore erosion and coastal squeeze, and (iv) loss of lands of economical and ecological values.

Coastal erosion is a natural phenomenon, which has always existed and has contributed throughout history to shape European coastal landscapes. Coastal erosion, as well as soil erosion in water catchments, is the main processes which provides terrestrial sediment to the coastal systems including beaches, dunes, reefs, mud flats, and marshes. In turn, coastal systems provide a wide range of functions including absorption of wave energies, nesting and hatching of fauna, protection of fresh water, or siting for recreational activities. However, migration of human population towards the coast, together with its ever growing interference in the coastal zone has also turned coastal erosion into a problem of growing intensity. Among the problems most commonly encountered in Europe are:

- the destruction of the dune system as a result of a single storm event, which in turn results in flooding of the hinterland. This is best illustrated by the cases of Holland Coast, Western Scheldt, Wadden Sea, Rosslare, Hel peninsula, Sylt, Camargue, Vagueira, and Castellon.

- the collapse of properties located on the top of cliffs and dunes as documented in the cases of South Down, Luccombe, Normandy, Hyllingebjerg – Liseleje, Castellon, Vale do Lobo, and Estela

- the undermining of sea flooding defences as a result of foreshore lowering such as in Knokke-Zoute, Humber Estuary, Ystad, Chatelaillon, Sable d'Olonne, Donegal, or coastal marsh squeeze such in Elbe and Essex

- the loss of lands with economical value such as the beaches of De Haan, Sylt, Mamaia, Vecchia Pineta, Giardini Naxos, Sable d'Olonnes, and Ghajn Tuffieha, the farming lands of Essex or with ecological value such as the Scharhoern Island along the Elbe estuary.

To a lesser extent, the decrease of the fresh water lens associated to the retreat in the dune massifs, which in turn result in salt water intrusion could be mentioned but this phenomenon has been only evoked but not fairly documented in the cases reviewed by the project. It is therefore assumed that this particular problem remains marginal in Europe.

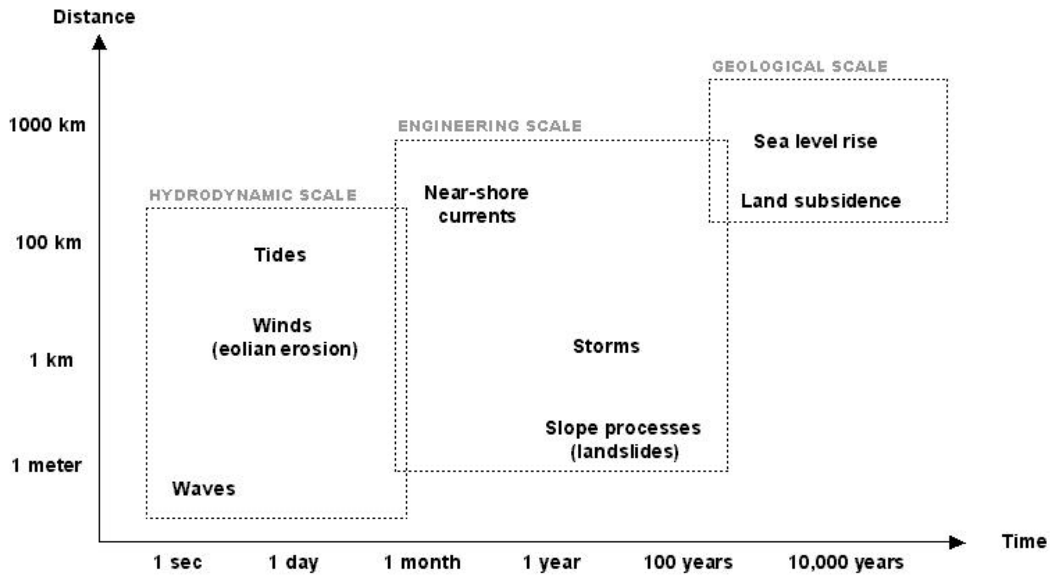
Coastal erosion results from a combination of various factors – both natural and human-induced – which has different time and space patterns and have different nature (continuous or incidental, reversible or non-reversible). In addition, uncertainties still remain about the interactions of the forcing agents, as well as on the significance of non-local causes of erosion.

This is highly confirmed by the totality of the cases reviewed. The various coastal types, as was demonstrated in the introduction to the cases, determine the difference in resistence against erosion. While hard rock coasts hardly erode, soft cliffs and sedimentary coast are much less resilient. Subsequently, various natural factors - acting on different time and spatial scales - reshape the geologically formed coastal morphology. Furthermore human-induced factors are present in many cases and they operate on the morphological development of the coastal area as well. In addition, the dominant cause of coastal erosion may stay "hidden" for decades if not centuries before scientist finally evoke it and quantify its amplitude. This often corresponds to causes whose effects are hardly noticeable on the short term but after decades, and causes which are non-local. River damming belongs to this category and evidence of its impact to erosion processes have been lately evoked and in a fewer number of cases, quantified and demonstrated. It is important to mention that this question of erosion induced by river damming is still subject to polemics or contradictory expertise as in the case of Tagus (Cova do Vapor), Douro (Vagueira) (Portugal), Rhone delta (France) or Messologi (Greece). In some other cases, such as Ebro (Spain), dam-induced sediment deficit has been well documented.

Figures 1-1 and 1-2 respectively summarise natural factors and human-induced factors responsible for coastal erosion and highlight the time and space patterns within which these factors operate.

Figure 1-1. Time and space patterns of natural factors of coastal erosion

Note that "distance" has to be understood as the geographical extent within which the factor action takes place or take place with a relatively stable intensity. "Time" reflects the temporal extent within which the factor occurs and causes erosion.



The natural factors include:

Waves. Waves are generated by offshore and near-shore winds, which blow over the sea surface and transfer their energy to the water surface. As they move towards the shore, waves break and the turbulent energy released stirs up and moves the sediments deposited on the seabed. The wave energy is a function of the wave heights and the wave periods. As such the breaking wave is the mechanical cause of coastal erosion in most of cases reviewed and in particular on open straight coasts such as those of Sussex, Ventnor, Aquitaine, Chatelaillon, Holland, Vagueira, Copa do Vapor, Estella, Valle do Lobo, Petite Camargue, Marina di Massa, Giardini Naxos, Ystad, or Rostock.

Winds. Winds acts not just as a generator of waves but also as a factor of the landwards move of dunes (Aeolian erosion). This is particularly visible along some sandy coasts of those Aquitaine, Chatelaillon, Rosslare, and Holland.

Tides. Tides results in water elevation to the attraction of water masses by the moon and the sun. During high tides, the energy of the breaking waves is released higher on the foreshore or the cliff base (cliff undercutting). Macro-tidal coasts (i.e. coasts along which the tidal range exceeds 4 meters), all along the Atlantic sea (e.g. Vale do Lobo in Portugal), are the more sensitive to tide-induced water elevation than mesa- or micro-tidal coasts (i.e. tidal range below 1 meter).

Near-shore currents. Sediments scoured from the seabed are transported away from their original location by currents. In turn the transport of (coarse) sediments defines the boundary of coastal sediment cells, i.e. relatively self-contained system within which (coarse) sediments stay. Currents are generated by the action of tides (ebb and flood currents), waves breaking at an oblique angle with the shore (long-shore currents), and the backwash of waves on the foreshore (rip currents). All these currents contribute to coastal erosion processes in Europe. By way of illustration, long-shore drift (transport) is responsible of removing outstanding volumes of sand in Vale do Lobo, Estela beach, Aquitaine, De Haan, Zeebrugge, Sylt or Jutland. Erosion induced by cross-shore sediment transport is best illustrated with the cases of Sable d'Olonne or Donegal. As for tidal currents, their impact on sediment transport is maximal at the inlets of tidal basins or within estuaries such as in the cases of the Wadden Sea, the Arcachon basin, the Western Scheldt and the Essex estuaries. In some places, near-shore currents, and associated sediment cells, follow complex pathways as epitomised by the cases of Estela or Rosslare, or Falsterbo.

Storms. Storms result from raised water levels (known as storm surge) and highly energetic waves induced by extreme winds. Combined with high tides, storms may result in catastrophic damages such as along the North Sea in 1953. Beside damages to coastal infrastructure, storms cause beaches and dunes to retreat of tenths of meters in a few hours, or may considerably undermine cliff stability. In the past 30 years, a significant number of cases have reported extreme historical storm events that severely damaged the coast. Illustrative examples include De Haan and Holland (storm of 1976), Chatelaillon (1962, 1972, 1999), Cova do Vapo and Estela (2000), Normandy (1978, 1984, 1988, 1990), and Donegal (1999).

Sea level rise. The profile of sedimentary coasts can be modelled as a parabolic function of the sediment size, the sea level, the wave heights and periods, and the tidal range. When the sea level rises, the whole parabola has to rise with it, which means that extra sand is needed to build up the profile. This sand is taken from the coast (Bruun rule). Though more severe in sheltered muddy areas (e.g. Essex estuaries), this phenomenon has been reported as a significant factor of coastal erosion in all regional seas: Atlantic Sea (e.g. Donegal, Rosslare), Mediterranean Sea (e.g. Petite Camargue, Messologi, Lakkopetra), North Sea (e.g. Holland coast), Baltic Sea (e.g. Gulf of Riga), and Black Sea.

Slope processes. The term “slope processes” encompasses a wide range of land-sea interactions which eventually result in the collapse, slippage, or topple of coastal cliff blocks. These processes involve on the one hand terrestrial processes such as rainfall and water seepage and soil weathering (including alternating freeze/thaw periods), and on the other hand the undercutting of cliff base by waves. The cases of Luccombe, Birling Gap, Criel-sur-Mer (Normandy), Sylt, Cova do Vapor, Vale do Lobo are particularly relevant in that respect.

Vertical land movements. Vertical land movement – including isostatic rebound, tectonic movement, or sediment settlement – may have either a positive of negative impact on coastline evolution. If most of northern Europe has benefited in the past from a land uplift (e.g. Baltic sea, Ireland, Northern UK), this trend has stopped (with exception of the coast of Finland), such as in Donegal and Rosslare, and even reversed (e.g. Humber estuary). Along these coasts, the sea level induced by climate change rises faster than the sea, which results in a positive relative sea level rise.

Human induced factors

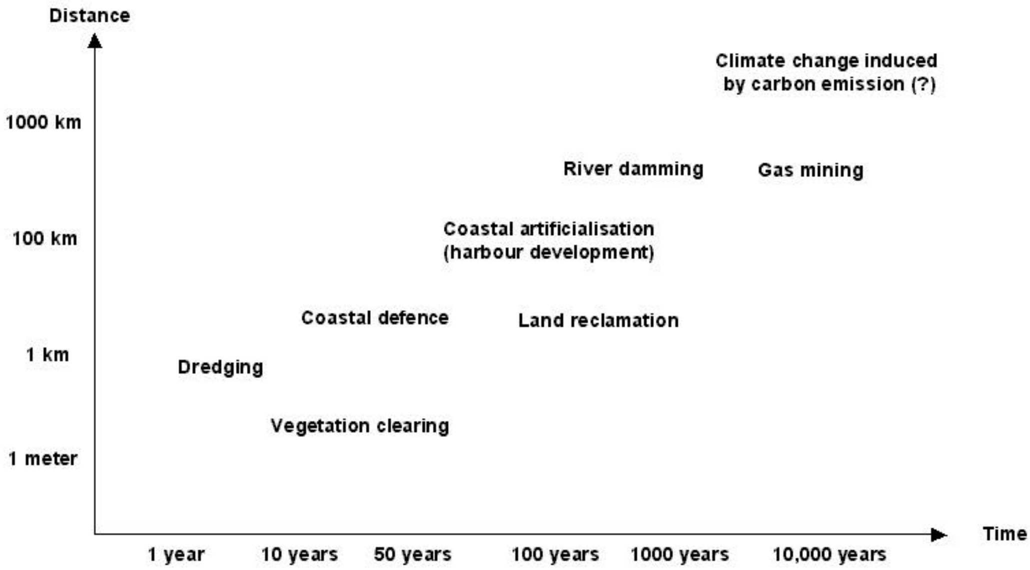
Coastal artificialisation including hard coastal defence. Coastal artificialisation may be defined as the engineering of the waterfront by way of seawalls, dykes, breakwaters, jetties, or any hard and rock-armoured structures, which aims at protecting the construction or other assets landwards the coastline from the assault of the sea. Such structures modify coastal sediment transport patterns through 3 major processes:

(i) trapping of sediment transported alongshore and a sediment deficit downdrift due to the fact that contrary to “natural” coastlines, hard structures do not provide sediment for the alongshore drift. Mainly by *harbour and marina protection structures* such as those of Brighton - Sussex (United Kingdom), Aveiro - Vagueira case and Vilamora - Vale do Lobo (Portugal), Rosslare (Ireland), IJmuiden - Holland case (Netherlands), Zeebrugge (Belgium), Skanor – Falsterbo (Sweden), Messina (Italy) or by *groines* such as those of Ystad (Sweden), Jutland (Denmark), Quarteira - Vale do Lobo, Vagueira, Estela (Portugal), Marina di Massa (Italy), and Hel Peninsula (Poland).

(ii) Incoming wave reflection by hard structures that hampers energy dissipation and augments turbulence resulting in increased cross-shore erosion. This phenomenon has been paradoxically boosted along those coastal stretches where seawalls have been built precisely to counteract coastal erosion, and is best illustrated by the cases of Chatelaillon and Sable d’Olonne (France).

(iii) Wave diffraction, which is the alteration of the wave crest direction due to the vicinity of seaward structures (such as jetties or breakwaters). This alteration results in wave energy to be either diluted in some places (less impact on the coastline) or concentrated in some other places (more impact on the coastline and subsequent erosion). Note that in the case of Playa Gross (spain), wave diffraction induced by a semicircular breakwater is on the contrary used as part of the coastal erosion management solution.

Figure 1-2. time and space patterns of human induced factors of coastal erosion.



Land reclamation. The impact of land reclamation projects undertaken in the 19th and first half of the 20th century on coastal erosion has become obvious only for a few decades. Within tidal basins or bays (where land reclamation projects are most easy to undertake), land reclamation results in a reduction of the tidal volume and therefore a change in the ebb and flood currents transporting sediments. As a result, relatively stable coastal stretches may begin to erode. Land reclamation projects undertaken in Rosslare (Ireland) (in 1845 and 1855) or the Western Scheldt (Netherlands) provide quite illustrative example of this phenomenon. For land reclamation projects undertaken along open coasts, such as the Maasvlakte project along the Holland coast (Netherlands), changes in coastal processes do not occur as a result of tidal volume reduction but as a result of changes in the coastline geometry and breaking angles.

River water regulation works. Such as for land reclamation, the impact of water flow regulation works on coastal processes has been highlighted only recently probably such impacts become visible after several decades. Damming has intensively sealed water catchments locking up millions of cubic metres of sediments per year. For some southern European rivers (e.g. Ebro, Douro, Urumea, Rhone), the annual volume of sediment discharge represents less than 10% of their level of 1950 (less than 5% for the Ebro) resulting in a considerable sediment deficit at the river mouth, and subsequent erosion in the sediment cell as illustrated by the cases of Ebro delta, Playa Gross (Spain), Petite Camargue - Rhone delta (France) and Vagueira (Portugal). Besides river damming, any activity which result in reducing the water flow or prevent river flooding (as a major generator of sediments in the water system) is expected to reduce the volume of sediments reaching the coast. This is best illustrated by the case of the Tagus which impact can still be felt at Cova do Vapor (Portugal).

Dredging. Dredging activities have intensified in the past 20 years for navigational purposes (the need to keep the shipping routes at an appropriate water depth), construction purposes (an increasing amount of construction aggregates comes from the seabed), and since the 1990's for beach and underwater nourishment. Dredging may affect coastal processes by a variety of way:

(i) by removing from the foreshore materials (stones, pebbles), which protect the coast against erosion. For instance, stone fishing in Hyllingebjerg-Liseleje (Denmark) triggered structural erosion. By way of illustration, it is estimated that 50% of the total volume of the protective pebbles (3 millions cubic meters) has been extracted from the chalk cliff of Normandy (France) since the early 1900's.

(ii) by contributing to the sediment deficit in the coastal sediment cell, such as in the Humber estuary, the coast of Sussex (United Kingdom) for construction purpose (extraction of sand, gravel and shingle), the Western Scheldt (Netherlands) for navigational purposes, Cova do Vapor (Portugal) where sand has been dredged off the coast to supply materials for the beaches of Costa del Sol, or Marinell di Sarzana and Marina di Ravenna – Lido Adriano (Italy) where dredging from river beds took place

(iii) By modifying the water depth, which in turn result in wave refraction and change of alongshore drift, as illustrated by the Wadden Sea (Netherlands).

Vegetation clearing. A significant number of cases have highlighted the positive role of vegetation to increase the resistance to erosion - e.g. Aquitaine (France) and the Baltic States: Gulf of Riga (Latvia), Klaipeda (Lithuania), Tallinn (Estonia). With the same idea, changes of land use and land cover patterns, which tend to reduce the vegetation cover on the top of cliffs may increase infiltration of water and undermine the cliff stability. This is best illustrated by the examples of the golf courses of Estela and Vale do Lobo (Portugal).

Gas mining or water extraction. A few examples illustrate the effect of gas mining or water extraction on land subsidence (Wadden Sea - Netherlands). Altough this phenomenon seems to have a limited geographical scope in Europe, its effects are irreversible and can be quite significant. In Marina di Ravenna – Lido Adriano (Italy) the land subsides nearly a meter over last 50 years, causing a major sediment deficit and a strong retreat of the coastline.

Ship-induced waves. This case is evoked in the case study related to the Gulf of Riga (Latvia).

Lesson 3

Coastal erosion induced by human activities have surpassed in Europe coastal erosion driven by natural factors. Human-induced coastal erosion mainly proceeds from the cumulative and indirect impacts of small and medium size projects, as well as from river damming. However, little attention is being paid to these impacts by project developers, Environmental Impact Assessment (EIA) practitioners and competent authorities.

With the exception of harbour authorities, geo-morphological changes along the coast are not being paid the attention they should deserve by the promoters of projects impacting coastal processes. The poor number of Environmental Impact Assessment (EIA) reports that address coastal sediment processes as a serious environmental impact largely reflects this. It has to be mentioned however that EIA reports are still very difficult to obtain even after the administrative authorities in charge of project consent have approved them. The opinion expressed here is therefore mainly based on EIA reports which could be only be retrieved a few number of case studies reviewed by EUROSION, as well as on discussions with some members of EUROSION

Advisory Board. EIA reports retrieved concerned the Maasvlakte extension (Holland coast - Netherlands), the annual dredging programmes of the Western Scheldt estuary (Netherlands), the Aveiro harbour extension (Aveiro - Portugal), the energy production plant of Penly (Normandy - France), the German offshore wind farms located east of the Wadden Sea, and the seafront rehabilitation scheme of Marina di Massa and Marina di Pisa (Tuscany - Italy).

The relatively poor integration of coastal sediment transport and induced morphological changes in EIA procedures may be explained by the fact that, except in the case of major projects such as the extension of big harbours, coastal erosion cannot be attributed directly to one single coastal development project (see *lesson 2*). Impact of small and medium size projects are instead cumulative with the impact of other developments, which tends to dilute the responsibility of each individual project for coastal erosion. This is confirmed by the few number of small and medium-size projects along the coast, which are required to conduct an EIA by the competent authorities during the "screening" phase (less than 10% of the total number of projects along the Holland coast). Even in those cases where an EIA is required, impact on coastal sediment processes may not be retained during the "scoping" phase as part of the environmental concerns to be covered by the EIA. Table 1 provides a brief overview of how coastal erosion coverage is currently taken into consideration by various types of developments.

Table 1-1. Coastal erosion within EIA procedures

Type of projects	*Impact on coastal erosion*	*Covered by EIA?*
Harbour infrastructure and activities (including navigational dredging)	High	Yes
River water regulation works (mainly dams)	High	No
Seafront construction	Moderate	No
Land reclamation near-shore or offshore (e.g. wind farm)	Moderate	Partially
Aggregate extraction (dredging) for construction and nourishment purposes	Moderate	Yes
Gas mining (relative sea level rise induced by land subsidence)	Low to moderate	No
Maritime navigation (ship -induced waves)	Low	No

The lack of consideration for coastal sediment transport processes in EIA procedures is undeniably emphasised by the poor level of sensitisation of project developers and EIA practitioners. Denial or underestimation of the impacts of human interference in the coastal zone, which possibly intensify the coastal erosion problems, results in a less effective approach.

A number of EUROSION advisory board members have recommended that existing EIA guidelines edited by the European Commission – and more specifically those dealing with indirect and cumulative impact assessments – provide a higher visibility and a practical understanding of coastal sediment transport processes.

Knowledge on the forcing agents of coastal erosion and their interaction tends to increase over time. However, this knowledge is fragmented and empirical as reflected by the many models commonly used throughout Europe to anticipate coastal morphological changes.

Since the 1950's, major efforts have been undertaken to understand the behaviour of coastal systems and highlight the interactions between waves, wind, tides, foreshore profile, sediment transport and finally coastline evolution. These efforts have led to the development of models, which are now commonly used in coastal engineering design.

Annex 1 provides an overview of models of coastal processes applied in the framework of cases studies reviewed by EUROSION or mentioned in their associated bibliography. This overview clearly shows that the understanding of coastal processes is still largely fragmented and empirical. As a result of this fragmentation, different theories building upon different concepts, assumptions and approaches have been developed since the 1950's and have resulted in different models more or less compatible. This multiplicity of models can be explained by the complexity of the phenomena involved in coastal morphological changes and their interactions, which remain largely unexplained. Because of their relevance for coastal erosion management, a particular attention was paid during the review to models simulating:

- elevation of water level induced by wind stress
- near-shore wave transformation including shoaling, refraction, reflection, diffraction
- response of dune profile to storms
- response of beach profile to sea level rise
- wave-foreshore interactions including wave breaking, run-up and overtopping
- sediment transport including alongshore and cross-shore transport of sand, mud and sand/mud mixture

The agents forcing the above mentioned phenomena – coastline geometry, wave heights and periods, wind speed and direction, astronomic tides, currents velocity, water depth, sea bottom roughness, bathymetry, foreshore profile and sediment size – are common to a majority of models, but the way these agents are combined varies from one model to another. In practice, a significant number of simple empirical and semi-empirical models (e.g. the Bruun rule or the CERC equation) are being developed with acceptable results for a limited number of situations (e.g. for open straight coasts, mild slope shoreline, estuaries, negligible diffraction and reflection phenomenon, etc.); the same models present however major limitations which make their use to other situations unacceptable. On the other side, robust theories such as the Bijker transport theory (1971) exist and cover a wider range of situations but require considerable fields measurements and computation resources.

The operational consequence of this broad range of models is that coastal engineers never really know in advance which model will fit into their specific situation. In general further improvements are needed to existing models in order to really stick to the conditions prevailing in a specific case studies. This is the case for example with the ESTMORF model specifically developed for simulating morphological changes in the Western Scheldt estuary (Netherlands). Lessons learnt from the case studies reviewed within EUROSION also shows that replicability of existing models may be hazardous, since the coastline response to engineered mitigation solutions may not be conform to model predictions. This is epitomised by the case of Rosslare (Ireland) where the coastline unexpectedly responded to a massive beach nourishment scheme via the formation of an offshore sand bar, or the case of Playa Gross (Spain) where the observed beach response to the wave and tide regime overrides model predictions under certain weather conditions.

Lesson 5

Past measures to manage coastal erosion have generally been designed from a local perspective: they have ignored the influence of non-local forcing agents and have disregarded the sediment transport processes within the larger coastal system. As a consequence, they have locally aggravated coastal erosion problems, and have triggered new erosion problems in other places. They still influence the design of present measures.

Historically, many hard constructions were built to stop local erosion in order to protect the assets at risk. Although an effective solution on the short term, their longer-term effectiveness was mostly unsatisfactory. In front of many seawalls, boulevards and revetments, the beach eroded as a result of wave reflection. This destabilized the constructions. Maintenance appeared to be costly and some of the constructions proved to be unequal to the powerful natural processes and broke down. This urged costly reconstructions or the building of new (additional) constructions. In other cases the building of groins and breakwaters resulted in a shift of the erosion to neighbouring areas and urged the need for further protection of the assets at risk. This resulted in a *domino effect* of hard constructions, for example in Hel Peninsula (Poland) where in time a complete groin field was created over a distance of 12 km. In many cases the groins did not prevent erosion on the long run. Nowadays, some coastal defence structures inherited from past management strategies are still "active" as the seawalls of Playa Gross (Spain, built in 1900), Chatelaillon (France, 1925), De Haan (Belgium, 1930), or the vegetated dunes of Western Jutland (Denmark) stabilized in the 1900's, and they keep on interacting – positively or negatively - with sediment processes. The traditional local perspective of coastal erosion management is illustrated by the poor number of Environmental Impact Assessment (EIA) reports that address coastal sediment processes as a serious environmental impact (*lesson 3*).

An exception to the picture described above can be found in some of the cases. A nice example is Marinella di Sarzana (Italy), where neighbouring communities successfully cooperated on a combined river and coastal zone management, resulting in an integrated project proposal, which is evaluated through the Environmental Impact Assessment procedures.

Lesson 6

As an attempt to better respond locally to non-local causes of coastal erosion and to anticipate the impact of erosion management measures, a number of cases mainly in Northern Europe have built their coastal erosion management strategies upon the concept of "sediment cell" as well as on a better understanding of sediment transport patterns within this sediment cell. Such approaches require a strong cooperation between regions which share a same sediment cell.

In understanding the causes and extent of coastal erosion, the introduction of the concept of the "coastal sediment cell" undeniably constitutes a major breakthrough, as it helps to delimit the geographical boundaries of investigations for erosion causes and impact of erosion mitigation measures (e.g. Normandy, Vagueira, Essex, Isle of Wight, Holland coast, Wadden sea). A coastal sediment cell can be defined as a length of coastline and associated near-shore areas where movement of sediments is largely self contained. In practice, this means that measures taken within a specific sediment cell may have an impact of other sections of the same sediment cell but will not impact adjacent cells.

From the "coastal sediment cell" perspective, a loss of sediment is less favourable than redistribution within the coastal system. Less sediment within the system restricts the ability of the coastline to adapt to changing circumstances. Furthermore, hard constructions like harbour-moles or breakwaters block (some part of) the natural sediment transport. Some amount of sediment is "imprisoned" by the constructions and is not freely available in the natural process. The same effects occur when stabilizing cliffs (eg. Sussex) , preventing the natural input of sediments from cliff erosion. Therefore, fixing of sediments (due to hard constructions) is less favourable than using measures that disturb the natural processes to a lesser extent or measures which even make use of the natural processes, for example beach- and foreshore nourishments. The latter choice is called "working with nature".

Building upon the concept of coastal sediment cell therefore lead to adopt the following three key management principles for the coastline which have been verified in the cases of Normandy, Sussex, Isle of Wight, Essex, Holland Coast, and Wadden sea:

1. Maintain the total amount of sediment (in motion or dormant) within the coastal system
2. When taking measures, try to work with natural processes or leave natural processes as undisturbed as possible
3. If no other options available, use hard constructions to keep sediments in its position

The concept of sediment cells presents however major limitations due to its time dependence: sediment processes within a specific sediment cell cannot be totally "self contained" and transfer of sediments among adjacent cells may finally become non negligible after a long period. Moreover, the concept of sediment cell is restricted to processes occurring along the shoreline and do not include land-based causes of coastal erosion such as reduction of river sediments or modification of river outflows and estuary water levels as observed in the Gulf of Riga. These limitations have led some cases, such as Essex, to request a fine-tuning of the sediment cell concept.

Lesson 7

Experience has shown that, at the present time, there is no miracle solution to counteract the adverse effects of coastal erosion. Best results have been achieved by combining different types of coastal defence including hard and soft solutions, taking advantage of their respective benefits though mitigating their respective drawbacks.

From the observation that coastal erosion results from a combination of various natural and human-induced factors (*lesson 2*) it is not surprising that miracle solutions to counteract the adverse effects don't exist. Nevertheless, the general principle of "working with nature" was proposed as a starting point in the search for a cost-effective measure (*lesson 6).*

However, this observation also undeniably takes in flank the idea that soft engineering solutions are preferable to hard ones. This is backed by a number of considerations derived from experience:

- Even well tried soft solutions - such as beach nourishment, which arouses a tremendous enthusiasm in the past 10 years - have been subject to serious setbacks. Such setbacks have been caused by inappropriate nourishment scheme design induced by poor understanding of sediment processes (technical setback), difficult access to sand reserves which induces higher costs (financial setback)), or unexpected adverse effects on the natural system and principally the benthic fauna (environmental setback). These are respectively well covered by the case of Vale do Lobo (Portugal) where 700,000 cubic metres and 3,2 millions Euros of investment have been washed away by long-shore drift within a few weeks only, the case of Ebro where the sediment volume needed to recharge the beach of sediments had been imported from another region, and the case of Sitges (Spain) where dredging of sand to be supplied causes irreversible damage to sea grass communities (Posidonia).

- Soft solutions, due to their particularity of working with nature, are found to be effective solutions only in a medium to long-term perspective, i.e. when coastal erosion does not constitute a risk in a short-term perspective (5 to 10 years). Their impact indeed slows down coastline retreat but do not stop it. When it does, the long term positive effect of soft solutions may be optimised by hard structures which make it possible to tackle an erosion problem efficiently but have a limited lifetime (side in general no more than 10 years). This has been particularly well documented in the cases of Petite Camargue (France) where presence of hard structures - condemned anyway – also turned out to provide sufficient visibility for soft defence such as dune restoration wind-screens to operate, the case De Haan (Belgium), where a seawall provide safety to social and economical assets though beach nourishment with a sub-tidal feeder berm provides long term stability to the surrounding dunes, and the case of Western Jutland (Denmark) where the use of detached breakwaters reduce by a factor expenses related to beach nourishments. In addition, most of the cases of United Kingdom which already benefit from Shoreline management plans (SMP) combines different types of techniques.

Annex 2 summarizes the major pros and cons associated to each individual coastal erosion management technique.

Lesson 8

Assignment of clear and measurable objectives to coastal erosion management solutions - expressed for example in terms of accepted level of risk, tolerated loss of land, or beach/dune carrying capacity - optimises their long-term cost-effectiveness and their social acceptability. This has been facilitated by the decrease of costs related to monitoring tools.

In most of the case studies reviewed, coastline retreat is a phenomenon observed for more than a hundred years. In a few cases, such as the Isle of Wight (United Kingdom), evidence exist that men have struggled against coastline retreat for thousands of years. In addition and though they get older, some coastal defence structures inherited from past management strategies are still "active" and they keep on interacting – positively or negatively - with sediment processes, as illustrated in *lesson 5*. In other cases, hard and soft solutions implemented had a lifetime that did not exceed a few months, such as the timber groins of Rosslare (Ireland) or Chatelaillon (France) – or even a few weeks such as the beach nourishment schemes of Vale do Lobo (Portugal). This highlights the needs for adequate monitoring of solutions all through the lifespan of coastal erosion management solutions since these solutions may not reach the efficiency targeted, or on the contrary, may continue to interact with other elements even beyond their initially planned life span.

Experiences from case studies also revealed that coastal erosion management solutions which have defined beforehand clear objectives and implemented regular monitoring programmes could also detect quicker any discrepancy between the expected coastline response and effective coastline response. They are also in a position to decide corrective actions which turn to save a significant amount of money at the long run as illustrated by the cases of Western coast of Jutland (Denmark), South Downs (United Kingdom) and Playa Gross (Spain).

It is however important to notice that regular monitoring programmes are still an exception in Europe and are not the general rule. There is in particular a significant gap between northern and southern Europe in the systematic use of coastline monitoring techniques as part and parcel of shoreline management policies. Such countries as UK, Netherlands and German Landers have generalized the regular use of LIDAR or ship borne surveys or locally apply ARGUS video systems, though other countries as Portugal, Greece, or even France implement coastline monitoring techniques only punctually and generally as experimental research projects. Annex 3 summarizes the different coastline monitoring techniques used in the case studies reviewed by EUROSION or mentioned in their bibliography.

These different coastline monitoring techniques have different resolutions and accuracy and some may offer more opportunities than the others. This is concretely reflected in the average unit cost related to each monitoring technique. Table 2 briefly presents the range of costs associated to various techniques. Information provided in this table assumes that the area to be monitored is larger than 100 km2 to enable significant economies of scale. Economy of scale is indeed an important factor to be taken into consideration as it makes it possible to reduce cost of possibly more than 50% of their initial value, as illustrated by the case of Holland Coast using LIDAR as a routine monitoring technique.

Table 1-2. Unit costs of a some coastline monitoring techniques (for areas superior to 100 km2)

Monitoring technique	*Resolution*	*Unit costs in Euros/ km2*
Satellite images		
- SPOT 5	2,5– 5 meters	5-8
- IKONOS	1 meter	10-13
Fixed remote sensing		
- ARGUS video system	1 meter	20-30
Ground surveying		
- Beach profiling using total stations or GPS	0,1 meter	100-200
Ship borne echo sounding		
- Multibeam sonar	0,1 meter	150-250
Aerial photogrammetry	0,1 meter	300-400
Airborne laser altimetry		
- LIDAR	0,1 meter	500-700

Multi-functional technical designs, i.e. which fulfills social and economical functions in addition to coastal protection, are more easily accepted by local population and more viable economically.

The perception of risk by local populations influences considerably the design of coastal defence solutions. A commonly spread idea among communities residing within areas at risk is that hard engineering provides better protection against coastal erosion and associated risk of coastal flooding. This belief, which may be founded at the short-but term but not necessarily at the long run, has been observed in a number of European provinces, such as the Dutch province of Zeeland durably marked by the coastal flooding of 1953. In this province, any attempt to retrocede polders to the sea by cutting dykes has resulted in the past in a storm of protest and finally withdrawal of projects as illustrated by the Western Scheldt compensation plan (1999). Designed both to compensate the loss of lands induced by dredging and increase the tidal volume of the estuary as a response to sea level rise (and therefore increase safety), this plan was withdrawn in 1999 due to strong opposition from local citizens.

For similar reasons, it is only recently that sand nourishment schemes, which constitute since 1992 the backbone of the Dutch policy of coastal defence along the Holland coast, have been receiving a large support from local population. This support is largely due to the positive side effects of sand nourishment on recreational activities associated with beach extension, and protection of fresh water lens induced by consolidation of dunes. This is also largely confirmed by a majority of sites throughout Europe which opted for beach nourishment – such as Giardini Naxos, Marina di Massa, Vecchia Pineta (Italy), Can Picafort, Mar Menor (Spain), Mamaia (Romania), De Haan, Zeebrugge (Belgium), Sylt (Germany), Hyllingebjerg (Denmark), Hel Peninsula (Poland), Chatelaillon (France), or Vale do Lobo (Portugal). In some Mediterranean cases, tourism opportunities induced by beach nourishment has become a local stake even if those areas which do not particular suffer from coastal erosion, which in some cases led to illegally mined sand, such as in the case Dolos Kiti (Greece).

Beyond beach nourishment scheme whose implementation has been boosted in the past 5 years – unsuccessfully in some cases (*see lesson no. 7*) - other technical designs have made it possible to combine coastal defence with other social, economical, and ecological functions. This is best illustrated by the examples of the natural area of Koge Bay (Denmark), reclaimed from the sea for nature, recreation and defence (against coastal flooding) purposes, and Sea Palling where artificial reefs have been experimented both to absorb incoming wave energy and regenerate a marine biota.

Seeking multi-functional design is also driven by financial considerations. A number of examples exhibit significant costs of coastal defence. They range from a few thousands euros for localised protection through wooden pile breakwaters or geotextiles – such as along Estela beach (Portugal, 20,000 Euros) – to several of millions euros – for complete reshaping of the beach by combination of sand nourishment, rock armoured breakwaters, and design studies - such in Playa Gross (Spain, 11 millions Euros). To these costs must be added maintenance and monitoring cost and, in the case of beach nourishment, the cost for repeating nourishment actions regularly. Technical designs fulfilling different functions therefore increase the chance to find co-funding partners on the long term.

Though critical for decision-making, the balance of coastal defence costs and their associated benefits is - in general - poorly addressed in Europe. This may lead to expenses, which are at the long run unacceptable for the society compared to the benefits.

If the costs of coastal defence and their breakdown by funding partners are rather well reported in most of the cases reviewed, only few of them have documented its benefits appropriately. Among those, the case of South Downs (United Kingdom) estimates that the 14 millions Euros of coastal defence at Shoreham and Lancing provide protection to 135 millions Euros of properties – including 1300 homes and 90 commercial premises – from the risk of coastal erosion and associated flooding within 100 years. Along the North Norfolk (United Kingdom) coastal cliffs, the example of Happisburgh demonstrates on the contrary that the costs of cliff stabilization combined with detached breakwaters estimated to several millions of Euros – as proposed by the local authorities - largely exceed the value of the 18 houses buildings and the road, which makes the project not easily bankable. Such assessments of cost and benefits tend to be systematically undertaken in the United Kingdom in so far as the shoreline management plans recommended by DEFRA give the impetus for it. This remains however an exception in other countries in spite of considerable expenses for coastal defence as illustrated by the Dutch coast where an average of 30 to 40 millions Euros are dedicated to beach- and foreshore nourishment each year, the case of Saintes-Marie de la Mer (Petite Camargue - France) where more than 60 millions Euros have been spent over the past 10 years for groins and dune regeneration, or the case of Portugal where 500 millions have been invested in dune and seafront rehabilitation and hard defence since 1995 along coastal stretch lying from the harbour of Aveiro to the resort of Vagueira.

It cannot be denied however that local decisions are made on the basis of at least qualitative information on the benefits. Such a qualitative assessment of benefits are briefly reviewed in a number of cases:

- Safety of people and goods – mainly houses – addressed in all cases
- Reduction of extreme water levels thanks to sedimentation in the bed of estuaries and tidal basins (Holderness, Humber, Essex, Wadden Sea)
- Better access to harbour facilities by dredging nourishment materials in navigational channels (Western Scheldt)
- Protection of fresh lens against salt water intrusion in fertile hinterlands (Aveiro, Holland)
- Revalorisation of the property market value induced by risk reduction (Playa Gross)
- Increase in beach frequentation induced by the foreshore extension (Sitges, Marina di Massa, Giadini Naxos, Vecchia Pineta), dry sand (Sable d'Olonne), or modification of plunging characteristics of breaking waves (Playa Gross)
- Rehabilitation of natural areas and associated biodiversity (Aquitaine, Koge Bay)
- Provision of shelters for fishermen's boats (Vagueira, Dolos Kiti, Shabla Krapetz)
- Absorption of nitrogen's by coastal marshes initially designed for coastal defence

SECTION 2
DETAILED ANALYSIS OF THE CASE STUDIES

INTRODUCTION

The following section presents the experiences from the cases studies. It does not aim at providing predefined management strategies, but rather at providing in-depth background information on comparable situations and the strategies adopted in these cases. In that it provides a solid basis for tailoring the management strategy to the situation at hand while avoiding measures that have proven to be ineffective or counterproductive.

In accordance with the terms of reference of EUROSION project, the review presented in this report considers for each technique its success and failure in stopping damage to erosion (over short and long term), its cost – including initial and maintenance, its side effects and its social acceptability. It furthermore considers the measures available for management of non-local causes of erosion.

The presentation of this review is chosen on the level of the different "Regional Seas": the Baltic Sea, the North Sea, the Atlantic Ocean, the Mediterranean Sea and the (Western part of the) Black Sea. Little information is also given for Ultra peripheral regions. Within each chapter information on national or regional level is displayed. This top-down approach provides a good overview of the available information on different scales. Furthermore, this approach suits the presence of common physical features of the coastal system (e.g. Atlantic coast experiences high energy hydrodynamic conditions) and socio-economic backgrounds (e.g. in Mediterranean Sea tourism is common driver for development of coastal area) and fits the regional seas conventions regarding integrated coastal zone management.

In this section the following questions have been addressed:

- What coastal types are mainly present and which local or non-local causes of erosion (scale, type) can be identified? (CH 1)
- What are the consequences for the values of the coastal area (or what is the socio-economic impact)? (CH 2)
- What policy is defined and how is it embedded within ICZM-perspective? (CH 3)
- Which (technical) measures have been taken recently and in the past and what are their costs? (CH 4)
- Where the measures successful or unsuccessful and which key factors have been identified? (CH 4)
- What are the expectations for the future?

Before going into detail, a summary of the review is provided for each regional sea.

SUMMARY

Baltic Sea

The Baltic Sea is bordered by 9 countries. These are Sweden, Finland, Russia, Estonia, Latvia, Lithuania, Poland, Germany and Denmark. About 16 million people live at the coast, and around 80 million in the entire catchment area of the Baltic Sea. The Baltic Sea covers 415,266 square kilometres, while its catchment's area is four times as large as the sea itself. The length of the Baltic coastline varies from 100 km for Lithuania to 46,000 km for Finland

The average depth of the whole Baltic Sea is around 50 meters. The deepest waters are in the Landsort Deep in the Baltic Proper, where depths of 459 meters have been recorded. The Baltic Sea is a virtually closed body of water. Its only outlet to the ocean is found around the Denmark area. Therefore, the exchange of Baltic seawater with water from the Atlantic Ocean occurs very slowly; in fact, it takes about 35 years for all the Baltic water to be refreshed by ocean water.

The main coastal types in the Baltic are hard rock coasts (mainly in the north), soft rock coasts alternated with shingle and sandy beaches (mainly in the southwest area) and soft rock coasts alternated with sandy beaches and dunes (mainly in the southern area). The alternation of soft rock coasts with sedimentary beaches is typical: the sedimentary beaches only exist thanks to the erosion of the soft cliffs. Therefore if the cliffs are protected from erosion, the result is erosion of the downstream sedimentary beaches.

The main driving forces for erosion in the Baltic Sea region are wind and wave action while in the future accelerated sea level rise will become of increasing importance. Tidal influence in the Baltic is negligible. The supply of sediment in the Baltic therefore mainly originates from wave-induced sediment transport, erosion of soft cliffs and river sediment discharge. The most intense storms are northwesterly storms, therefore the coasts in the eastern (Baltic States) and southern (Poland and Germany) part of the Baltic are exposed to the highest wave energy. In normal conditions, the highest waves reach 2-3 m but in more extreme events wave heights of 5 m can be reached.

There is a clear divide between the north and the south of the Baltic Sea due to the isostatic change occurring here. In the northern part (Finland and Sweden) isostatic land uplift rates (5-10 mm/yr) compensate for sea level rise whereas in the southern countries (Denmark, Germany, and Poland) land uplift is negligible and the rate of relative sea level rise is increasing, up to 4 mm/yr locally in Daugava river mouth - Gulf of Riga (Latvia). The rising coast and the presence of more hard rock cliffs in the north mean that erosion is much more localised than in the south. Besides, a potential future increase in storminess (frequency and intensity) - due to climate change – will increase strong incidental erosion events.

Erosion rates of cliffs in the Baltic area vary from 0,5-1,5 m/year though extremes of 2-3 m/year are possible. At the sedimentary coasts erosion is caused by wave attack during storm surges, longshore transport gradients, relative sea level rise and sediment deficiency and reaches values of 0,5-1,5 m/year. However with extreme storms tens of meters can be eroded at once. Besides natural causes of erosion, human interference such as the construction of piers and ports, dredging, damming, shingle and stone mining has intensified erosion in the Baltic region.

The industrialization that started in the latter part of the nineteenth century caused dense population, industry and tourism in the coastal areas of the Baltic Sea region. Erosion is an increasing threat at these coastal areas, mainly in the countries located in the southern part of the Baltic. The economic situation of the countries in the Baltic Sea region is not overall comparable. The GDP/capita clearly shows a difference between the “richer” countries in the Baltic (Denmark, Sweden, Finland and Germany) where this value lies around 25,000 Euro and the low labour cost countries (Latvia, Lithuania, Estonia and Poland) where this value lies around 8,000 Euro.

The impact of erosion in the coastal zone depends on different parameters. First of all there is population density, which is high in the big cities all around the Baltic (> 500 persons / km^2). Furthermore, other functions can be threatened such as tourism, nature and economic value. The economic value at risk is usually high in low-lying areas where floodings can occur, like Germany, Poland, parts of Denmark and the south of Sweden. At cliffs and elevated land only the property threatened directly by erosion is at risk. Coastal protection is mainly applied to protect human lives and economic value in the Baltic area. In some cases tourism or natural values are protected actively; the awareness of the importance of these other functions is growing the last years.

Accelerated sea level rise, together with a potential increase of storminess (intensity and/or frequency) will increase the capital at risk in the Baltic area as well as in any other area. The adaptation costs needed to protect human environment against this sea level rise is relatively low (related to GDP/Capita) for the richer countries. This reflects the fact that, given the right preparation (good maintenance for example) richer countries can adapt to sea level rise more easily.

At present the responsibility for planning of coastal protection schemes usually is located at a national level. The most frequently applied policy options in the coastal zone of the Baltic area are hold the line and limited intervention. Limited intervention is applied in areas where the threat to economic values is small; the advantages of dynamic coasts for nature conservation have also been acknowledged in the Baltic. Hold the line is still applied when high economic values are threatened by erosion, historically it was mainly executed with hard measures like seawalls, revetments, slope protection, groins and more sparsely detached breakwaters.

However since the 1970s a shift towards the use of soft measures, nourishments, started in Germany and Denmark. The last decade this shift has taken place in all Baltic area countries and the use of nourishments has increased significantly in the entire area. Hard measures turned out to be failing after some time by storm damage or increased foreshore erosion, and furthermore caused increased erosion downstream. Nourishments, altough only temporary effective, have shown to be successful in mitigating the effects of interruption of longshore transport and not causing a disturbance of the natural equilibrium in the Baltic area. Repetition of nourishment is needed for effectiveness on the long-term.

In the past, private landowners or local groups have often tried to protect their property individually in the Baltic Sea area. This individual approach often resulted in unprofessional designs and a lack of maintenance causing quick deterioration of the structures, and a lack of common approach causing the problem to be moved but not solved. Through the failures of these coastal protections, the importance of a common approach, a design by professionals and good maintenance was acknowledged in the Baltic area. However, maintenance is still relatively poor and underestimated in some parts of the Baltic.

Besides, or even instead of, measures to stop or slow down erosion, measures like foredune and forest maintenance are applied to mitigate the effects of storm surges in the Baltic. This strategy has shown to be cost effective mainly in low labour costs countries like the Baltic States. This is likely to change with entry to the EU, when labour costs probably increase.

ICZM is in a very early stage in the Baltic Sea area, though some ICZM programs have started the past years (HELCOM, VASAB 2100, Baltic21 and Procoast). In some projects steps towards integral approach for the planning and financing process is seen (mainly in Denmark and Germany), furthermore the importance of other functions besides safety, like tourism and nature, has clearly been acknowledged but this has generally not yet been implemented in legislation and organization in the Baltic area.

North Sea

The North Sea is bordered by 8 countries. These are: Finland, Sweden, Denmark, Germany, Netherlands, Belgium, France and United Kingdom. It is linked to the Atlantic Ocean in the north and also in the southwest, via the Channel. To the east it links up with the Baltic Sea. The Kattegat is considered an interchange zone between the North Sea and the Baltic Sea.

Including estuaries and fjords, the total surface area of the North Sea is approximately 750,000 km^2 and its total volume 94,000 km^3. The drainage area of the North Sea covers about 850.000 km^2 and is inhabited by about 184 million people.

The coasts of the North Sea vary from coastlines intersected by fjords, via cliffs with pebble beaches to low cliffs with valleys to sandy beaches with dunes and estuaries with mudflats and saltmarshes. Most of the coasts around the North Sea are macro-tidal and sedimentary and therefore, the typical coastal types along the North Sea are sandy beaches and dunes, shingle beaches, saltmarshes, estuaries. Along the estuaries and along several coastlines dikes and revetments were built, resulting in artificial coastlines. At the east coast of the United Kingdom, as well as the west coast of Denmark and France soft cliffs are found locally.

Various natural causes of erosion can be identified along the North Sea. Summarized, these are sea level rise (2 mm/yr on average), gradients in longshore sediment transport for sedimentary coasts and storms (cross-shore sediment transport) for cliff coasts and dune coasts.To some extent, like observed in the Baltic Sea, the northern coasts are generally less susceptible to erosion and flooding because of rising land levels and more resilient rock. Erosion is also caused by human interference, affecting the natural processes of sediment transport. Examples are the construction of coastal protection structures, construction of ports and jetties, or sand mining and dredging.

The countries around the North Sea are well developed and industrialized, with high population densities in the coastal areas. Erosion threatens the user functions, which are mainly urbanization, agriculture, industry, transport and energy and, finally, tourism and recreation. The capital at risk is high, especially for (parts of) low-lying countries that may flood after a dike or dune breaches, for example in Belgium, The Netherlands and Germany.

The effect of sea level rise on coastal defence measures is recognized and coastal zone management plans are developed, in which the future erosion is taken into account. As a result of the economical situation, it is expected that these countries may be able to counteract the future erosion more easily.

Historically the most frequently used policy option was to hold the line when safety of human lives and of economic investments are at steak. This was mainly executed with hard measures, but the last few decades the emphasis is shifting in the direction of soft measures (nourishments). Do nothing has historically been applied when no investments or human lives were threatened. Later, the option do nothing is also suggested when a coastal protection measure would cause too much negative effects at adjoining coastal stretches or when this options enhances the natural behaviour of coastlines and estuaries.

In the North Sea countries in general a growing awareness of environmental issues has developed among the general public and politicians, especially during the last few decades. As a result of the economical situation and the rather high population, authorities are willing to invest in the preservation of areas that are valuable from an ecological point of view, such as salt marshes, mud flats and islands where bird colonies breed. A rehabilitation of the natural sea-land environment, new technical potentialities and political accents have made that since the seventies preference is given to “soft” measures, i.e. beach nourishment, respecting the natural dynamics of the shoreline (coast or estuary). A further advantage is the sufficient availability of sediment in the relatively shallow North Sea. On the other hand, the long-term consequences of structural deepening of the foreshore due to sand extraction is not well known.

A less accepted policy option is managed realignment. Large floodings in the past with loss of life and property left a legacy in present day attitude towards coastal zone management in low-lying countries in the North Sea region. The general perception of the necessary defence against the sea makes hinder the acceptance of the managed realignment option. Despite this, at least in South-East England a major change in policy in the direction of managed realignment is observed, which recognises the implications of çoastal squeeze’with its loss of intertidal land and the valkue of rec-reating habitat both fo nature conservation and as a contribution to a more sustainable sea defence.

In the North Sea area, most countries have a long tradition of coastal management and of integrated strategies. Compared to other countries in Europe, these countries have therefore made most progress in establishing ICZM, although national legislation concerning ICZM is not present yet in any of the North Sea countries.

It is clear that there are moves to develop ICZM – either on a statutory or non-statutory basis – in all the North Sea countries. But at this moment, the picture is by no means uniform.

Atlantic Ocean

The Atlantic Ocean borders Western Europe along the following EU-countries: the United Kingdom, Ireland, France, Spain and Portugal. It is linked to the North Sea via a wide stretch of open water between Scotland and Norway in the north and the Channel in the south. Further south, the Atlantic is connected to the Mediterranean via the relatively narrow strait of Gibraltar.

The coastlines of remote overseas areas such as the Azores Islands (Portugal) and the Canary islands (Spain) have also been examined. The nine Azores islands are located on the Microplate of Azores, which lies at the intersection of three tectonic plates; the African, the North-American and the Euroasian plates. The group extends some 480 kilometres in a northwest-southeast direction. The Azores islands have a population of 240,000. The Canary Islands lie along the north-west coastline of Africa, directly in front of Morocco. The island group consists of seven large islands and five smaller ones and have a population of around 950,000.

Generally speaking, the coastline around the Atlantic Ocean is made up of hard and soft cliffs interspersed with sandy and shingle beaches and dunes. The high relief, hard cliffs and rocky coastlines are mostly found along northern Spain, northern Portugal and parts of northern France. The softer coasts can be found along West Ireland (e.g. Donegal or Rosslare) and south United Kingdom (Sussex), where soft cliffs with shingle and sand beaches and smaller dunes alternate between small bays and estuaries. Larger, extensive dunes can be found along the coast of north France (Aquitaine).

Erosion of the Atlantic coastline is consequence of natural and human-induced factors. The high-energy, storm generated waves from the Northern Atlantic and the macro-tidal regime (medium range 2-4 m, maximum up to 15 m in Bay of Mont Saint-Michel- France), are the dominant erosive forces along the Atlantic coastline. Together they create extreme circumstances with strong alongshore tide and/or wave driven currents and cross-shore wave driven currents that can easily erode beaches and undermine cliffs. In the future, climate change is expected to induce accelerated sea level rise (at present 2-4 mm/yr) as well as a potential increase in storminess. Both will enhance erosion along the Atlantic coast. Human interference, such as the construction of seawalls or groins, damming of rivers and sand mining, has enhanced the erosion locally.

The northern countries (Ireland, United Kingdom and France) are more industrialized and developed than the southern countries (Spain and Portugal). In both northern and southern Europe, erosion threatens urbanization (the safety of human lives and investments), tourism and nature. Furthermore, in Spain, Portugal and France fishing and aquaculture are of great importance in the coastal zone. In the United Kingdom and Ireland, a lot of agricultural land is found in the coastal zone. The explosive growth of the population in the littoral zone, partly due to tourism, has increased the pressure on the coast especially along the French, Spanish, Portuguese coasts and the southern coast of the United Kingdom. It appears that most of the coastal areas in the Atlantic Sea region are at high risk due to the low-lying coastal plains that are at risk of flooding.

The policy option ‘hold the line’ is often applied when seaside resorts or other recreational facilities are at risk. Especially in the southern countries France, Spain and Portugal but also often in the southern part of the United Kingdom and Ireland tourism plays a leading role at the protected sites. Furthermore, high population densities and economic investments are protected applying the policy option hold the line, like in the United Kingdom, Ireland and Portugal.
‘Do nothing’ and ‘managed realignment’ are possible at some of the seaside resorts and recreational facilities if the capital at risk is relatively low and the recreation facility or houses can be moved landward without too many problems. ‘Do nothing’ is usually applied at cliff coasts where no flooding risks are present and therefore the capital at risk is relatively low. In a flooding area, a new defence line is usually defined (thus ‘managed realignment’).

At many sites along the Atlantic coast, a mix between hard and soft engineering solutions is adopted when dealing with erosion issues. Various types of hard solutions were applied in the cases considered. Although applied in nearly all cases, beach nourishments are executed on a much smaller scale (in terms of m^3) than in the North Sea and the Baltic Sea regions. Whereas in the North Sea regions soft measures are often taken to combat erosion, along the Atlantic Ocean coasts the soft solutions are often combined with hard measures, probably due to the high energy conditions of the coast.

Integrated Coastal Zone Management is still in an orienting phase in the Atlantic region. About half of the regions have developed some kind of progress in ICZM. Although national ICZM-policies are not yet present in any of the Atlantic Sea countries, on a local scale it is implemented by means of for instance interregional cooperation (e.g. Normandy and Picardy, France). The ICZM-projects (OSPAR) mainly concern environmental issues and they are executed mainly on a local scale. Some of the TERRA and LIFE projects focus on coastal erosion issues.

Mediterranean Sea

The Mediterranean Sea covers 2.500.000 km^2 with an average depth of 1.500 metres the deepest point being over 5.000 metres. The coastline extends 46.000 km running through 22 countries. The Mediterranean Sea is a residual sea between Europe, Africa and Asia as the result of tectonic plate's motion. The sea is connected to the Atlantic Ocean by the Strait of Gibraltar on the west and to the Sea of Marmara and Black Sea by the Dardanelles and the Bosporus on the east. The Suez Canal in the southeast connects the Mediterranean with the Red Sea.

The selected case studies are located at eroding parts of the Mediterranean Sea coasts. Some of the largest deltas in Europe can be found: those of the Ebro (Spain), the Rhone (France) and the Po (Italy) rivers, including a number of lagoons (Messologi lagoon area-Greece, Mar Menor-Spain). Furthermore, (limestone) cliff coasts are widespread (Lu Littaroni La Liccia-Italy, Xemxija Ghajn Tuffieha-Malta, Sitges-Spain) and many sandy beaches and dunes (for example Dolos Kiti-Cyprus) are present.

Driving forces of erosion processes along the Mediterranean coast are pretty similar amongst them, but a high diversity results from geo-morphological features of each different area. Erosion is mainly due to winter storms, when material from beaches is transported elsewhere, part of it to deeper water. Natural sediment input from rivers used to balance the loss. Sea level rise shifted the equilibrium. Sea level rise is high in the eastern parts of the Mediterranean (up to 20 mm/yr in the Levantine basin), as well as in the Tyrrhenian and Adriatic Seas (5-10 mm/yr.). A decrease in sea level can be found in the north Ionian Sea (5 mm/yr). Part of the observed sea level change in the Mediterranean is related to the water temperature. Besides, sediment is trapped in rivers by dams and reservoirs, which effect is ongoing. Moreover, quite a number of man-made causes are present: obstacles to alongshore drift (ports dykes e.a.) and a weakening of the coastal material resilience due to the developement and urbanization processes.

Today, 82 million people live in coastal cities; by 2025 there will be an estimated 150-170 million. Over 100 million tourists flock to Mediterranean beaches every year and this number is expected to double by 2025. This causes a high pressure on the environment. In general, erosion of the beach impacts on tourism, is a threat to valuable property and increases the risk of flooding. Part of the erosion problem is not the erosion itself, but the growing investments in the coastal zone. The comfortable climate boosts the many tourist towns along the Mediterranean Area. Residential housing of local inhabitants is expaning as well.

Coastal management since about 1960 resulted in some heavily engineered coastlines in the Mediterranean Sea at places where human interests had to be protected. By building hard constructions erosion was tried to stop. Although in many cases the works did not have the desired result, many seawalls and groins continued to be constructed and shifted the problems to the future or neighbouring areas. As the pressure on the coastal zone due to human-induced activies and relative sea level rise keeps expanding, the need for sustainable solutions that do justice to the environmental values is growing.

Over the last decades a trend is visible towards more flexible solutions. Soft measures (nourishments) are being applied more often. A disadvantage of nourishment is a necessary repetition and possible (irreversible) damage to sea grass communities (Posidonia).

Integrated Coastal Zone Management principles are not commonly used in the Mediterranean. Some of the cases illustrate management curtailed to the specific area.

Black Sea

The Black Sea is an inland sea lying between southeastern Europe and Asia Minor. It is connected with the Aegean Sea by the Bosporus, the Sea of Marmara, and the Dardanelles. The Western part of the Black Sea is part of Europe, concerning the Bulgarian and Romanian and part of Turkey. The Northern and Eastern shores are bordered by Ukraine, Russia, and Georgia; the entire southern shore is Turkish territory.

The Black Sea basin is relative deep, down to -2.245 m. The Black Sea has a length of about 1.200 km from east to west, a maximum width of 610 km, and an area (excluding its northern arm, the Sea of Azov) of about 436.400 km^2. The sea receives the drainage of a large part of central and Eastern Europe through the Dnepr, Dnestr, Southern Bug, and Danube rivers. It also receives waters from a considerable section of eastern European Russia.

The whole region is at present tectonically active. The very recent rapid subsidence characterizes not only the abyssal Black Sea, but also a series of more-or-less elongated basins extending westwards to Italy. The basin has been undergoing almost continuous sedimentation. The coastline of the western Black Sea is characterised by soft-rock cliff and the Danube delta. Beaches are widespread, along the delta and the cliffs.

The Black Sea is nearly tideless, because it is not coupled to the oceans, and it is too small to generate tides of its own. Wind and waves are therefore the main forces that act on the shores and those result in an average sediment transport from north to south.

Given the length and variation of the western Black Sea coast there is variety of causes for coastal erosion. First of all, the ongoing rise of rise of sea-level is composed of the eustatic world-wide change, and a local subsidence or uplift related part. The local part introduces variations in relative sea-level rise along the Western Black Sea between 2 - 4 mm/yr . Relative sea-level rise is larger in the Danube delta area (local subsidence) than along the remainder of the shores. The natural factors involved include changing river discharge into the Black Sea, rainfall-evaporation balance and water exchange through the straights linking the Black Sea to the Mediterranean. Human causes vary from large-scale impact by the reduction of the fluvial contribution in sediments, due to damming, interruptions in the alongshore sediment transport by jetties, to the local impact of various hard measures.

Erosion on the Danube delta impacts on the ecologically important wetlands of the delta and locally on coastal communities. Erosion on the remainder of the western Black Sea coasts affects coastal communities and has impacts on the important economic activities. In this respect tourism is the most important factor for most sites on the Black Sea.

The applied policies to deal with coastal erosion vary, from limited interventions, hold the line, tot do nothing. In the Danube delta only a small percentage of the beaches are kept at their place (hold the line) and the remainder is allowed to prograde and retreat (do nothing). This follows from the role of the Danube delta as an ecologic, rather than in economic important area. The hold the line option is applied in Bulgaria and Romania, where economic factors are at risk.

Technical measures on the Black Sea shores are mainly hard, experience with nourishments are limited and not very positive. The not-so-positive experience is related to the technical details of the particular nourishment, and not the with technique in general. Hard measures vary from dikes and sea walls to detached breakwaters. The effectiveness of the hard measures varies strongly on their design in relation with the erosion problem.

Future developments follow the trends that are observed today. Pressure on the shorelines will undoubtedly increase, when inhabitation and tourism increases as the economy in Bulgaria and Romania grows. An accelerated rise in sea level may add to the already existing problems.

Integrated Coastal Zone Management is starting in Bulgaria and in Romania. Coastal zone management plans are being developed, with strategies to deal with erosion and environmental rehabilitation.

1 REGIONAL SEAS

1.1 Introduction

This chapter introduces the different regional seas and the adopted methodology of coastal classification to distinguish the different coastal systems within a regional sea. For each regional sea a general description, a short geological background and relevant physical processes are given. In the next step information is presented about coastal erosion as observed in the case studies (within the regional sea) in relation to the type and most common causes of erosion. First the adopted coastal classification is described and some general remarks about coastal erosion are made.

1.2 Coastal classification

The EUROSION project approach uses a revised form of the coastal typology developed for the European Coastal and Marine Ecological Network (Phase II report, 1998) and of the CORINE coastal erosion classification. In the further descriptions of regional seas the following four major coastal types are distinguished:

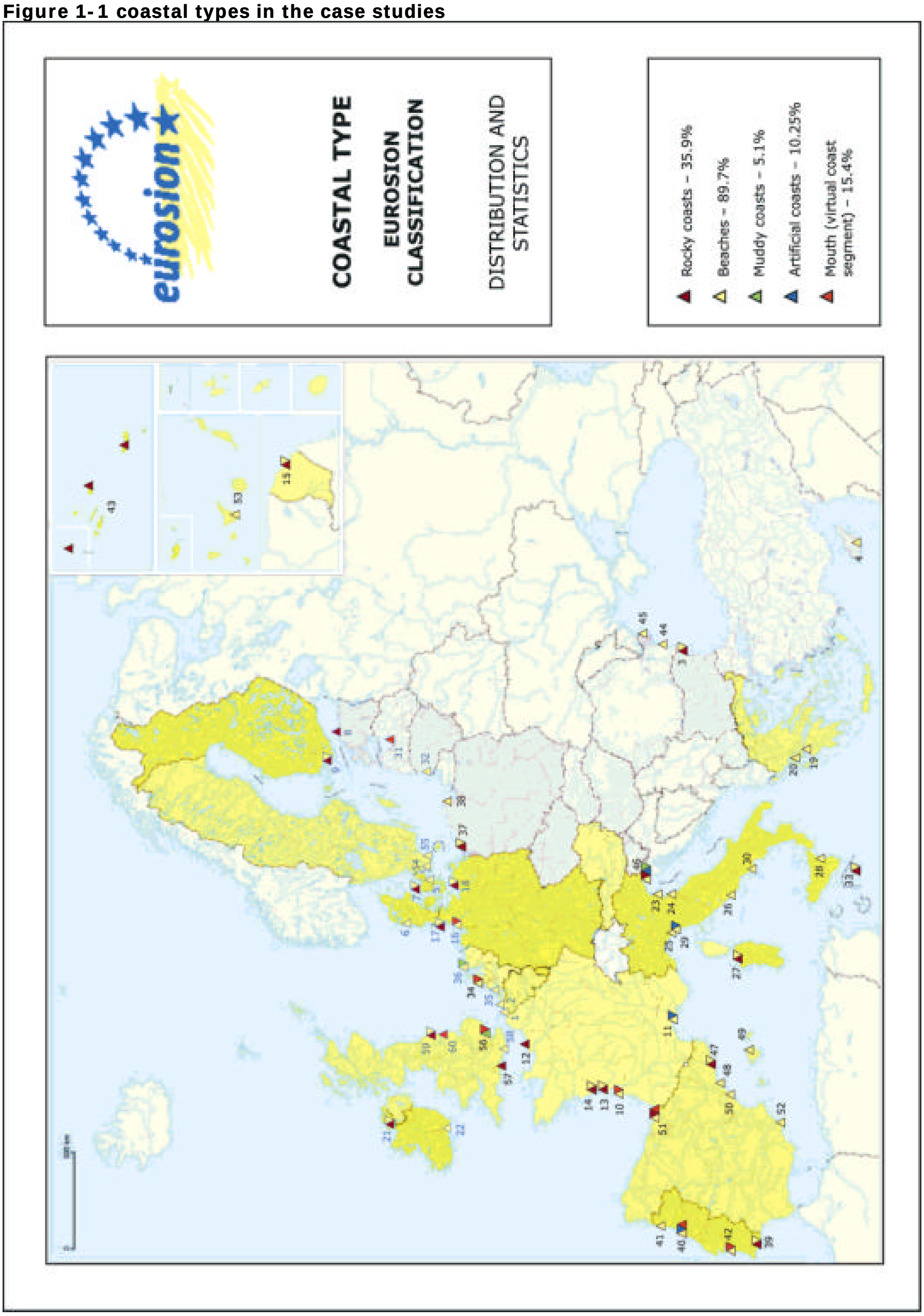
- Hard rock coast
- Soft rock coast
- Microtidal sedimentary coast (with microtidal river delta's), and
- Macrotidal sedimentary coast (with estuarine and wadden systems)

In each of these coastal types, the following geomorphological coastal formations and habitats can occur:

- cliffs
- sandy beaches and dunes
- shingle beaches
- tidal marshes (salt marshes, mudflats or wadden)
- estuary
- narrow vegetated shores
- river delta's
- artificial coastlines (dykes, polders)

The different coastal types in the case studies are presented in Figure 1-1, note that the category rocky coasts represents both soft and hard rock coasts.

Figure 1-1 coastal types in the case studies



1.3 Erosion

In the following paragraphs attention is given to the amount, type and causes of erosion as observed in the different coastal systems within each regional sea and it's underlying physical processes. Distinction will be made between natural causes of erosion and erosion due to human influence. When dealing with erosion problems on a regional/national (policy) scale or on a local/regional scale (technical measures) a profound knowledge of the geo-morphological processes and causes of erosion is fundamental to a sound choice for a policy option and any related measures.

In relation to the type of erosion two components can be distinguished: structural and acute erosion (see Box 1-1). In some areas structural and acute erosion cause problems, while in other areas clearly one type of erosion is of main importance.

Box 1-1 Types of erosion

Structural erosion is a continuing process of erosion due to adaptation of the coastal system to changed conditions. A common natural cause is (accelerated) sea level rise. Human influence often triggers or strengthens structural erosion. A sediment deficit may arise as a result of landsubsidence due to the extraction of gas / water or as a result of the reduction in sediment supply to the coast due to activities in the river catchments (canalisation, dams, irrigation works etc.). Furthermore, structural erosion is induced locally by an interruption of the net longshore transport due to construction works (groynes, harbor moles etc.).

Acute erosion is mainly caused by storm events. During a storm, erosion rates can be very high. However, during calm periods, following the stormy period, the sediment is often redistributed and the beach will (at least partly) be rebuilt. In many cases, acute erosion due to storm events is therefore only a problem at sedimentary beaches when infrastructure, buildings or other structures are threatened or destroyed. Acute erosion is a more serious problem at cliff coasts, since the cliffs cannot rebuild in calmer conditions.

In case of structural erosion it is of importance to understand the relationship between the total availability of sediment and the forcing of the erosion (sea level, waves, tides). Sediments are delivered to the coast by the rivers due to erosion of the hinterland. Undercutting and collapse of soft coastal cliffs is another natural source of sediment for the coastal area. Coastal erosion may originate due to a reduction in the availability of sediment, instead of a change in forcing. Moreover, episodic events to the delivery of sediments (particularly for deltas) can be of importance. A further complication arises when the land is sinking (due to isostatic change brought about by tectonic effects, due to water abstraction or reduced precipitation, or because of sediment consolidation).

In relation to the main causes of erosion distinction can be made between natural and human causes. The following natural causes have been considered: relative sea level rise, dynamic coastal evolution – i.e. fluctuations - and storms. The following human causes have been considered: hard defences and harbour barriers, urbanisation and promenade construction, river damming and sand extraction.

When considering causes of erosion, the dominant time and spatial scale of the underlying processes have to be taken into account. It's meaningless to discuss erosion without pointing out the scale considered. When managing erosion problems, the coastal system to be considered is mostly larger than the area in which erosion takes place. A coastal system should be considered with coherent and large enough time- and spatial scale.

In some cases the coastal area consists of natural barriers, like rocky outcrops. Between those natural barriers the sediment is redistributed and the sediment budget as a whole is hardly changing. Such an area can be regarded as a Coastal Cell. In other cases no specific natural barriers are found. In that situation the coastal manager should define the scale of the coastal system at interest.

1.4 Baltic Sea

1.4.1 General description

Brackish water and shallow coastal areas derived from glacial and post glacial deposits characterize the Baltic Sea, which is bordered by nine countries: Sweden, Finland, Russia, Estonia, Latvia, Lithuania, Germany and Denmark (see Figure 1-2).

Figure 1-2 Baltic Sea area with case studies

About 16 million people live at the coast, and around 80 million in the entire catchment's area of the Baltic Sea. The Baltic Sea covers 415,266 square kilometres, while its catchment's area extends over an area about four times as large as the sea itself. The length of the Baltic coastline varies from 100 km for Lithuania to 46,000 km for Finland (see Table 1-1).

Table 1-1 Coast length countries in Baltic Sea region[11]

Country	Denmark	Estonia	Finland	Germany	Latvia	Lithuania	Poland	Russia	Sweden
Length (km)	7,300	3,800	46,000 (1,100)*	2,000	500	100	850	850	7,600

*Straight coast length without islands and indentations

The average depth of the whole Baltic Sea is around 50 meters. The deepest waters are in the Landsort Deep in the Baltic Proper, where depths of 459 meters have been recorded.

The Baltic Sea is a virtually closed body of water. Its only outlet to the ocean is found around the Denmark area. Therefore, the exchange of Baltic seawater with water from the Atlantic Ocean occurs very slowly; in fact, it takes about 35 years for all the Baltic water to be refreshed by ocean water.

1.4.2 Geology and coastal classification

Geology

The Baltic Sea has been influenced in its development by the variations in strengths of two competing geological phenomena, both direct consequences of the melting of the glaciers: land uplift and sea level rise. During the Quaternary period most of the Baltic Sea region was covered by ice. Due to sea level rise after the last Ice Age (about 12,000 years ago), the Baltic changed from a lake to a sea (Yoldia), when the rising sea level pushed salt water upstream to the Danish channels and beyond. After passing the sill, the seawater had free access and gradually the whole basin became brackish. This so called Littorina Sea was, in fact, even saltier and larger than the Baltic Sea is at present. Since the later Yoldia however, land uplift has been the indisputable winner and is still conquering land from the sea in many places around the Baltic.

From that time on the land areas, which had been pressed down by the ice cover, started to rise. The countries in the south (southern tip of Sweden, Denmark, Germany and Poland) were the earliest to be free of ice. At present these countries therefore suffer of land subsidence instead of uplift (see Figure 1-3). The northern countries (Lithuania, Latvia, Estonia, Finland and Sweden) were freed from ice later and nowadays still have an average rise of 0.5-1.0 meters per 100 years.

Since the end of the latest Ice Age (about 12,000 years ago), several marine transgressions caused active erosion of Quaternary glacial drift deposits and consequently affected the alongshore sediment distribution along the Baltic coast. The common feature of this geographical zone therefore lies in the abundance of sediment supply, much of it derived from the soft glacial material deposited during the various ice ages, especially at the end of the last glaciation. Furthermore, at hard rocky coasts, indentations and small islands were formed during the transgressions.

As a result, the common coastal and sedimenttypes in the Baltic Sea are soft moraine cliffs, hard rocky cliffs, sand dunes and beaches. The sediment characteristics are varying over a wide range within the Baltic Sea region, exact information on sediment characteristics is available in the case studies.

[1] EUCC, www.coastalguide.org

Figure 1-3 **Isostatic rebound (mm/yr) for the Baltic – North Sea regions**[2]

Changing shorelines and emerging islands are specific for the northern part of the Baltic Sea (Finland, Sweden and Estonia), where archipelagos with thousands of rocky islands dominate. The latest geological development of the southwest areas of the Baltic Sea (Latvia and Lithuania) features grading of the shoreline, offering natural protection against erosion, and dune, lagoon and wetland formation. The coasts consist of beaches (sandy but also with pebbles, gravel and boulders) and moraine bluffs (soft cliffs). A few large islands of calcareous bedrock characterize the southern part of the Baltic (Germany, Poland and Denmark). The Littorina transgression exerted the most decisive influence on the development of the coastline of the southern Baltic. Sandy coastal plains and (soft) moraine cliffed coasts occur alternately. Over time at the coastal plains spits and barriers, partly enclosing bays as lagoons, were formed.

Coastal classification

Sedimentary coasts:

In the Baltic Sea the following coast types of sedimentary coasts are present: sandy beaches and dunes, non-tidal salt marshes, shingle beaches, narrow vegetated shores, deltas (though at a very small scale) and artificial coastlines. Because of the lack of tidal influence intertidal habitats and estuaries are not present. Non-tidal salt marshes have developed in the southwest as well as the southern areas. Big deltas are not present in the Baltic area; at some places the coast has been built up by river sediment discharge on a small scale (for example at the Daugava River in the Gulf of Riga).

Hard rock coasts

[2] Doody, 2002

Hard rock coasts can be found mainly in the northern area (Finland, Sweden and Estonia).

Soft rock coasts

In the southwest area (Estonia, Latvia and Lithuania) shingle and sand beaches alternated with soft rock coasts are found. The southern area (Germany, Poland and Denmark) consists of sand beaches and dunes alternated with soft rock coasts.

1.4.3 Physical processes

The Baltic Sea is a nearly tideless sea; tidal ranges can reach about 10 cm at most. The most important driving physical processes therefore are wind and waves. The wave climate in the Baltic Sea is moderate; in general the highest waves reach 2-3 meters. Depending on fetch and coastal orientation in some areas wave heights of 4-5 meters can be reached. The dominant wind- and thus wave- direction in the Baltic area ranges between north- to southwest. The northwest storms are the most intense. Therefore, the highest fetches and thus wave heights during storms are reached at the eastern (Baltic States) and southern coasts (Germany, Poland). Furthermore, during storm surges, the wind can raise or lower the water level with at least one meter. In this way the water level can attain considerable heights. Differences in water levels can cause currents in the Baltic Sea, however the current velocity due to these water level differences don't exceed 0,3 m/s.

The coastal areas in the Baltic Sea are covered with ice for varying periods, ranging from 2 to 6 months a year. Rafting and piling up of ice on the shores can occur, including ice-push effects extending tens of meters up the shore and involving transportation and deposition of stones and boulders.

The main sediment sources in the Baltic Sea originate from longshore transport, erosion of cliffs (mainly the easily eroded soft cliffs) and in some areas river discharge. Examples of river discharge of importance are the Oder in Poland, Daugava in Gulf of Riga and Nemunas River in Lithuania. Soft cliffs alternated with sedimentary beaches are seen regularly. In many places soft cliffs have high erosion rates, in this manner feeding downstream sedimentary beaches (sandy or shingle). If the soft cliffs are protected from erosion, a retreat of the downstream beaches has been observed in several places. An example of the soft cliff- beach alternation is seen at Rostock, where the beaches can only exist thanks to the erosion sediment of the soft cliffs upstream.

Another important process in the Baltic Sea area is relative sea level rise (RSLR) due to climate change. Because the tidal range is negligible, the influence of relative sea level rise will be relatively high, compared to other areas. The isostatic rebound for the Baltic is shown in figure 2.2. Espescially in the southern area land subsidence is small (Denmark, Germany and Poland) and relative sea level rise will increase significantly. In the southwest area, land is rising a little bit and the relative sea level rise will be small, while in the northern area sea level rise is completely compensated by the land uplift rates. Locally, the relative sea level rise can be higher. An example can be found in the Gulf of Riga (Latvia), where the local RSLR reaches 4 mm/yr over the last 50 years due to a combination with higher river discharges.

In the last century the worldwide sea level rise has been 1-2 mm/year, but according to predictions the rate of sea level rise will increase significantly. The most likely value is in the range from .. to .. cm in the next 100 years (Warrick et al, 1996[3]), thus 4-5 mm/year.

Besides sea level rise, climate change may also result in an increase in storm frequency and intensity. In the southwest area, in Estonia, Latvia and Lithuania, a frequent occurence of intense storms has been noticed in the last case decades.

1.4.4 Erosion

General description
The erosion at the Baltic coast can be structural, acute or a combination of both. An important parameter in erosion is the net longshore transport. The net longshore transport value is varying in the Baltic Sea; it depends on the wave climate, the sediment type and the coastal orientation. Some areas (like Køge Bay) are sheltered from waves and there is no net transport. Other sheltered areas with small net transports are the Gulf of Riga (bay form) and Talinn (Gulf of Finland). The Kattegat is also reasonably sheltered; net transport reaches values of up to 30.000 m^3/year. The net longshore transport is much higher in the open Baltic Sea at easily eroded (soft) coasts; along the coasts of Sweden, Germany, Poland, Lithuania and Latvia net transports reach average values of 200-300.000 m^3/year. Maximum net transport up to 1.000.000 m^3/year can occur locally. Relative sea level rise (as was mentioned before, mainly occurring in southern part of the Baltic Sea: Poland, Germany, Denmark and south-Sweden) is supposed to be one of the main causes for structural erosion in the last decades.

Acute erosion has also increased, especially in the open Baltic Sea, where several intense storms have been noticed in the last decades.

Hard rock coasts
Cliffed and rocky coasts occur in both high and low relief areas, where the underlying geological structures are relatively resistant to the erosive forces of sea, rain and wind. Therefore, at hard rock cliffs, the erosion rate in general is small and mainly caused by wave attack. For example, at Talinn an erosion rate of the rocky cliffs of 0,1 m/year is present.

Soft rock coasts
Soft cliffs in the Baltic area are mainly eroded by wave attack. The erosion rates at these cliffs are higher than at rocky cliffs, because the resistance against erosion is much lower. The erosion rate also depends on the cliff height. Structural erosion rates varying from 0,5-1,5 m/year are most common for soft cliffs in the Baltic. Extremes of 2-3 m/year however can occur in some places.

Sedimentary coasts
Sand dunes in the Baltic area have shown to be mainly eroded by storm events. Furthermore, in some cases, erosion of the dunes due to wind forces occurs.

Several driving forces have shaped the *sandy and shingle sedimentary beaches* in the Baltic area:

- Structural erosion due to a spatial gradient in longshore transport (which can either be caused by natural processes, for example wave-induced sediment transport gradient in a

[3] Warrick, R.A., C. Le Provost, M.F. Meier, J. Oerlemans and P.L Woodworth, 1996. 'Changes in Sea level'. Chapter 7 of IPCC 1996a, 362-405

bay, and/or by human interference, for example the construction of groins interrupting the wave-induced net longshore transport);
- Structural erosion due to accelerated sea level rise;
- Acute erosion due to storm events.

Structural erosion rates of sedimentary beaches vary from 0,5-1,5 m/year; however during storm events tens of meters can be eroded at once (acute erosion).

Muddy coasts
The sea level determines the level of coastal *wetlands.* A rise in sea level will mostly results in loss of marshes. When the landward boundary of the marshes is restrained in a further landward shift, the process of 'coastal squeeze' will occur. Here tidal range is a key factor: in general, the smaller the tidal range, the greater the susceptibility to a given rise in sea level. Since tidal influence is negligible in the Baltic, the marshes here are highly susceptible to sea level rise. Coastal wetlands serve two important functions in the coastal system:
- Habitat and conservation; support specialized plants, important fish nursery areas and feeding, breeding and roosting area for birds[4];
- Sea defences; salt marshes are effective dissipaters of wave energy and provide the first line of defence against tides and waves, particularly during stormy conditions. Hence, they reduce the costs of fixed Sea defences[4].

Erosion due to human interference in the coastal zone

Besides the natural causes for erosion described above, like (potentially increasing) storm events, (accellerated) sea level rise and a longshore transport gradient, human interference can increase erosion significantly. There are many examples of human interference along the Baltic coasts.

- Ports, port extension and piers

In the last century, especially ports, port extensions (big seaports at Riga, Klaipeda, Ystad, Rostock and Talinn) and piers (Rostock, Poland and Klaipeda) have caused great disturbances of the longshore transport and thus of the existing equilibrium. As mentioned before, the disturbance of the longshore transport by piers of breakwaters can cause great erosion at the leeside of the construction.

- Locally executed (unprofessional) coastal protection measures

Other examples of human interference are local coastal protection measures, executed by plot owners that have counter effective results. Stone dumping can have adverse effects, increasing erosion through an increase of turbulence (for example in Sweden at Ystad, and in Denmark at Hyllingebjerg). It was often not realized or it was not thought to be of importance, that a hard revetment might solve their immediate problem but would cause problems further downstream.

- Damming of rivers

Since the 1930's, the construction of the cascade of dams on the Daugava river and dredging of sand for construction purposes from the Lielupe lower stream has essentially reduced the amount of river sediments reaching the Gulf of Riga. These interventions have caused a deficit of sediment output feeding the foreshore and beaches of the sedimentary coast. This deficit in

[4] Dixon, A.M., Leggett, D.J., Weight, R.C. (1998). 'Habitat creation opportunities for landward coastal realignment: Essex cases studies', Journal of the Chartered Institution of Water and Environmental Management, 12, p107-112

its turn has enhanced the coastline retreat in the areas adjacent to the Daugava river mouth in the end of the 20th century.

- Dredging

Regular dredging of bottom sediments at the Seagate of Klaipeda has corrupted the northbound longshore sediment drift, which for centuries had supplied the Lithuanian mainland coast with sand brought from the eroded Sambian promontory. Furthermore, also at Klaipeda, 500.000 m^3 of polluted sand was taken away from the sedimentary coast(beaches) of the case study area after the disastrous crude oil spill from a wrecked tanker in November 1981. The dredging has caused a deficit of sediments at the mainland foreshore and beaches at Klaipeda and has increased erosion significantly.

- Stone fishing

Another example of human disturbance causing erosion is stone fishing. The removal of stones was observed in front of the soft rock cliffs at Hyllingebjerg in Denmark. The natural protection of the soft rock cliffs was hereby removed and this increased erosion.

Future erosion

For the erosion in the future, climate change expressed by (accellerated) sea level rise and potential increase of storm frequency and intensity will be of great importance. The local rate of sea level rise is difficult to predict and the eventual effect uncertain. More in-depth studies will be required. The coastal types mostly affected by sea level rise are sedimentary coasts (especially low-lying sedimentary plains and salt marshes), especially in the nearly tideless Baltic Sea area.

Furthermore, the coast has lost resilience by the building of hard structures to fix the coastline. This will increase the erosion of the beach and foreshore area in the future. Damming and sand mining have decreased the supply of sediment to the coast and will therefore also increase future erosion.

1.5 North Sea

1.5.1 General description

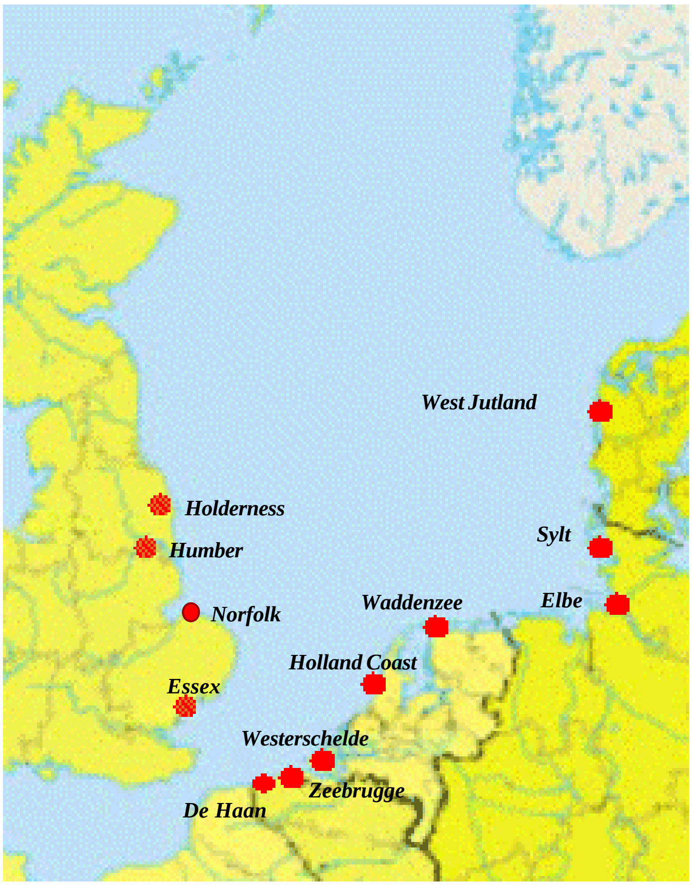
The North Sea is situated between the countries Norway, Denmark, Germany, the Netherlands, Belgium and United Kingdom (see Figure 1-4). It is linked to the Atlantic Ocean in the north and also in the southwest, via the Channel. To the east it links up with the Baltic Sea. The Kattegat is considered an interchange zone between the North Sea and the Baltic Sea.

Including estuaries and fjords, the total surface area of the North Sea is approximately 750,000 km^2 and its total volume 94,000 km^3. The drainage area of the North Sea covers about 850.000 km^2 and is inhabited by about 184 million people. Table 1-2 gives an overview of the length of the coastlines of the countries bordering the North Sea.

Table 1-2 Coast lengths of countries bordering the North Sea[5]

Country	Norway	Denmark	Germany	Netherlands	Belgium	United Kingdom
Length (km)	22,000	7,300	2400	450	65	12,400

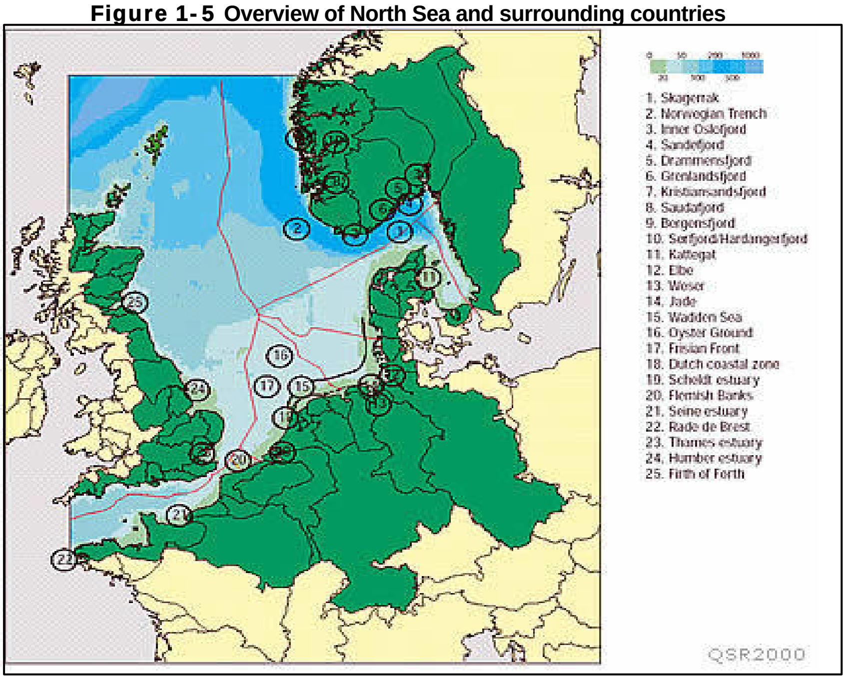
Figure 1-4 North Sea area with case studies



The coasts of the North Sea vary from coastlines intersected by fjords, via cliffs with pebble beaches to low cliffs with valleys to sandy beaches with dunes and estuaries with mudflats and saltmarshes. The average depth of the North Sea is about 95 m, although along the Dutch and Belgian continental shelf, the North Sea is relatively shallow (average depth of about 20 m). The depth of the sea increases towards the Atlantic Ocean to about 200 m. The deepest locations of the North Sea are located near Norway (up to 700 m).

[5] EUROSION Scoping study- Final draft report (September 2002)

Figure 1-5 Overview of North Sea and surrounding countries



The North Sea receives its river water input both directly and through the Baltic Sea. The yearly direct river water input is estimated to be about 300 km^3 whereas the input via the Baltic Sea is about 470 km^3.

The North Sea is a sensitive ecosystem that is under a great deal of pressure from intense human activities, such as fishing, sand and gravel extraction, shipping, oil and gas extraction, tourism and industry. Densely populated, highly industrialized countries surround the entire North Sea.

1.5.2 Geology and coastal classification

Geology

An overall cooling of the earth's climate during the Pleistocene epoch caused a series of ice ages, generating immense glacial ice sheets that invaded the European region and forming the present day coastlines. The ice sheets radiated from Scandinavia and covered Finland, North West Russia, North Germany, the Northern part of The Netherlands and the British Isles. The glaciation of the Pleistocene was not continuous, but consisted of several glacial advances interrupted by interglacial stages, during which the ice retreated and a comparatively mild climate prevailed. In all probability at least four major glacial stages occurred, the last glacial period ending about 11,000 years ago.

The glaciers made important alterations in the topography of the glaciated regions, levelling hilly sections to low, rolling plains, both by erosion and by deposition of drifts, eroding hollows that later became lakes, and forcing rivers to cut new channels by filling their former beds. The drift, consisting of a deposit of mixed clay, gravel, sand, and boulders, is the characteristic sediment of these glacial periods. Large sections of continental Europe are covered by drift.

After the glaciations, in the relatively warmer Holocene epoch, the retreat of these glaciers led to an elastic rebound of the earth's crust due to the removal of the enormous weight of the ice. Simultaneously the availability of increasing amounts of water from the melting ice sheets caused global marine transgressions (sea level rises).

Nowadays, the North Sea is a rather shallow semi-enclosed basin of continental shelf water with a surface of ca. 575,000 km2 (1,000 km long and 640 km wide). Its depth ranges from about 30 m on average in the southeast to 200 m in the northwest with a maximum depth op 660 m along the coast of Norway. It contains several shallows, the largest of which is the Dogger Bank, midway between England and Denmark.

Along most of the North Sea coastline the remnants of the glacial deposits from the Pleistocene period lie over much older deposits from the Tertiary period and Mesozoic era. Offshore the seabed is covered with deposits of sand, sand and mud or smaller pockets of gravel. Much of these deposits have been transported and 'reformed' to morphological dynamical bank systems along the coastline during the Holocene marine transgressions and occasional regressions of the sea. The sediment characteristics are varying over a wide range within the North Sea region, exact information on sediment characteristics is available in the case studies.

In some areas, such as the Wadden Sea islands along the northern coastline of the Netherlands, Germany and the western coastline of Denmark, submerged residual cores of glacial deposits form the basis on which barrier islands are created by the interaction of waves, (rip)currents and tides reworking the local (glacial) sand deposits. In other areas, glacial sediments were deposited against existing cliffs during the glacial retreat (Eastern Great Britain, Holderness and East Anglia) extending the cliff coastline seawards. Nowadays the sea is steadily eroding these cliffs moving the coastline back to the original location.

However, in more recent years (last several 1000 years) the marine transgression has decreased considerably. Large-scale erosion of the present North Sea coastline still persists, but the effects of rivers, current climate changes and human intervention are starting to become more enhanced, especially on a local scale.

Coastal classification

Hard and soft rock coasts

Although large parts of the north-eastern coast of the United Kingdom are rocky, the sites selected for the case studies around the North Sea are mainly sedimentary. Soft rock cliffs are found only at Holderness and very locally in Essex.

Sedimentary coast

The typical coastal formations along the North Sea are sandy beaches and dunes, shingle beaches, saltmarshes, estuaries. Along the estuaries and along several coastlines dikes and revetments were built, resulting in artificial coastlines. For the different countries surrounding the North Sea, the following coastal distinction can be made:

- South-east coast of the United Kingdom: estuaries, shingle beaches and saltmarshes;
- Belgium: sandy beaches and dunes
- The Netherlands: estuaries, sandy beaches and dunes and artificial coastlines;
- Wadden Sea coast of Germany: estuaries, sandy beaches and artificial coastline;
- West coast of Denmark: sandy beaches and dunes and artificial coastline.

The south-coast of Denmark and the Schlesweig-Holstein coast are the only micro-tidal coasts along the North Sea. These are sedimentary coasts with sandy beaches and dunes.

1.5.3 Physical processes

A large variation in tidal range is observed at the North Sea coasts, varying from 0.5 m near Denmark to about 6 m in the Channel. Micro-tidal as well as macro-tidal conditions are therefore found along the coasts of the North Sea. At the east coast of the UK, tidal currents go south on flood and north on ebb, whereas this is the opposite for the countries bordering the east side of the North Sea. Tidal current velocities range from 1-2 m/s.

The dominant wind and wave direction in the eastern part of the North Sea are northwesterly to southwesterly, with mean annual offshore wave heights of about 1 to 2 m and extreme wave heights up to 10 m. At the east coast of the United Kingdom the dominant wind and wave direction is north-easterly. As a result of its orientation, the south-eastern part of the coast of the United Kingdom is relatively sheltered from strong winds. Average wave heights of about 0.5 m are recorded, although this coast can be severely affected by easterly storms.

Storm surges can occur during northerly winds. Since the North Sea is connected to the Atlantic Ocean on the northern side, these wind directions cause the largest wind set-up, up to 3 m. Climate change can possibly intensify storms.

In the North Sea sea level rise in the last 40 years was about 2 mm/yr. Predicted rates for sea level rise for the next century vary between 0.5 and 9 mm/yr. This includes the effects of soil subsidence.

1.5.4 Erosion

General description

Along the North Sea coasts various types of erosion can be observed. Whether the dominant type of erosion is structural or acute depends to a large extent on the type of coast that is under consideration. Furthermore, different types of erosion can be observed at the same coastal stretch. For example, the Holderness coast is a soft rock cliff coast with beaches in front. Under normal conditions, structural erosion of the beach is observed because of the southerly-directed longshore sediment transport. Cliff erosion during these conditions is limited. However, more severe conditions may cause acute cliff erosion, with erosion rates up to 20 m per year.

The sediment transport depends on various factors, such as the type of coast, the wave direction and height and the composition of the coast (sand, mud, cliffs). Along the coasts of Belgium, the Netherlands and Germany, the net longshore sediment transport has in a north, northeasterly or easterly direction, depending on the orientation of the coastline. Sediment transport rates with average values ranging between 150,000 and 400,000 m^3 per year are observed.

The predominant westerly waves attack the Island of Sylt and the Jutland coast almost perpendicularly. Therefore, at the southern part of the Island of Sylt net sediment transport is southwards, whereas it is directed northwards at the northern part of the island. However, during storms (north-westerly) the coasts of Jutland and Sylt are exposed to large waves causing southerly longshore sediment transport rates from 500,000 to 1,000,000 m^3 per year.

The east coast of the United Kingdom is less exposed to waves and therefore the tide plays a relatively important role, especially in the estuaries in the southern part of the North Sea.

The main causes of erosion along the North Sea coasts are:
- Sea level rise for estuaries
- Gradients in longshore sediment transport for sedimentary coasts
- Storm surges for cliff coasts and dune coasts

Erosion of different coastal types due to driving forces

Hard rock coasts
no interesting information available.

Soft rock coasts
Soft rock coasts along the North Sea are found in Holderness and Essex. Soft rock cliffs are present locally, usually along with sedimentary coast (sandy or shingle beaches or estuarine coasts). The direct effects of soft rock erosion can be observed after a severe storm. The coast actually recedes as a series of landslips, which can take a bite out of the soft rock cliff top at one time. Erosion rates up to 20 m within a single storm were observed. However, such a land slip may be followed by a long period in which no cliff erosion occurs.
Observed yearly erosion rates as a result of storms vary between 0,5 m/year in Essex to 2 m/year at the Holderness coast.

Eroding soft rock cliffs serve as a sediment source for the beaches directly in front of the cliffs and for the coastal system as a whole. Beaches in front of cliffs form a protection against direct wave attack. Therefore, structural erosion of the beaches in front of the cliffs indirectly threatens the stability of the cliffs in the long term.

Sedimentary coasts
Along the micro-tidal sedimentary coasts in the southeastern part of the North Sea sandy beaches and dunes are found, sometimes with lagoons behind them, for example along the Jutland coast in Denmark. The erosion for these coasts is both acute and structural.

Acute erosion occurs when dunes erode as a result of severe wave attack. Since the area is exposed to rather high waves during storms, large erosion rates can occur.

Structural beach erosion is found as a result of diverging longshore sediment transport along the sandy coasts. During storms, the longshore sediment transport rates are larger, amplifying not only the sediment transport but also the erosion rates. The average yearly erosion rates are about 2-4 m/year with a maximum of 10-12 m/year.

Apart from erosion caused by waves, local erosion and migration of tidal inlets resulting from breaching of dunes has resulted in uncontrolled erosion of the Jutland coast, with tens of meters per year.

The macro-tidal sedimentary coast can be subdivided into different types of coast. Depending on the location of the site and on the dominant processes (waves or tide), the most important types that are found are sandy beaches with dunes and estuaries with saltmarshes.

Sea level rise is considered to be the main natural cause of erosion in the estuaries and salt marshes along the British and Dutch coast. For an estuary to follow the relative sea level rise, it needs to respond by accreting and eroding in different parts so that it seems to rise and move landward. Therefore, it needs to import sediment. The estuary's ability to adapt to the rising rate of sea level rise is uncertain. For the Humber it was found, that the overall volume of the water contained by the estuary appears to have been roughly constant over the last 150 years, implying that the supply of sediment has been adequate to meet the demand imposed by rising sea levels over this period.

In many cases erosion is limited by natural features, such as the local geology, or by the presence of defences. Salt marshes in front of these defences may erode through a process called coastal squeeze (see Box 1-2).

Box 1-2 Coastal squeeze in the Humber Estuary

Within the Humber Estuary, the rising sea level will result in a relative increase in wave height, threatening to over-top existing flood defences. As a result of a rise in sea level the height of the low and high water marks rise. Within an undeveloped estuary this would cause the sea to inundate low-lying land around the estuary and the intertidal mudflats and salt marshes would gradually migrate further inland. However, within the Humber Estuary the existing flood defences and new development encroaching onto the mudflats hold the existing high water mark in place. Therefore as sea level rises, the width of the intertidal zone will be reduced, with significant losses of the intertidal habitats. This phenomenon, which is known as coastal squeeze, also reduces the buffering protection afforded to the flood defences by the presence of intertidal mudflats and marshes and can result in erosion and undermining of defences.

Along coasts where sandy beaches and dunes are present the erosion is usually a combination of longshore and cross-shore transport processes. This is particularly relevant for coasts where a tidal channel is present near the coast. An example is found west of Zeebrugge in Belgium. During a storm, sediment is transported in cross-shore direction, ending up in the tidal channel 'Appelzak'. In contrast to beaches with a shallower foreshore, this sediment is not transported back to the coast during calm conditions, but is transported in longshore direction. In principle, this process is similar to the process of cliff erosion, where cross-shore transport occurs during storms and the sediment is carried away by longshore sediment transport.

Erosion due to human interference in the coastal zone

Human interference has significantly affected the natural processes of sediment transport and the resulting erosion and sedimentation along the coastlines of the North Sea. The effects of the actions and measures that were taken could, and still can, not always be predicted.

- Hard constructions for coastal protection

In an attempt to combat the negative effects of erosion many measures were taken at several locations. In the past, mainly hard constructions were applied for this purpose. The main disadvantage of these measures is that they are irreversible and not flexible. Another possible disadvantage is that hard measures do not always turn out to be effective in stopping the erosion. On the long run, many hard measures will fail and nourishments would be needed to protect them.

At various sites, hard constructions were applied in order to protect the coast. Along the Holderness coast, for example, at various locations private constructions were made to protect assets locally. While these constructions provide a short-term protection to the properties directly protected, their general nature and design is of concern. Private defences are often not of the same engineering standard as those publicly funded. They could pose safety problems and because of this – danger to beach users. They could also often be easily undermined during periods of beach “drawdown ”.

- Construction of ports and jetties

The construction of ports has resulted in increased erosion rated at various locations along the North Sea coast. For ensuring safe navigation into the port and for preventing siltation of navigation channels, relatively long jetties are required. Especially for large ports these jetties may block the longshore sediment transport, resulting in lee erosion. This is seen, for example, at the coast at the east side of Zeebrugge, where construction and the extension of the jetties in 1970 have resulted in serious erosion of the Knokke-Heist coast. The erosion along the Essex coast is partly attributed to a reduction of sediment input in the coastal zone as a result of the presence of the Harwich Harbour. Similar effects were observed at the Holland coast, north of IJmuiden, and along the Jutland coast, where jetties were constructed to prevent siltation of an entrance channel.

- Sand mining and dredging

Whereas beach nourishments may have a positive effect on coastal erosion, sediment extraction for sand mining locally attributes to erosion of the foreshore of the coast and may lead erosion of the beach and dune system om the longer term.
Local deepening of the seafloor can alter wavepatterns and cause gradients in sedimenttranports, resulting in local erosion.

Dredging is often required in estuaries and navigation channels in order to maintain a navigable depth. The Western Scheldt in the Netherlands is the connection between the North Sea and the port of Antwerpen. In the beginning of the 1970’s and also in the end of the 1990’s, the Flemish government deepened and widened the navigation channel to Antwerpen. As a result, the yearly amount of dredging has increased from 4 Mm^3 (1970) via 8-10 Mm^3 (1995) to an expected amount of 14 Mm^3 in 2002. Apart from these dredging activities for maintenance purpose, redistributing sediment, sand excavation takes place from the Western Scheldt estuary. Since 1955 about 90 Mm^3 of sediment has been excavated. A negative side effect of dredging is that it increases the tidal volume of an estuary, thereby possibly increasing water levels and tidal current velocities.

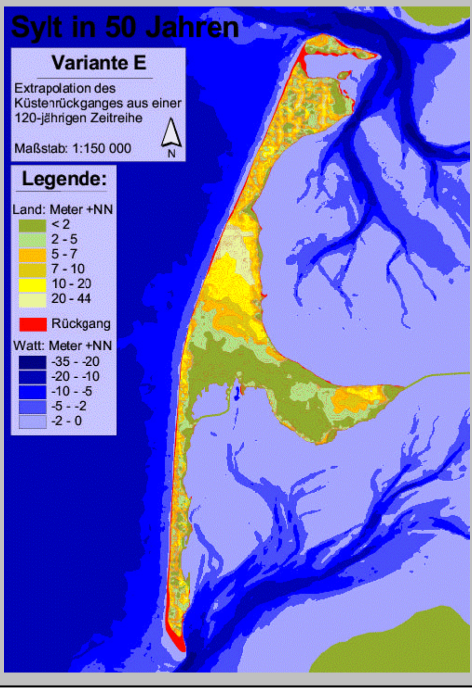
Future erosion

Different scenarios have been defined for sea level rise. Each of these scenarios shows that sea level rise will remain one of the most important issues in coastal zone management. Not only sea level rise is expected, but as a result of global warming along the North Sea coastline, an increase in frequency and duration of storms can be expected, resulting in more frequent and higher floods. Therefore, structural erosion as a result of sea level rise is expected to continue and continuous adaptation would be required.

The estimation of the quantity of the erosion is subject to many uncertainties. Often, it is assumed that the erosion rates that are observed at present can be extrapolated into the future. For Sylt, the future erosion was estimated using morphological models (see Box 1-3).

Box 1-3 Assessing future erosion with morphological models

For the coast of Sylt, morphological calculations were carried out in order to assess the future erosion. For the next fifty years, a model was set up to calculate the expected erosion of the island of Sylt through extrapolation. The result of these calculations can be seen in the figure. The List area (northern spit), Kliffende at Kampen, Wenningstedt at Westerland and Rantum-Hornum area (southern spit) will be affected most in the next fifty years according to these computations. These are therefore the most concerned areas to take care of in the future.



Furthermore, foreshore erosion linked to the sea level rise will become more serious as the rate of sea level rise increases. Foreshore erosion is on the long term a threat to sea defence and increases the expenditure needed to keep them in an acceptable condition. Ultimately, maintaining the sea defences could become so difficult that it would be necessary to set them back to a new line or carry out other works elsewhere which would achieve the same effect.

1.6 Atlantic Ocean

1.6.1 General description

The Atlantic Ocean borders Western Europe along the following EU-countries: the United Kingdom, Ireland, France, Spain and Portugal (see Figure 1-6). It is linked to the North Sea via a wide stretch of open water between Scotland and Norway in the north and the Channel in the south. Further south, the Atlantic is connected to the Mediterranean via the relatively narrow strait of Gibraltar.

Table 1-3 Coast lengths of countries bordering the Atlantic Ocean[6]

Country	Spain	Portugal	France	Ireland	United Kingdom
Length (km)	4,964[1]	1,793[2]	3,427[3]	1,448	12,400[4]

[1] Including the Mediterranean but excluding the Canary Islands (ca. 1,590 km)
[2] Including the Azores islands
[3] Northern coastline (bordering Atlantic and English Channel)
[4] Isle of Wight has 110 km coastline

Figure 1-6 Atlanic Sea area with case studies

The Atlantic coast is used for a wide variety of purposes ranging from agriculture, fishery and industry to living, tourism and nature. The explosive growth of the population in the littoral zone partly due to tourism has increased the pressures on the coast, especially along the French, Spanish, Portuguese coasts and the southern coast of the United Kingdom. For example, in Portugal 60% of the population lives in the coastal zone, but in the summer this increases to 80%.

In this study the coastlines of remote overseas areas such as the Azores Islands (Portugal) and the Canary islands (Spain) have also been examined. They will be discussed separately.

6 CIA-World factbook 2002

The nine Azores islands are located on the Micro-plate of Azores, which lies at the intersection of three tectonic plates; the African, the North-American and the Euro-Asian plates. The group extends some 480 kilometres in a northwest-southeast direction. The Azores islands have a population of 240,000.

The Canary Islands lie along the north-west coastline of Africa, directly in front of Morocco. The island group consists of seven large islands and five smaller ones and have a population of around 950,000.

1.6.2 Geology and coastal classification

Geology

Tectonic movements such as deformation or isostatic changes have created the landscape where cliffs and beaches alternately occur along the southern European Atlantic coast. In the North, the topography of Ireland and the United Kingdom is largely influenced by the more recent glacial age (11,000 years ago).

The high energy level of the waves and tides in the Atlantic Ocean create an irregular coastline of hard and soft rock cliffs interspersed with sedimentary coasts (sandy beaches, estuaries, dunes etc.). The Irish, southern United Kingdom, north Spanish and Portuguese coasts contain consist of many diffs, whilst the more protected French and south Spanish coasts are more often interspersed with softer coastal types such as bays, dunes and sandy beaches. The Aquitaine coast in France for example, consists of a 230 km long beach and dune system.

In the following passages each country is described geomorphologically:

In Ireland geological controls have resulted in extensive rock dominated and cliffed coastlines for the southwest, west and north of Ireland. In contrast, the east and southeastern coasts are comprised of unconsolidated Quaternary aged sediments and less rock exposures. Glacial and fluvial action however, has also created major sedimentary areas on western coasts. The resulting coastline of Ireland is highly irregular in form, characterized by a bay-headland type configuration. Coastal settings include rocky open coast, bays and estuaries, raised shorelines and drowned valleys. Significant coastal systems within these include those of cliffs, beaches and barriers (sand and gravel types), lagoons, dunes, machair (sand 'plains'), salt marshes, wetlands and mudflats.

Shingle beaches and cliff coasts from the Lower Cretaceous and Chalk characterize the coastline of in the south of the United Kingdom (Sussex) and northern France (Normandy). Together with wide intertidal platforms, the shingle beaches reduce erosion rates and protect the cliffs.

The northern French coastline is varied: some shorelines are rocky escarpments (Brittany) whilst others have long sandy beaches and dunes (the Nord, Aquitaine, Vendée and Landes areas). The overall area of sandy dunes is about 160.000 ha (including dunes covered with vegetation) situated along an estimated 910 km of coastline.

In Spain, the Atlantic Ocean lies along northern Cantabric and Galician coast. The coast is generally characterized by the existence of mountain ranges very close to the coast with very few coastal lowlands. The result is a coast with high cliffs and very frequent inlets and pocket beaches and “rias” (the term comes from this NE Spanish coast) outlets and islands. The continental shelf is very narrow in Basque Country and Cantabria and broadens from Llanes to La Coruna, going narrow again until Portugal.

The Portuguese coastline is composed of younger and less resistant rocks. It is a morphologically diverse coast, having extensive sandy shores backed by dunes (St. Jacinto, Estela), rocky coasts with low and high cliffs (St. Vincente Cape and south of Costa da Caparica), pocket beaches, bays (Setubal bay), estuaries and spits (North West coast), lagoons, barrier islands, amongst other features.

The Andalucian Atlantic coast consists of a plain zone (Guadalquivir/Guadiana system) and a more abrupt zone related to the Betic mountain range (Trafalgar cape to the Algeciras embayment). It has a Mediterranean hydrographic system in which the tides play an important role. The coast is mainly sandy with (mobile) dunes in some cases reaching a considerable height (Doñana Natural Park)The geology of Azores is complex due to the combination of volcanic phenomena and the movement of the oceanic plates. The islands, which host several dormant and inactive volcanoes, are made up of volcanic rocks constituting predominantly of basaltic lavas and trachytics and deposits of stone pumice.

An irregular submarine relief dominates the local sea bathymetry near the coastline. This irregular relief manifests itself through the presence of predominantly cliff coasts. The highest cliffs are found on the exposed side of the islands (mostly north-west side) and can reach up to 350 m above the sea level. The protected side (usually the south-east side) has sandy beaches laid in lower coasts, bays and inlets.

The Canary Islands are also volcanic islands made up of pyroclastic and basalt rocks. Next to the rocky coastlines at the base of the volcanoes, they have some beaches made up of wind blown sand originating through the constant action of the NE trade winds on the easily eroded flows and tufa.

Coastal classification

Hard rock coast

In a broad sense, the Atlantic coastline is made up of hard and soft rock cliffs interspersed with sedimentary coast: sandy and shingle beaches and dunes.

Hard and sorft rock coasts occur in both high and low relief areas where the underlying geological structures are relatively resistant to the erosive forces of sea, rain and wind. They are mainly present along Atlantic coasts, in western France. In areas of high relief the landscape is often characterised by steep cliffs, rocky outcrops and deep, usually clear offshore marine waters with small embayments.

The cliffed landscape is widely present in the Atlantic Europe. The more exposed rocky and cliffed coastlines extend along the northern France, the northwest of Spain and Portugal.Throughout much of this zone the coast is characterised by a macro-tidal range which in the west of the France is the highest in the area.

In the southern zones of Portugal, spectacular west-facing cliffs also occur. In Spain and Portugal relative sea level change is due more to local isostatic change or to tectonic effects than the impact of glaciation.The rocky shores and cliffs within this zone tend to be composed of younger rocks laid down under warm seas to form chalk and limestone.

The coastlines of northern France and northern Spain also include ‘estuaries’ within the hard rock dominated landscapes.These occur on the ‘rias’ (river valleys drowned by the rising waters following the last glacial period) with typically narrow, steep, often wooded, valley sides.

Soft rock coast

The soft rock coasts can be found along West Ireland (e.g. Donegal or Rosslare) and southern United Kingdom (Sussex), where soft rock cliffs with shingle and sand beaches and smaller dunes alternate between small bays and estuaries.

Sedimentary coast

Larger, extensive dunes can be found along the coast of north France (Aquitaine). In fact, along the exposed west-facing “Atlantic” shores coastal plains with sedimentary habitats occur.These may be relatively extensive as in the case of the Loire and Gironde in western France. Western France also has one of the largest expanses of dunes anywhere in Europe at “Les Landes” in the south. Here their development involves the progressive stabilisation of dune forms as the sand is blown inland and vegetation helps to create the more typical undulating dune landscapes.
In the coastline Atlantic Ocean-Channel-Northsea, the overall extention of the sandy dune ranges accounts for about 160.000 ha (including tree covered dunes) out of a dune coastline estimated at 910 km.

Now and then artificial coastlines (e.g. revetments, seawalls for cliff protection) can be found along the Atlantic coast.

1.6.3 Physical processes

The tides along the Atlantic coast are macro-tidal with a medium range of 2 m neap tide and 4 m spring tide. The highest tidal range (during spring tide) occurs along the French coast in the bay of Mont-Saint Michel and reaches up to 15 m! Tidal currents vary between 0.5 m/s along the French coast to 1-2 m/s along the Irish coast. Further to the south in Spain and Portugal, currents can exceed 2.0 m/s during flood and 1.8 m/s during ebb, with correspondent medium values of respectively 1.5 m/s and 1.4 m/s.

The Atlantic coast along France, north Spain and north Portugal is under the influence of a temperate oceanic climate characteristic of middle latitude coasts adjacent to the Atlantic Ocean. The regime has frequent and prolonged rainfall of relatively low intensity and year-around storms. The maximum rainfall occurs in autumn and the minimum rainfall occurs in summer. In south Portugal and south Spain, the climate is warm-temperate and oceanic with an acute dryness in the summer and soft winter temperatures.

Along the Irish, Portuguese and north Spanish coast, the dominant wave direction is NW (~50%) creating a wave climate characterized by a long distance swell with a medium significant wave height ranging from 2-3 m with a wave period of 8-12s. Along the exposed parts of the French coast (e.g. Haute-Normandy), the mean annual significant wave height is higher: 3.5-4.5 m, whilst in protected areas (e.g. Aquitaine coast) they are lower: about 1.4 m with a period of 6.5 s.

In the period between October and March, storms come in from the North Atlantic with significant wave heights exceeding 8 m (offshore they can reach values of 15-20 m) and periods reaching up to 16-18 s. Also, the winds in combination with waves can produce wind set-up along the coast. In Spain (Gross Beach, Donostia) values up to 6.5 m (H_s = 6 m) have been measured. In Portugal even higher waves have been observed.

During storms and high seas, the high-energy waves create a strong longshore drift and large amounts of sediment transport. The direction of the coastline and the incoming waves determine the direction of the longshore drift. In most cases storms come from W-NW ensuring a southerly or easterly orientated current. During calmer periods sediment is transported with the tidal currents. The resultant current (net difference between ebb and flood tides) is north to south along the Irish and Portuguese coast and east to west along the Northern French and Spanish coasts. Due to the slower current velocities, this sediment that is transported with the tidal current usually has a smaller grain size (e.g. mud and sand). Nevertheless, the main role of tidal transport is in the estuaries, inlets and channels.

Wind also transports sediment on land. Wind driven sediment transport plays a significant role in dune movement along the coast. In France the dominant winds are south-west to north-west (50%), with higher wind speeds (>8 m/s) representing 10-20% of the total.

In the future, due to global warming, it is possible that the coast will experience fewer but more powerful storms. In combination with a sea level rise they will produce a larger threat to the coastline and for buildings and infrastructure along the shore. In some cases (e.g. Spain and Portugal) the relative sea level rise is mainly a result of local isostatic changes rather than human interference (e.g. CO_2) or glaciation. In others, the removal of ice after the last glaciation period is the dominant factor (south United Kingdom). But in Ireland the effect of (the relative) sea level rise can be greater. Up to now land uplift has always compensated the sea level rise. However, scientists believe that this uplift (approximately 0.1-0.3 mm/year) has stopped which means that in the future the predicted sea level rise may have a larger impact.

In the southern part of the United Kingdom tide gauge measurements have provided estimations for a relative sea level rise of 2.0 mm/yr to 4.0-5.0 mm/yr.

In the Azores, the tide is much smaller and ranges between a maximum high spring tide of +1.80m and a minimum low spring tide of +0.20m. In the North Atlantic, north of the Azores, the wind rose sector with the highest probability of occurrence is between SE and NW. Winds with higher velocities (more than 18 m/s) occur with higher frequency coming from the W quadrant. These winds create waves with a significant wave height of 1-6 m and a medium wave period is 6-12 s. Maximum wave heights usually occur in the period October to March and can reach up to 1.8 times the significant wave heights: ca. 12 meters. Most waves come from a south-northwest direction.

The Canary Islands are characterized by the trade winds blowing almost constantly from a NNE direction, with storms coming from the third quadrant. They have a warm desert climate (ca. 21ºC) with dry summers. The dominant climatic characteristics are a regular temperature, high atmospheric humidity and scarce rainfall with evaporation 10 times superior to precipitation.

1.6.4 Erosion

General description

The high-energy, storm generated waves from the Northern Atlantic and the macro-tidal regime, are the dominant erosive forces along the Atlantic coastline. Together they create extreme circumstances in which strong longshore tide and/or wave driven currents and cross-shore wave driven currents that can easily erode beaches and undermine cliffs. The absence of plentiful replenishing sediment in the aftermath of storms and the physical collapse of the cliffs ensure a retreat of the coastline.

Erosion of different coastal types due to driving forces

Hard rock coasts

High and low relief hard rock cliffs erode at a slow rate (Azores islands), often depending on their lithological composition (e.g. layers with softer rocks in between hard rocks decrease the overall resistance and increase the erosion rate). Macro-tidal regimes ensure that the waves can undermine the cliffs more effectively.

Soft rock coasts

Chalk cliffs can be found in south United Kingdom (Sussex) and north France (Normandy). Their erosion rate, which is dependent on the energy in the incident waves, is faster than that of hard rock cliffs. Intertidal flats and shingle beaches protect the base of the cliff by decreasing wave height and energy. If these are removed, cliff erosion is accelerated.

Macro-tidal sedimentary coast

The sea levels that are reached during high tides and under set-up conditions during storms enable stronger longshore currents and higher waves to reach the beaches and dunes facilitating erosion. During relatively calm periods, the beaches and dunes are replenished with sediment. However, in most cases replenishment is prevented by human interference such as defence constructions along the dunes, harbour constructions and groins, damming of rivers (and thus sediment supply) and other activities such as sand extraction.

Erosion due to human interference in the coastal zone

Human interference is of paramount importance for the imposing increase in erosion rates along parts of the Atlantic coast. Local coastal defence measures as a result of expanding urbanisation often enhance natural erosion rates in surrounding areas by interfering in the delicate dynamic balance (adjusting capacity) between the sea and the land. The almost explosive growth of tourism in the littoral areas has led to rash and ad hoc construction of coastal defence works, especially in the southern part of the Atlantic coastline (e.g. Vale do Lobo or South Aveiro region, Portugal).

For example in Portugal, nowadays the erosion rate along some shorelines is a few metres per year. These values contrast with the computed 'natural' retreat rate observed in the 1940's and 1950's, which rarely exceeded 0.2-0.4 metres per year. It shows that the current coastal erosion in Portugal is mainly produced by human modifications to the natural processes of erosion.

➢ Hard constructions for coastal protection

Groins and harbour piers block natural sediment movement patterns and create 'sediment starved' longshore currents that erode beaches of sedimentary coasts downstream instead of replenishing them. Seawalls and cliff stabilisation works block natural replenishment through erosion.

The natural protective shingle beaches in front of the soft rock cliffs along the south of the United Kingdom coastline near Sussex have been (partly) removed by piers and groins, which cause leeside erosion. Cliff stabilisation works temporally stop cliff erosion, but therefore also stop the supply of shingle, decreasing the volume of the beach and thus allowing incoming waves to reach the cliff more easily. This problem is also present in North France (Haute-Normandy) where cliff erosion takes place with an average of 20 cm/year, mostly as a result of the impact of harbours and defence constructions on longshore drift of shingle.

At Châtelaillon in France, a seawall that was built to stop the lowering of the beach profile resulting from cross-shore wave induced erosion. The beach eventually disappeared and the seawall had to be protected with rocks. In bays, where littoral drift bypasses the entrance, this effect is even greater. In the bay of Sables d'Olonne, the reflection of waves on a seawall increased the cross-shore sediment transport in seaward direction. Because of the topography of the bay (pocket beach with headlands), no new sediment is transported into the bay to replenish the loss.

At Rosslare in Ireland, nowadays cliffs do no not supply sufficient material to replenish the beaches. Human influence (land reclamation and breakwater constructions) has caused the sedimentation patterns to change.

Near Vale do Lobo in Portugal, interruption of littoral transport due to the construction of groins and harbour jetties has speeded up the erosion of the local beaches which protect the soft rock cliffs. Now cliff erosion takes place during storms. Also intensive watering of the land near cliff edges (golf course) is increasing the possibility of cliff erosion.

- Damming of rivers

Another influencing factor is the reduction or even blocking of the sediment supply from the rivers into the seas by the building of dams. Torrential river floods often transport large amounts of sediment and are important for the local sediment budget. In Vagueira (Portugal), constructions in the Douro River decreased littoral transport. The same occurs in Estela (also Portugal), where dredging activities in the Cávado River and morphological changes in the river basin reduce littoral drift and cause the local dunes to erode. Also in Cova do Vapor (Portugal), the damming of the Tagus river, urbanisation and sea level rise ensure that insufficient sediment can be supplied to replenish the sediment that gets eroded during storms by waves and currents. Disappearance of the local beaches accelerates the erosion rates.

In north Spain at Playa Gross, erosion of the local beaches is due to the loss of sediment input from Urumea River, where dams in the river bed were built to control the torrential waters. In SW Spain, Guadiana river dams are strongly affecting SE Cadiz Gulf like in Isla Canela Coast.

- (Clandestine) Sand mining and dredging

The exploitation of sand from beaches (e.g. in Vagueira, Portugal) and dunes for e.g. agricultural or industrial purposes interferes with the natural sediment budget and causes erosion. This is also the case along the shingle beaches in Sussex (United Kingdom) and Normandy (France).

In Ireland the removal of cobbles from the dune protecting storm ridge by building companies and tourism has led to an increase of erosion. Furthermore tourists trample on the dune vegetation killing it and removing the stabilizing layer on the sand dunes so that they become exposed to aeolian erosion.

1.7 Mediterranean Sea

1.7.1 General description

The Mediterranean Sea (see Figure 1-7) covers 2.500.000 km^2 with an average depth of 1.500 metres the deepest point being over 5.000 metres in the part known as the Ionian sea, between Greece and the south of Italy. The maximum length of the Mediterranean Sea from Gibraltar to Syria is about 3.800 km and the maximum distance in the north-south direction from France to Algeria about 900 km. The coastline extends 46.000 km running through 22 countries. The Mediterranean Sea is a residual sea between Europe, Africa and Asia as the result of plats motion. The sea is connected to the Atlantic Ocean by the Strait of Gibraltar on the west and to the Sea of Marmara and Black Sea by the Dardanelles and the Bosporus on the east. The Suez Canal in the southeast connects the Mediterranean with the Red Sea, this connection is not relevant from an hydrological point of view.

Its major islands are:
Cyprus, Crete, and Rhodes in the east; Sardinia, Corsica, Sicily, and Malta in the center; Majorca and Minorca in the west.

Major countries bordering the sea are:
Spain, France, Italy, Croatia, Albania, Greece and Turkey on the north shore, Lebanon, Syria and Israel on the east, Egypt, Libya, Tunisia, Algeria and Morocco on the south shore.

Parts of the Mediterranean are given their own names, for example the Aegean Sea, the Ionian Sea,the Adriatic Sea, etc.

Figure 1-7 Mediterranean Sea area witrh case studies

Table 1-4 EU Countries coast lengths in Mediterranean Sea region

Country	Spain	France	Italy	Greece	Slovenia
Length (Km)	2.093	1.700	7.600	16.000	47

The major rivers of the region have generated invaluable wetlands such as the deltas of the Nile, the Ebros, or the Rhone. Although the Mediterranean sea covers only one per cent of the world's marine areas, it contains some six per cent of its marine species. Some of the world's most endangered species, such as the monk seal, can be found in the Mediterranean. Fish stocks are down to 20 per cent of natural levels in some areas, and the Mediterranean is now a net importer of fish.

Today, 82 million people live in coastal cities; by 2025 there will be an estimated 150-170 million. Today the southern countries account for 32 per cent of the region's population; by 2025 that is expected to have reached 60 per cent. Seasonal population pressures are also expected. Over 100 million tourists flock to Mediterranean beaches every year and this number is expected to double by 2025.

The Mediterranean coast is perceived as being not very vulnerable to sea-level rise, although it is not clear whether this perception is fully correct. The Mediterranean is seen as little vulnerable because of tectonic uplift (Cyprus, most of Italy's east coast and rocky and steep coastlines (Croatia,Turkey, Malta). Moreover, countries such as Malta and Spain have considerable experience with adaptation to problems in the coastal zone, such as erosion. There are a number of exceptions to this general sense of invulnerability to sea-level rise. Such exceptions include the Ebro and Rhône deltas, and the historical city of Venice. Furthermore, there are many, small `pockets of vulnerability'. Although these do not cover large amounts of land or substantial shares of the population, they may be important economic assets (*e.g.,* sandy beaches) or important ecological areas (*e.g.,*coastal wetlands). Other issues and developments may well be more important than sea-level rise. These include other aspects of climatic change (primarily changes in precipitation and temperature), but also issues such as population and economic growth, and changes in the national and international political situation. Generally, coastal zone managers in the Mediterranean do not pay a lot of attention to accelerated sea-level rise, even though long term investments are made.

1.7.2 Geology and coastal classification

Geology

The geology of the Mediterranean is extremely complex and subject of continuous scientific debate. The large scale evolution is dominated by the tectonic convergence of Europe and Africa. The convergence leads to large vertical (uplift and subsidence) and horizontal (displacement of landmasses and basins) movements and active volcanism (Italy Sicily, Greece). The vertical movements differ regionally and even locally, with different rates and styles (abrupt or continuous) of movement. The surface geology also differs strongly alongshore, with outcrops of various types rocks of different ages as well as a broad range of quaternary sediments. Given the complexity and variation in geology along the Mediterranean shores, this must be considered on a local or regional scale.

There are three major geomorphical settings within the Mediterranean basin; areas with stable margin characteristics, areas with unstable convergent margin charactericstics, and areas with extensional margin (rifting) characteristics. Thus the Mediterranean basin is a location of an intercontinental interplate system; with compressional and extensional events occurring within close proximity. Subsidence-related and other vertical displacements are also found in compressional and extensional areas. A few notable events occurred during the Cenozoic which affected the entire Mediterranean; the Messinian "salinity crisis", when the closing off of the Mediterranean-Atlantic seaway caused complete isolation of the Mediterranean and thus widespread evaporation; and then the Pliocene "revolution", when the channel opened back up, causing reestablishment of marine conditions; and the Quaternary "transgressive raised terraces," of controversial geological origin; among others.
At least, six major basins can be structuraly and morphologically differentiated: Alboran, Liguro-Provençal, Tyrrhenian, Adriatic, Ionian and Levantin
The Central portion of the Mediterranean basin exemplifies the juxtaposition of compressional and extensional tectonic activity in the area. The region bordered to the west by Sicily and to the east by Turkey's west coast (encompassing the Aegean, Ionian, and Adriatic seas) exhibit a particular set of features.

Coastal classification

The two broad categories of coastal landscapes (high cliffs and low-lying flat land) are not mutually exclusive, nor restricted to particular geographical areas.

Hard rock coast

Cliffs and more gently sloping rocky shores are often composed of various types of limestone which form the basis for the karst landscapes of the hinter-land.

Sedimentary coast

Along the micro-tidal sedimentary coasts in the European part of the Mediterranean sea sandy beaches and dunes are found, frequently with spits and lagoons in low coasts. In Spain, with the exception of some river mouths, coastal low lands are very limited in the Andalucian Mediterranean coast and from Murcia to Cataluña a group of mountains ranges bordering the sea are setting the edge of this coastline. In France, on the continental Mediterranean shore, most of the dunes stands are located in the Golfe du Lion. The beaches and deltaic coastline is evaluated at 230 km (of which 120 km are "lidos"). The latter are low-lying dunes, the main part of which has been pulled down because of urbanisation processes. In Corsica dunes are not much developed, they often show up as a sandy arrow or a coastal string, and most of them are located on the eastern part of the island. In Italy, continuous belts of sandy beaches are mostly developed on the Adriatic coast of the peninsula.

Deltas and narrow coastal plains, generally occupied by wetlands and lagoons, help to define the landscapes of the Mediterranean coasts. These are present throughout the region and are most extensive in areas backed by mountains where major eroding catchments deliver large quantities of sand and silt to the coast. Short torrents, without water during most of the year, are draining enormous volumes of water in response to heavy local rains, in very short periods. This causes floods which also enhance sedimentary processes. This process combined with the small tidal range help to create some of the largest deltas in Europe: those of the Ebro, the Rhone and the Po rivers. All of these have been modified in some way by human activity whether through changes to the cycle of deforestation in the hinterland, damming of rivers delivering the sediment or drainage and other activities in the deltas themselves. Developed deltaic coast is restricted to the Po delta, which occupies the northern Adriatic. Barrier islands coasts, with associated lagoons and coastal lakes, are characteristics of the territories north of the Po delta, and occur along a coastal stretch of 130 km.

1.7.3 Physical processes

The circulation pattern of the Mediterranean is complex, with a limited exchange with the Atlantic Ocean through the Gibraltar Strait. Fresh water supply comes from few large river systems, including Nile, Rhone, Ebro and Po and numerous smaller rivers and streams. The basin is relatively salt, because of the excess of evaporation over fresh water influx. Because the Mediterranean is more or less land locked, the climate is dominated by land-masses rather than marine influence. The main circulation in the Mediterranean is a counterclockwise movement of the water. The water coming in through the Strait of Gibraltar flows eastward along the north coast of Africa, and then branches off. A counterclockwise current is created in the eastern Mediterranean. In the western Mediterranean the current continues along the north coast of Sicily, and then moves to the north, west and south, along the coasts of Italy, France and Spain, back to Gibraltar. The outflow to the Atlantic Ocean is a subsurface current below the inward current. The current flows with a speed of one to two knots (one knot = one nautical mile or 1.852 metres per hour). It is more powerful in summer than in winter, because there is more evaporation during the summer. There are a few secondary currents moving in the same direction: there is one to the north of Algiers, and another one to the west of the Tiber. These special currents are strong and dangerous in narrow channels, such as the Strait of Messina.

The Mediterranean is micro-tidal, with small variations alongshore due to basin shape. Seas that are almost completely closed have, like lakes, only a very small tidal range, i.e. a small difference in sea level between high and low water. In the Mediterranean tides are only significant in the Gulf of Gabes (to the south-east of Tunisia) and the northern Adriatic. The general mediterranean astronomical tidal range is about 20 centimetres. In the Adriatic it can reach about 90 centimetres. The latter sea can almost be regarded as a channel, between the straight Italian coast, and the coast of the Balkan peninsula, with many small islands, most of which run parallel to the coast. In the Adriatic Sea not only the tidal range is different: the surface currents are created primarily by the wind. They can reach a speed of three and a half knots.

Water level variations results from climatic influence in the form of atmospheric pressure changes and winds. The complex basin geometry, and the variations in weather hinder the description of one wind- and wave-climate. As to the general climate of the Med: it is windy, with mild, wet winters and relatively calm, hot, dry summers. Spring is changeable, autumn is relatively short. The flow of the air into the Med takes place through gaps in the mountain ranges. In the summer most mediterranean winds come from the north. A number of special winds occurs. Some of these are: Levanter, Gibleh, Sirocco, Mistral (or Maestrale), Libeccio, Tramontana and Bora.

The size of coastal cells (i.e. coastal units with marked physical boundaries that share their sediments) along the Mediterranean varies strongly depending on the local and regional geology and sediment-transport pathways. Sediment sources vary accordingly. Sediment sources can be fluvial, cliff erosion, biogenic production and alongshore redistribution. On certain parts of the Mediterranean the input of biogenic carbonates (shells of various organisms) plays an important role in the sediment budget. The production of biogenic carbonates can be coupled to specific habitats on shoreface and slope, dominated by Posidonia Oceanica (see for instance the Mallorca case study).

The eastern Mediterranean has been subject to a high sea level rise during the past decade at a rate up to 20 mm/yr in the Levantine basin. Sea level rise of 5-10 mm/yr is also observed in the Algerian-Provencal basin as well as in the Tyrrhenian and Adriatic seas. The north Ionian sea, on the other hand, shows an opposite trend, i.e., a sea level drop of ~-5 mm/yr. Sea surface temperature trends are highly correlated to sea level trends, which suggests that at least part of the observed sea level change has a thermal origin. The Mediterranean sea level rise observed by satellite altimetry during the last decade is possibly related to the warming trends reported from hydrographic cruises in the intermediate and deep waters of the eastern Mediterranean since the early 1990s, and of the western basin since the 1960s.

The relative sea level rise can have important implications for the future of the deltas of the Mediterranean Sea. However here the pattern of change is much more complicated with tectonic movements caused by a variety of influences (e.g. volcanic activity and earthquakes). When this is coupled with human influences which exacerbate sea level rise, significant problems of erosion, salt water intrusion and flooding can occur.These effects are especially important in the major deltas where a decrease in sediment availability and subsidence due to water pumping or the sheer weight of infrastructure may be some of the factors which give rise to substantial problems of erosion and flooding as is being experienced in several of the major Mediterranean deltas.

1.7.4 Erosion

General description

Driving forces of erosion processes along the Mediterranean coast are pretty similar amongst them, but a high diversity results from geo-morphologial features of each different area (Geodiversity). As a natural process of hundreds of years, erosion is mainly due to winter storms, when most of the material is extracted from beaches and transported elsewhere down the coast line, a fraction of it being lost forever under the bathymetric of –10 m/-15 m and, naturally, replaced by new material from continent shelf erosion transported by rivers.

All these forces reach to a natural equilibrium point where as much material is eroded as it is sedimented. However, the rising of sea level introduces a condition of displacement of that equilibrium which again set different acting forces to work. Lately, since most of the new material remains trapped in dams and reservoirs along Mediterranean river basins, at least one of the acting forces is not present and the equilibrium does not occur naturally. Moreover, quite a number of man-made causes are present throughout the Mediterranean Sea: obstacles to longshore drift (ports, dykes, and so on), and a weakening of the coastal material resilience due to development and urbanization processes.

So, a lot of erosive problems in the coastline are the evident manifestation of the coastal dynamics disturbances. It is the result of different impacts and processes that can be summarised in the next points:

- Sea level rise whose effects, however slow, can provoke an irreparable impact over the low littoral, specially when the natural adaptation possibilities are hampered by urban settlements.
- The reduction of the sediment sources, specially the ones originated in the river-basins. This reduction is often the consequence of changes related to the catchment area regulation, mainly with dams.
- The increasing number of barriers to sediment transport: mainly coastal defence and harbour structures. This is often the direct cause of many accounted regressive sand beaches and coastal dunes.
- The occupation and alteration of beaches and coastal sand dunes in most of the cases due to the tourist and urban pressures. These alterations degrade the beach stability, reduce the bulk of moving sediment and increase the erosive problems over urban settlements and roads.
- Non controlled extractive activities in river basins and in coastal sand dunes that contribute to weaken the available volume of sediments. In some regions like Murcia and Almeria greenhouse crops has have a strong influence in this phenomenon for sand coming from coastal dunes has been used as a substrate.

Erosion of different coastal types due to driving forces

Hard and soft rock coasts

Rocky coasts are widespread in Mediterranean sea (Western Corsica, Riviera, Liguria, Sardinia, Puglia, Cataluña, most of Greek coastland, etc). The erosion rate is generally small and manly caused by wave attack (wave generated by boats and ships can erode unprotected shorelines or accelerate the erosion in areas already affected by natural erosional processes).

Microtidal Sedimentary coast

In Greece there are beaches with sand dunes and wetlands too. But the increment of tourism, majority in the small islands, and the construction of hard engineering structures along the coast modify highly the natural processes of erosion. An example of erosion in the Po Delta system is given in Box 1-4.

Box 1-4 Erosion in the Po Delta

The Goro Po mouth is located in the southern part of Delta Po system in the High Adriatic Sea, at the south of Venice. Po river, after 600 kilometres of its main course, divides their waters in five branches (respectively from north to south, Maestra, Pila, Tolle, Donzella and Goro rivers). Every branches produced its depositional coastal plain body and deltaic front.

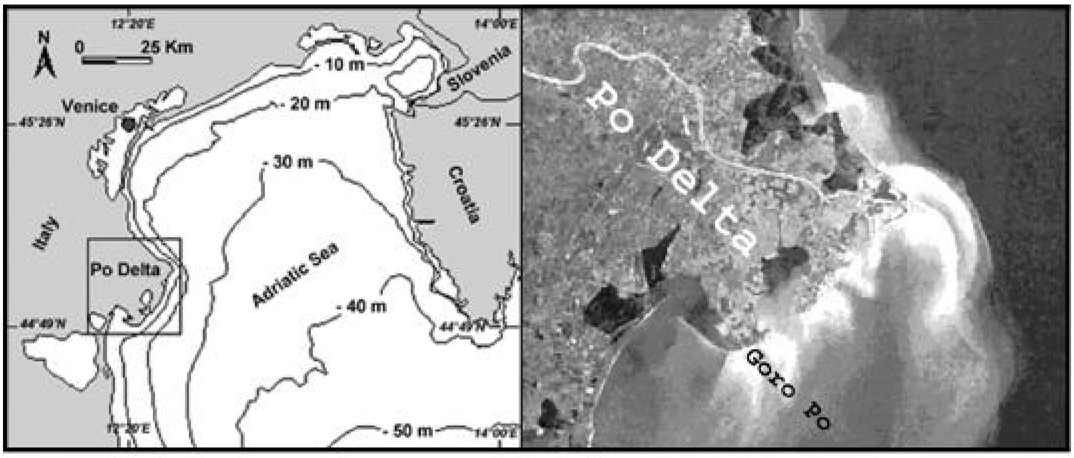


Figure. Po Delta apparatus location. In the southern part of Delta lobe near the Goro Po mouth, there is the described area.

The deltaic littoral area is mainly characterized by bars sometimes related to wide spits evolution, that edge large inner land lagoons with high anthropic pressure. A submerged delta area, ranging about 6 to 10 km width toward the sea, closes the deltaic apparatus. In all the “Scanno di Goro” spit (Simeoni *et al*., 2000) a beach of about 60 meters wide and a submerged bar at 350 metres distance about are present. The considered mouth area is a focal point for the “Sacca di Goro” lagoon, because the littoral spit system starts from this point, and separates the lagoon from the Adriatic sea.

At nowadays in Goro Po area a sandy beach edged by coastal dunes ridges and submerged bars on the bottom are present. The spit defines the homonymous behind lagoon, 200 hectares wide and about one meter deep. The morphology of the emerged lands in the Delta area shows wide portions under the present sea level.

The Goro Po mouth shows a clearly asymmetric morphology dues to the **erosive trend** acting in left side of the mouth and a large bar in the upstream side. All these conditions indicate that the environment evolution is strongly controlled by waves (Del Grande and Tessari, 2000; Simeoni *et al*., 1998).

Erosion due to human interference in the coastal zone

In the Mediterranean, while sea level fluctuations in historical times seem to be largely determinated by local tectonic effects, climate change may have represented an additional factor particularly affecting the most important natural wetlands and coastal lowlands in different coastal areas. Human-induced effects maximise the problems linked to sea level rise, via the following damaging activities:
-A reduction of river sediment supply.
-The destruction of natural shoreline defences, such as sand dunes and coastal ridges, for coastal urban development relating to commercial or tourist activities.
-The excessive pumping of groundwater, which may increase subsidence due to the lowering of piezometric surfaces of confined aquifers, as well as to compaction phenomena.

➢ Damming

Dams prevent natural sedimentation processes by restraining the flow of riverine fresh water, so reduce sediment supply to the coastal system and deltas.
Of the over 6000 large dams in Europe, Spain has the most (1200), followed by Turkey, France, Italy and United Kingdom whom each have more than 500 large dams.
Mediterranean regions are a very clear example of problem related to damming. In fact, the major part of rivers have a torrential regime and so the effects of dams are stronger: in this case, dams have a very short life and detain a lot of sediments that otherwise would reach the beaches. The example of the Ebro delta is highly representative: less than a 5% of the sediment carried before damming is reaching the delta (serra, 1997[23]).

➢ Gravel mining

In stream gravel mining is, together with dams, the main cause of sediment deficit in many rivers. In stream mining directly alters the channel geometry and bed elevation while disrupting the continuum of sediment downstream.
One of the most dramatic examples of wild gravel mining in the Catalan Coastal Ranges can be followed in the not regulated Tordera River (970 km^2). There, around $5 \cdot 10^6$ t of sand and gravel were extracted during the sixties and seventies until 1982, when mining was prohibited. This means ten times more the annual sediment yield of the Tordera River, including both suspended and bedload (Rovira et al., 2002). Fluvial sediments were converted to aggregated for construction in the Costa Brava area during the rapid growth of tourism during those decades.

➢ Ports, port extentions and marinas

Large ports (harbours) and small ports (marinas and leisure activities) are one of the main causes of coastal erosion, especially in wave-dominated coasts with important sediment transport drift.

➢ Urban and economic development

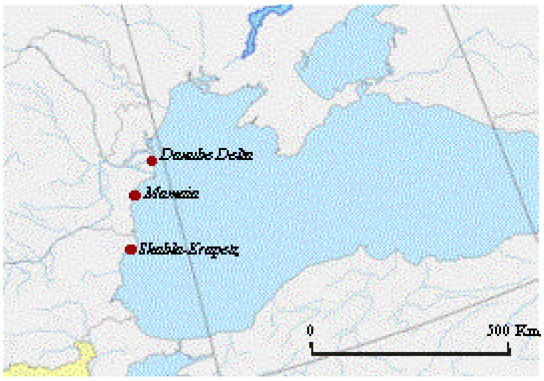
Roads, buildings, and other infrastructure can limit or affect the natural response of coastal ecosystems to sea level rise. As populations in coastal areas have grown and economic activity has intensified so a range of often inter-related and conflicting pressures have emerged in the coastal zones focused around agricultural use, industrial and port use, residential use, tourism, coastal water quality and fisheries. These in terms have caused pressure for coastal development and land reclamation around estuaries and lagoons.
In France, for example, natural coastal areas are being lost at a rate of 1 per cent a year; 15 per cent have disappeared since 1976, and 90 per cent of the French Riviera is now developed.

1.8 Black Sea

1.8.1 General description

The Black Sea is an inland sea lying between southeastern Europe and Asia Minor (see Figure 1-1). It is connected with the Aegean Sea by the Bosporus, the Sea of Marmara, and the Dardanelles. Romania, Bulgaria, and the European portion of Turkey bound it on the west. The Northern and Eastern shores are bordered by Ukraine, Russia, and Georgia; the entire southern shore is Turkish territory.

Figure 1-8 Black Sea area with case studies



The Black Sea basin is relative deep, down to -2.245 m. The annual supply of fresh water is 340x10^6 m^3, of which the Danube contributes 200x10^6 m^3. Annual water exchange through the Bosporus Strait with the Mediterranean is 120x10^6 m^3, The salinity of the Black lies around 33 ‰, and is influenced by the supply of fresh water and the supply of salt Mediterranean water.The basin is strongly stratified, the upper 200 m are well mixed and oxygenated, the water below are oxygen depleted. A lack of dissolved oxygen below 100 m, together with high concentrations of hydrogen sulfide prohibits the growth of anything except for a specially adapted bacteria. This also gives the water a dark 'gloomy'look when looking away from the shallow shelf areas

The Black Sea has a length of about 1.200 km from east to west, a maximum width of 610 km, and an area (excluding its northern arm, the Sea of Azov) of about 436.400 km^2. The Crimean Peninsula projects into the Black Sea from the north, forming the shallow Sea of Azov on the east and the Karkinitskiy Gulf on the west. The former is almost entirely cut off from the Black Sea. The sea receives the drainage of a large part of central and Eastern Europe through the Dnepr, Dnestr, Southern Bug, and Danube rivers. It also receives waters from a considerable section of eastern European Russia, through the Don River (which flows into the Sea of Azov) and from the western Caucasus region through the Kuban (which also flows into the Sea of Azov), and a number of smaller rivers; and the Black Sea drains northern Asia Minor through the Çoruh (Chorokh), Yesil Irmak, Kizilirmak, and Sakarya rivers. The floor of its single central basin lies about 1.830 m below the surface, and the greatest depth exceeds 2.135 m.

The coast of the Black Sea is fairly regular, excepting the peninsula of the Crimea in the north. The southern coast is lined with fairly steep mountains, the Pontic Range, and these mountains plunge steeply into the sea. The water depth is greatest along the southern coast, creating excellent ports but relatively poor fishing. Along the northern shore the major rivers mentioned above have formed a shallow shelf, which extends many miles into the sea. The shelf environment, with sunlight reaching the bottom, has a wealth of bottom growth, which in turn supports a large fish population.

1.8.2 Geology and coastal classification

Geology

The Black Sea was formed as a residual basin of the ancient Tethys Sea from about 250 Ma (beginning of the Mesozoic Era) to 40 Ma (Late Eocene) years ago. Most of the studies suggest that the Black Sea opened during the Cretaceous as a back-arc basin behind the Rhodope-Pontide volcanic arc and in continuity with the now-closed Sredna Gora Zone in Bulgaria.

Some authors suggest that the west and east Black Sea basins have separate origins. Multichannel deep seismic reflection and refraction, gravity, and magnetic data show that the western and eastern halves of the Black Sea have different structural features. The west Black Sea basin trends east-west and is floored by oceanic crust overlain by > 14-km-thick, flat-lying, undisturbed probably Cretaceous to Holocene sediments. It is separated by the mid-Black Sea ridge, a region of thinned continental crust, from the north-west-trending east Black Sea basin, which has oceanic crust with < 12 km of sediment cover. Unlike the west Black Sea basin, the ridges and basins in the eastern Black Sea are intersected by a large number of faults. This suggests that the major part of the west Black Sea basin opened during the Late Cretaceous by back-arc rifting of a Hercynian continental sliver from what is now the Odesa shelf. In contrast, the east Black Sea basin, which has a more complicated structure, opened as a result of the counterclockwise rotation of the east Black Sea block that started in the mid-Cretaceous (97.5 Ma).

The whole region is at present tectonically active. The very recent rapid subsidence characterizes not only the abyssal Black Sea, but also a series of more-or-less elongated basins extending westwards to Italy. The basin has been undergoing almost continuous sedimentation. The sedimentation rate was about 0.1- 0.2 m/Ka during the time span from the Late Miocene to the Late Pliocene (5.3-3.4 Ma), increasing to 0.3-0.6 m/Ka in the Late Pliocene, and increasing sharply to 1.2-1.3 m/Ka starting in the Günz-Mindel Interglacial Age about 0.8-0.5 Ma, when lacustrine megavarve deposition and episodic slumping set in.

During the past 20 Ka, the sedimentation rate has been controlled primarily by climatic changes and the impact of man. During the peak Würm Glacial Age rates were characteristically low because of the wide area coverage of ice sheets and permafrost in a reduced drainage area. From 15 to 7 Ka, there was a rapid increase in sedimentation rate as a result of deglaciation and massive release of detrital material. From there on to about 2 Ka, sedimentation averaged around 10 cm/1000 years, only to rise again as a consequence of human activities via deforestation, land use, etc.

Coastal classification

The European part of the Black Sea is the eastern, concerning Bulgarian and Romanian coasts. In the eastern part of Bulgaria, by the Black Sea Coast, there are well outlined wide beaches. These occupy approximately 130 km of the Bulgarian Black Sea coast (378 km). The Kamchiya-Shkorpilovtsi Beach Line is the longest (12 km). These beaches are wide and strewn with fine sand.

The Romanian coastline can be divided into two major geo-morphological units: Hard and soft rock coast in the southern and sedimentary coast in the northern unit.

Hard and soft rock coast

The southern unit, between Midia Cape and Vama Veche (covering 80 km), is predominantly covered by active and inactive cliffs (52.6%); with some beaches at the river mouths (28.8%) and harbours (Midia, Constanta and Mangalia 18.5%). Cliff heights differ from one place to another (from 3-4 m up to 35 m). Some areas of high shore are made of loess of soil, whilst others are composed of Sarmatiam limestone. The sediment, which appears near the beach face of the lagoons (Eforie, Costinesti, Tatlageac, and Saturn, Mangalia), consist mainly of medium coarse organogenic sands (more than 70%). This zone is divided into two sub-units. The first one, Midia headline-Singol headline, displays a transitional character with large barrier beaches, links a series of active headlines. The second one, Singol headline- Vama Veche shore, is characterised by active cliff erosion. There, the coastline is interrupted by barrier beaches, which are located in front of lagoons

The Romanian continental shelf up to the 200m isobath is 22.998 square kilometres. Its width is considerable-ranging from 100 km in the northern sector to about 80 km in the southern one.

The main morphological features on the continental shelf are the Danube Prodelta (more than 5.500 square kilometres), adjacent to the delta territory, and the Viteaz Canyon (Danube Canyon) at the shelf-edge.

Sedimentary coast

The northern unit (covers 164 km in length) extends from the Musura Bay to Midia Cape, including the Danube Delta and Biosphere Reserve and lateral lagoon complex Razim-Sinoe. This area is characterised by sandy beaches, low altitude and gentle submarine slope. The sediments of the superficial layer present great variety of mollusc shells and clay. Fine and very fine sands cover more than 75% of this area.

1.8.3 Physical processes

The Black Sea is nearly tideless, because it is not coupled to the oceans, and it is too small to generate tides of its own. Wind and waves are therefore the main forces that act on the shores. Winds and associated pressure systems can lead to temporary changes in the sea-level of up to 40 cm. The dominant wind-direction is form the North, both in intensity (wind speed) and in duration. Storms mainly occur in winter periodes. The wave directions follow the wind directions. Waves with a height of up to 6-7 m reach the shores, from all directions but west. Given the orientation of the western Black Sea coastline (roughly north-south), and the dominant wave direction the resulting residual current is directed from north to south. Sediment-transport is also directed from north to south. The case studies from Mamaia beach (Romania) and Shabla-Krapetz (Bulgaria) give detailed distributions of waves and wind during the year.

The change in relative sea level is composed of the eustatic world-wide change, and a local subsidence or uplift related part. The local part introduces variations in relative sea-level rise along the Western Black Sea between 20 tot 40 cm per century. Relative sea-level rise is larger in the Danube delta area (local subsidence) than along the remainder of the shores.

1.8.4 Erosion

Erosion is one of the main problems along the coast of Romania. Between Sulina and Vama the extent of erosion reaches up to 60% - 70% of the shore length and shows an increasing rate.

The northern part of the coast zone (Sulina –Vadu) lost about 2.200 hectares (that is 77 hectares/yr) from 1962 to 1991. The shoreline retreated up to 340 metres in the last three decades, with an average of about 200 m. At the same time, the accretion amounted to only 169 hectares, that is 6 hectares/yr. At present, the shoreline is strongly affected by man-made structures (hydrotechnical offshore works placed on Midia and Singol Headlines).

Protection systems (hard and soft) have been built along the coastline of Romania. The construction of this started some 65 years ago, chiefly in the southern area. Otherwise, erosion effects are expected to become increasingly important with impacts of climate change and accelerated sea level rise.

Erosion was estimated to have affected 236.8 km of the coastal area of Bulgaria, at an average rate of 0.11m/y. (eroded area 26.600 sq meters and eroded volume of 575.300 t/y.). The rate of coastal erosion is highest in the loess parts of the north coastal zone (up to 1.5-2.0 m/y.) and in the clayey alevrolites in the southern part (up to 2.0-2.5 m/y.). A scour of the accreted sand coasts has further been recorded (Dachev, 1995). On the basis of a period of 30 years of investigation, it was established that 61.700 m. of beaches (44.3%) have been eroded at mean rate of 0.385 m/y.

Natural and anthropogenic factors are pointed out as the main causes for sea-level rise. The natural factors involved include changing river discharge into the Black Sea, rainfall-evaporation balance and water exchange through the straights linking the Black Sea to the Mediterranean.
Given the length and variation of the western Black Sea coast there is variety of causes for coastal erosion. The Danube delta and the remainder of the coast will analysed separately

Soft-rock coasts

Acute erosion due to wave action, leading tot ongoing cliff retreat.
Structural erosion due to
- Man-made structures, that influence the longshore orientation of the coastline (for instance the Midia harbour extensions near Mamaia, Romania)
- Relative sea level rise
- Abrasion of biogenic sediment (shells)
- Diminished input of biogenic sediments (shells)
- Sand extraction (now prohibited)

On a longer time scale the changes in the large scale littoral system, induced by the reduced supply of sediment from the Danube will enhance coastal erosion.

microtidal sedimentary coast: Danube Delta

Of the delta 57% of the shores are subject to erosion, 36% accrete and 7% remains stable.
Structural erosion due to
- The damming of reaches of the Danube river, which prohibit the influx of fresh fluvial sediments to the shores;
- The construction of the Sulina-jetties, which hinder the alongshore exchange of sediments and change the long-term equilibrium coastline shape;
- Changes in the tributaries of the delta, which the location and influx of sediments.

These man-induced changes go along with natural changes in coastline orientation (negative and positive), that are inherent to deltaic shores.
Relative sea-level rise induces a continued coastal retreat. Under limited conditions the adaptation of the coastal profile can be estimated following the Bruun-rule.
The Danube case study presents are more elaborate description of the causes and magnitudes of erosion and sedimentation on the shores of the Danube delta

Erosion due to human interference in the coastal zone

The human modifications and actions contribute to accelerate the local problems of coastal erosion. Jetties, groins, and breakwaters, for example, are designed to trap littoral sediments. By withholding sand that would normally be carried to downdrift shorelines, they create a deficit in the sand supply. Seawalls, revetments and bulkheads keep sediment from entering the local littoral current. Wave difraction from any of these structures can cause localized scour at the base of the structure and at its endpoints.

Removal of sediment from the coastal sediment budget by human actions is also a concern. These include commercial extraction of sediments from coastal rivers, dredging and disposal of sediment in confined or upland areas, and employment of improper beach cleaning and management techniques.

- Damming

Dams prevent natural sedimentation processes by restraining the flow of riverine fresh water, so reduce sand supply to the coastline and deltas.

In Bulgaria, numerous dams have been built as parts of hydrosystems and hydrojunctions - Iskur, Arda, the Batak Hydropower System, Dospat-Vucha, Belmeken-Sestrimo, and also about 2000 small dams.

The Romanian coastal zone experiences a strong disequilibrium of the sedimentary processes because the damming and diversion of the Danube River has severely reduced the sediment supply of the shore zone.

- Gravel mining

In stream gravel mining is, together with dams, the main cause of sediment deficit in many rivers. In stream mining directly alters the channel geometry and bed elevation while disrupting the continuum of sediment downstream.

Removal of sediment from the coastal sediment budget by human actions is a common activity. These include commercial extraction of sediments from coastal rivers, both in Romania and Bulgaria.

- Ports, port extentions and marinas

Large ports (harbours) and small ports (marinas and leisure activities) are one of the main causes of coastal erosion, especially in wave-dominated coasts with important sediment transport drift.

Hydrotechnical works built both on the Danube and tributaries have resulted in serious decrease of the Danube´s sediment load with negative consequences on the littoral sediment balance. Since 1858 until 1988 the flow volume increased from 178 to 203 km^3/yr but the sediment load decreases from 65 millions to 38 millions tones/yr. Prevalent drift direction is north to south and the quantity of the transport is 1.2 million tones/yr. The longshore transport is controlled by the Sulina jetties (8km long) which are breaking the southward longshore drift. They are taking off from the sediment littoral budget the sediment input of the Sulina arm by carrying it too far and too deep from the shoreline. Accelerated erosion was recorded between 1962 and 1985, followed by a moderate erosion period until 2000.

Maximum shore retreating distance was 145m in the case of Sulina - Sf. Gheorghe sector and maximum accretion was of 101m distance near Sulina branch outlet.

The permanent extension of commercial activities led to the necessity of building enlargements to three harbours on the Romanian seashore: Constanta, Midia and Mangalia. The protective sea walls of Midia and Constantsa harbours act against the natural development of the beaches situated to the South of them.

- Urban and economic development

Roads, buildings, and other infrastructure can limit or affect the natural response of coastal ecosystems to sea level rise. As populations in coastal areas have grown and economic activity has intensified so a range of often inter-related and conflicting pressures have emerged in the coastal zones focused around agricultural use, industrial and port use, residential use, tourism, coastal water quality and fisheries. These in terms have caused pressure for coastal development and land reclamation around estuaries and lagoons.

Therefore, as in all countries, the acceleration of the costal erosion in Romania and Bulgaria is produced by the development of the coast.

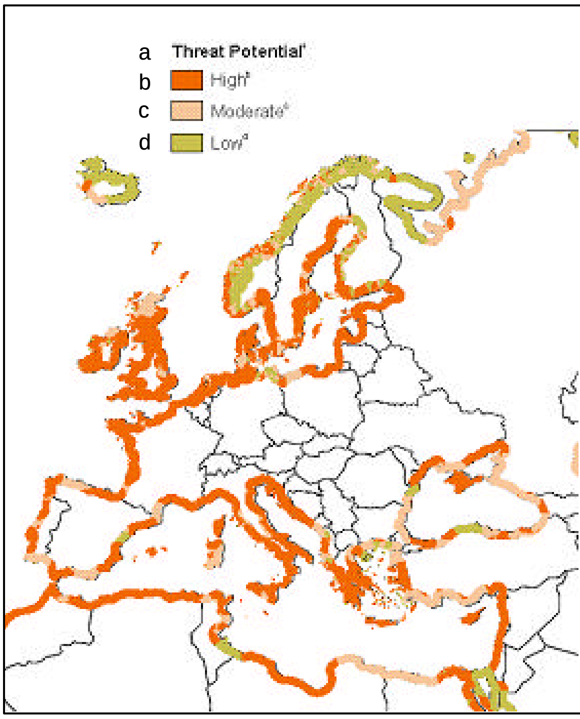
The permanent extension of commercial activities led to the necessity of building turism infrastructures and resort complexes near the beaches even if in many cases they aren't secure. Landslides and marine and river abrasion fall into the "calamities" group. Their occurrence poses a threat to security of settlements, resort complexes, roads, rail tracks, causes irreversible damage to agricultural land. About 1000 landslides in 350 settlements and resort complexes with a total surface area of 250.000 dca. have been registered in the Republic of Bulgaria.

2 SOCIO-ECONOMICS AND ENVIRONMENT

2.1 Introduction

Coastal zones worldwide occupy less than 15% of the Earth's land surface, yet they accommodate more than 60% of the world's population. It was estimated that by 2025 there could be up to 75% of humanity residing in coastal areas (UNCED, 1992). Most of the world coastal ecosystems potentially threatened by unsustainable development are located within the northern equatorial zones.
In Europe about 86% of the coasts are at either high or moderate risk (Bryant et al., 1995, see also Figure 2-1), whereas worldwide about one third of the coastal regions are at high risk. These figures clearly indicate the importance of the socio-economic development of the coast in relation to coastal protection strategies and policy options. Therefore, in this chapter the socio-economic factors for the different water systems will be described.

Figure 2-1 European coastal ecosystems threatened by development[7]



Notes:
a. Threat ranking depicts potential risk to coastal ecosystems from development-related activities.
b. Coastal areas falling within a city or major port footprint or having a population density exceeding 150 persons per square kilometer, a road network density exceeding 150 meters of road per square kilometer, or a pipeline density exceeding 10 meters of pipeline per square kilometer.
c. Coastal areas with a population density of between 75 and 150 persons per square kilometer, a road network density of between 100 and 150 meters of road per square kilometer, or a pipeline density of between 0 and 10 meters of pipeline per square kilometer.
d. Coastal areas with a population of less than 75 persons per square kilometer, a road network density of less than 100 meters of road per square kilometer, and no pipelines known to be present.

First of all, the economical situation of the different countries in the coastal system is compared. The population and GDP (Gross Domestic Product) can give an indication of the economical situation in the countries considered.

Impacts of erosion in the coastal zone can be expressed by using several indicators. For example, the population density gives information about the number of people that are possibly affected by coastal development. However, next to urbanization other functions can make a

[7] Bryant D., Rodenburg E., Cox T., Nielsen D, 1995. 'Coastlines at Risk: An Index of Potential Development-Related Threats to Coastal Ecosystems,' WRI Indicator Brief (World Resources Institute, Washington, D.C.,1995).

coast valuable and thus at high risk for erosion or flooding. Furthermore, sea level rise will increase the impact of coastal erosion in the future. Throughout this entire chapter, the relation between the impact of coastal erosion and the chosen coastal strategy and measures has been identified as much as possible.

Finally, the costs of measures are described in relation with hard or soft measures, the policy option, the functions at the coast and the capital at risk. Details on realization and maintenance costs are limitedly available.

2.2 Baltic Sea

Economic situation

An overall socio-economic analysis for the Baltic region is difficult to make. The economic situation of the different countries in the Baltic area is not really comparable; there are low labour cost countries like Estonia, Latvia, Lithuania and Poland and there are the high labour costs countries like Sweden, Denmark and Germany. This can make a significant difference in the approach of erosion problems. In Table 2-1 this difference becomes very clear in the parameter GDP/capita. In Poland, Estonia, Latvia and Lithuania, this parameter is about one third of the richer countries around the Baltic Sea such as Denmark, Finland, Germany and Sweden.

Table 2-1 Economic information of Baltic Sea region countries[8]

	Population 2001 [*1000]	GDP [million euro]	GDP/capita [euro]
Denmark	5,349	176,490	32,995
Finland	5,181	131,670	25,414
Germany	82,193	2,025,534	24,644
Sweden	8,883	246,619	27,763
Poland	38,649	342,100	8,851
Estonia	1,436	12,400	8,635
Latvia	2,417	15,900	6,578
Lithuania	3,696	27,600	7,468

In the case of the former Soviet states (Estonia, Latvia and Lithuania) there is a difference between the "old" approach, where low labour costs were the main factor determining coastal defense strategies, and the "new" approach, which is much more influenced by legislation and planning acts. An example of the influence of the economic situation on the chosen strategy is given in Box 2-1.

Box 2-1 Consequences of economic situation for chosen coastal strategy

In the Baltic States, Estonia, Latvia and Lithuania, the focus in coastal defence strategy has primarily been "limited intervention". Through foredune and forest maintenance, the damage of storm activity is mitigated as much as possible. Foredune and forest maintenance are labour intensive measures, which are cost effective in these countries as a result of the low labour costs. In countries like Denmark and Sweden, these measures would probably not be cost effective and therefore are not the main strategy.

[8] EUCC, Coastal erosion policies: defining the issues, Scoping study, final draft report, September 2002

Impacts erosion in coastal zone

Especially in the southern countries of the Baltic (due to land subsidence and thus relative sea level rise), coastal erosion is an increasing threat, because of the expected climate change (accelerated sea level rise and possibly increasing storm frequencies). In many coastal areas the requirements of a dense population, industry and tourism are in conflict with the requirements of coastal protection.

- Population density

In Figure 2-2, the population density around the Baltic Sea is shown. The figure shows clearly that the coasts of Denmark and Germany are most densely populated (on average 100-200 persons/km^2), especially around the larger cities (Hamburg, Copenhagen). The population density is a bit smaller, but still high, at the Polish and south Swedish coast. At the coast of the Baltic States, Finland and the rest of Sweden the population density decreases even more (average circa 50 persons/km^2). However, locally high densities can still occur around the big cities in these countries.

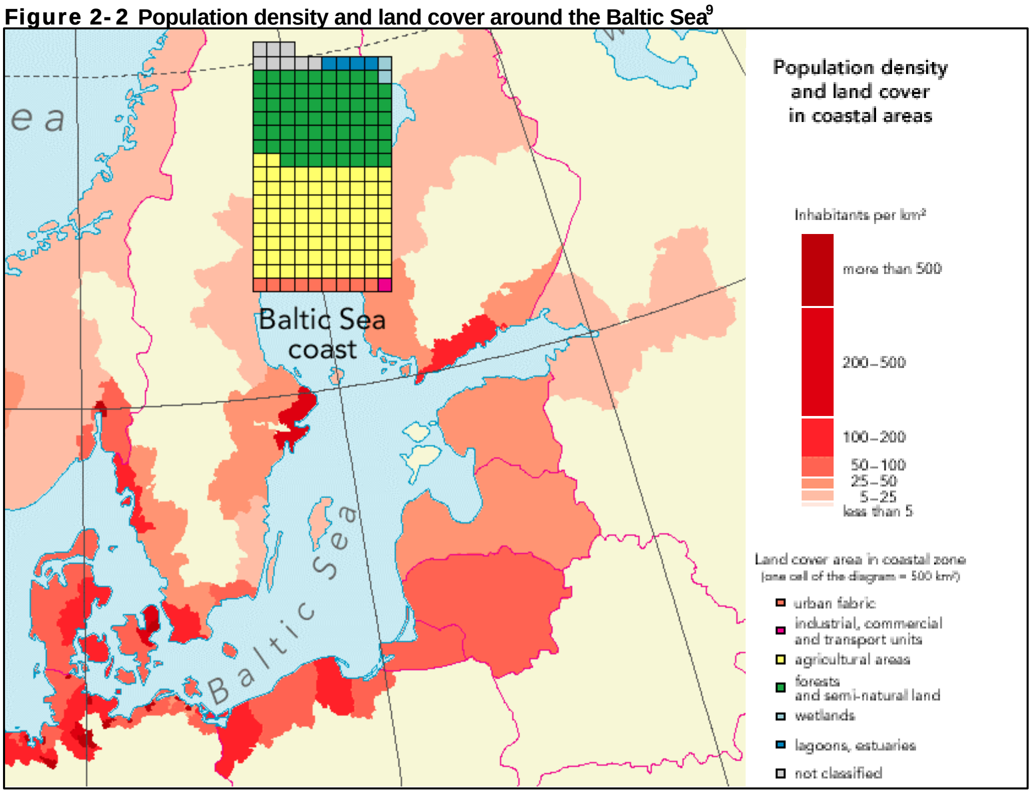
In the case studies, exact population densities were often not available. However, population density can be reviewed in a qualitative way. At Hyllingebjerg, Poland, Rostock and Ystad population densities are not high (100 persons/km^2) in the coastal area. Køge Bay (suburbs Copenhagen), Talinn, Klaipeda and Riga are densely populated case areas (>500 persons/km^2). This indicates that although there is a large difference in the average population densities in the different countries, the population density is locally high around all larger cities.

- Major functions and land use

In Figure 2-2 the land cover area in the coastal zone of the Baltic Sea region is shown (in percentages of the coastal area). Land cover is by far dominated by forests and semi-natural land (around 40%) or agricultural areas (around 50%). A much smaller area is urbanized or for industrial use (around 6%). Furthermore, a small portion of land cover (2%) consists of lagoons, estuaries (1500-2000 km^2) or wetlands (500-1000 km^2).

Erosion problems are often located at urbanized areas because erosion causes the largest damage in these areas. The case studies are almost all urbanized areas (except for Hyllingebjerg and the coast of Finland, where only summer cottages are present). The major functions at the Baltic area case study coastal areas are usually one or more of the following:
-Urbanization;
-Tourism and recreation;
-Industry, transport and energy (ports);
-Nature conservation.
Other functions, such as fishery, forestry and agriculture are usually of minor importance.

Figure 2-2 **Population density and land cover around the Baltic Sea**[9]



Conflicts can exist between the main functions, although in the strategy for combating erosion all major functions in the case study areas were usually taken into account. The main conflict, seen in some areas is a conflict between nature conservation on one side and tourism and recreation and urbanization and industry on the other side. Coastal erosion is usually not a real threat to nature. On the contrary: a dynamic coast can often stimulate nature (see Box 2-2 for an example). This fact alone creates conflicts of interest in coastal zone management with other functions.

Box 2-2 **Rostock, Germany: example of combination of coastal protection-nature conservation**

> At **Rostock** (Germany), the natural areas have remained in spite of all the hard measures that were taken to protect the coast in the past. There are now several National Parks in the area. To preserve the natural areas also in the future, coastal dynamics has been acknowledged at the Mecklenburg-Vorpommern coast, especially in the National Parks. The policy is to maintain safety but to let nature go its own way as much as possible. The policy option is to “hold the line” if absolutely necessary but if possible “limited intervention” is practiced to enable the existence of a dynamic coast.

Sometimes, functions can also be combined in a very effective way. With the Køge Bay Beach Park a large recreational area with possibilities for nature development was created, while the park also functioned as protection against flooding for the suburbs of Copenhagen.

[9] Land use: CORINE Land Cover; Population data: EEA, 1996 (modified from GISCO 1996)

➢ Assessment of capital at risk

From Bryant et al (1995), it appears that most of the coastal areas in the Baltic Sea regions are at high risk. This also follows from the case studies, which are practically all at high risk.

Capital damage by erosion is largest when erosion leads to flooding of the hinterland, at low-lying and/or subsiding land (e.g. Køge Bay, Ros tock, West coast Poland, Falsterbo). At cliffs and elevated land (Hyllingebjerg, Baltic States, Finland), erosion does not result in flooding of the entire hinterland. The capital value at risk due to flooding can reach incredible heights. . An example of the economic values can be given for the Mecklenburg-Vorpommern coast. If a similar flood like the one that occurred in 1872 would occur at this moment, a total damage of about €1.65 million in entire Mecklenburg -Vorpommern would be the result. An example of actual damage inflicted by a storm event is shown in Box 2-3.

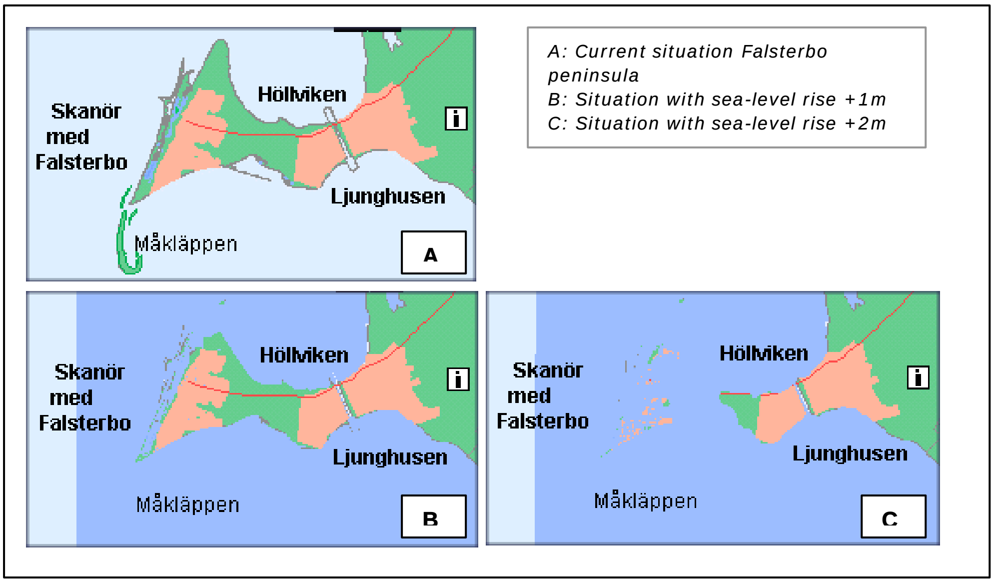
Box 2-3 Klaipeda coast (Lithuania): capital damage inflicted by 1999 hurricane

The costs of the damage inflicted to the coastal zone at Klaipeda-Palanga coast by the December 1999 hurricane were about €950,000 in total:
-Eroded seaward slope of the foredune on a 36 km strip (2 km of foredune completely erased),
-1,250 thousand m^3 of sand and 15 thousand m3 of till washed away,
-Damaged Palanga promenade pier,
-Destroyed stair and paths leading to the beaches.
The total capital at risk at this coast is valued at € 4 –6 million.

➢ Future impacts of erosion in coastal zone

As mentioned in chapter 1, sedimentary coasts (low-lying sedimentary coastal plains, barriers and spits) are also especially threatened by sea level rise. For example the Falsterbo Peninsula in Sweden is very low-lying and built up of unconsolidated sand; the extreme effect of possible future sea level rise at the peninsula is shown in Figure 2-3.

Figure 2-3 Effect of possible future sea-level rise on the Falsterbo Peninsula, Sweden



Climate change may also result in an increase of storminess (frequency of occurrence and intensity) which will cause an increase in erosion and flooding areas. The possible future impacts of erosion and the capital at risk in the coastal zone is illustrated in Box 2-4.

> Currently, the increasing erosion threatens recreational functions as well as a number of houses at the Talinn coast. The capital at risk is about €0.4-0.6 million. However, if the coastal erosion increases during the next few decades due to an increase in storminess (sea level rise is compensated for by isostatic land uplift in this area), then quite a substantial capital might be exposed to risk from erosion, flooding and ice pile-up. Particularly these threats apply to several newly built low-lying residential areas, seaside roads and the railroad. The potential capital at risk might reach the range of €20-40 million.

Box 2-4 Talinn (Estonia): increase in capital at risk by climate change

An assessment was made for the changing flood risks with sea level rise, the capital at loss and possible adaptation costs to protect human environment in the SURVAS[10] project for five countries. Of the countries around the Baltic Sea, Poland and Germany were included in the study. For a sea level rise of 1 m, for Poland a capital value loss of 24% of GNP was estimated and for Germany a capital value loss of 30% of GNP. Although these figures are about the same, the adaptation costs needed to protect human environment against this sea level rise is 2,2% of GNP for Germany, and 14,5% of GNP for Poland. This reflects the fact that, given the right preparation (current coastal protection is usually maintained in a better way), richer countries can adapt to sea-level rise more easily.

Finally, the area of coastal wetland (marshes) is highly susceptible to sea level rise, since tidal influence is negligible in the Baltic. In Table 2-2 an estimate is given for the expected loss of coastal wetlands at the Baltic coast by the 2080s. The range of losses varies from 84 to 98 percent of the present coastal wetlands in 1990 (circa 500 km^2).

Table 2-2 Estimated coastal wetland losses due to sea level rise Baltic coast by the 2080s[11]

Minimum Wetland Stock in 1990 (km^2)				
Region	Saltmarsh	Unvegetated Intertidal Areas	Total	Range of Losses by the 2080s (%)
Baltic coast	226	271	497	84 to 98

2.3 North Sea

Situation

The economic situation of the countries located around the North Sea is comparable. It concerns reasonably prosperous countries with GDP/capita of about Euro 25,000 (see Table 2-3).

[10] Proceeding of SURVAS Expert Workshop on European Vulnerability and Adaptation to impacts of Accelerated Sea-Level Rise (ASLR), Hamburg, Germany, June 2000

[11] EUCC, EUROSION Project, Trends of Coastal Erosion, second draft version (September 2002)

Table 2-3 Economic information of North Sea region countries[12]

	Population 2001 [*1000]	GDP [million euro]	GDP/capita [euro]
Belgium	10,262	248,338	24,200
Denmark	5,349	176,490	32,995
UK	59,832	1,547,903	25,871
Germany	82,193	2,025,534	24,644
Netherlands	15,983	401.089	25,095

The countries are well developed and industrialized. In these countries of prosperity in general a growing awareness of environmental issues has developed among the general public and politicians, especially during the last few decades.

Furthermore, an important factor in the North Sea area is the history of coastal management. In this region, most countries have a long history of coastal management (land reclamation, coastal flooding and defending the coast). Germany, Belgium and the Netherlands, for example, have fought against flooding for a long time. In these countries, hundreds of thousands of lives were lost during storm surges since the Middle Ages[13]. As a result, there is a strong feeling among the public of these countries, that the sea is a bitter and cruel enemy. In relation to coastal policy options, giving the sea more space (“managed realignment”) is generally not accepted in low-lying, densely populated countries where the fear of the sea has been formed in history. In higher situated lands, like in England, the attitude against the sea is much less hostile.

Impacts erosion in coastal zone

- Population density

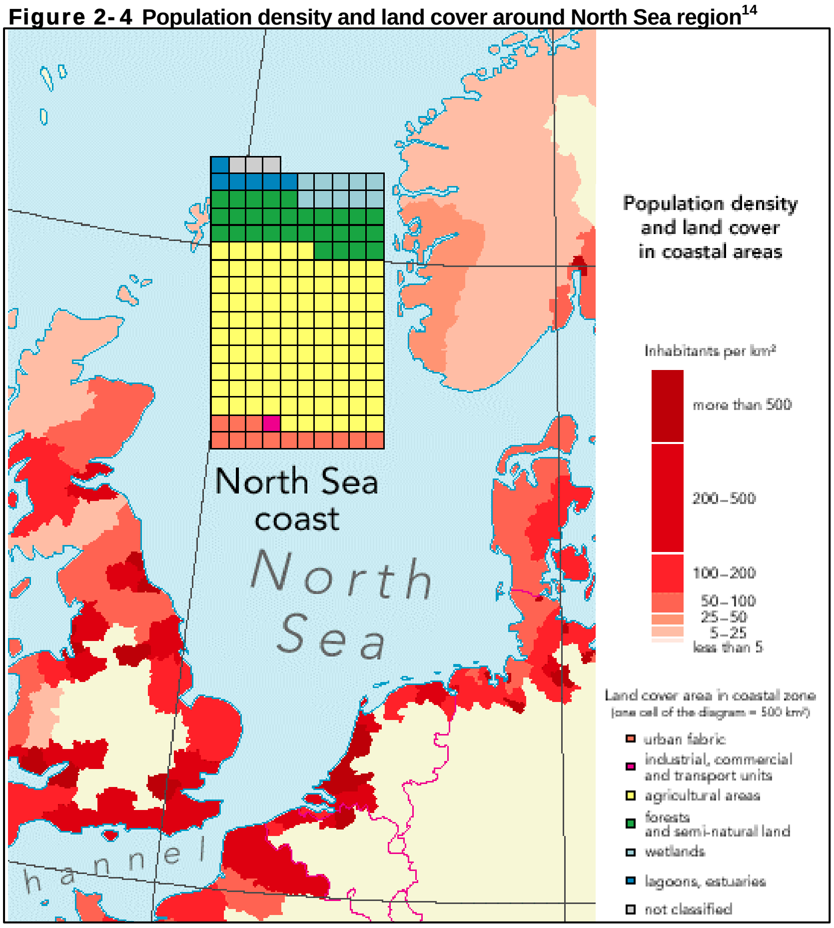
The population density around the North Sea area is shown in Figure 2-4. In the entire North Sea region the average population density is high. This density is highest in the Netherlands, with more than 500 persons/km^2 along almost the entire coast. In England and Belgium the density is (on average) more than 200 persons/km^2, while at the German and Danish coasts (North Sea) the population density is a bit smaller, 50-100 persons/km^2. However, locally large population densities are also present along these coasts, for example at Hamburg at the Elbe estuary.

Furthermore large areas of wetland are present in the North Sea (around 6% meaning 5000 km^2), while lagoons and estuaries cover about 3000 km^2. The large tidal influence in the North Sea has created a relatively large area of wetlands and estuaries.

[12] EUCC, Coastal erosion policies: defining the issues, Scoping study, final draft report, September 2002

[13] Rupp, S. and Nicholls, R.J., Managed realignment of Coastal Flood Defences: A comparison between England and Germany, March 2002.

Figure 2-4 Population density and land cover around North Sea region[14]



The main functions at the case studies are:
-Urbanization;
-Tourism and recreation (dune areas);
-Nature conservation (estuaries and dune areas);
-Agriculture (mainly at estuaries, cliffs);
-Industry, transport and energy (mainly ports, transport in estuaries).

At the low-lying beaches and dunes (De Haan and Zeebrugge in Belgium, Holland Coast, Sylt in Germany and West coast of Jutland in Denmark), the main functions protected are urbanization and beach- and dune recreation. Nature conservation can be of importance in the dune areas. An example of a multi-functional coastal area where all these functions are present is Sylt (see Box 2-5). There are recreational beaches at the West coast of Jutland. However, in contrast to the other countries Denmark possesses large stretches of beaches and therefore the loss of recreational beaches is not considered to be a problem. This shows that the importance of recreational beaches is relative, whereby urbanization should always be protected but recreational facilities are replaceable.

[14] Land use: CORINE Land Cover; Population data: EEA, 1996 (modified from GISCO 1996)

Box 2-5 **Sylt (Germany): example of combination of different functions**

> The vulnerable island **Sylt** has a multi-functional socio-economic character (e.g. tourism) and is covered by a mixture of natural and cultural territories. Besides high-level standards in living and recreation facilities, Sylt provides unique biotopic aspects. Except in its cultivated and inhabited western tip, the island Sylt is covered by dunes and heath land. In 1985, the region was designated as national park in recognition of the high ecological significance of the Wadden Sea. It serves, for example, as a place where migratory birds feed and rest and as an important nursery for many fish and crustaceans. The long west coast with its sandy beaches attracts many tourists and has considerable economic importance not only for the island but also for the federal state.

In the estuaries (Westerschelde in the Netherlands, Humber in England, Elbe in Germany), the main functions are nature conservation, transport (shipping), and urbanization. Furthermore, valuable agricultural land is usually present around estuaries (because of land reclamations in the past). A conflict between transport (shipping route) and coastal protection/nature occurs in most of the estuaries, see Box 2-6. The intertidal marshes are of great importance, for nature conservation as well as the safety of the hinterland (see example Elbe in Box 2-7).

Box 2-6 **Examples of conflict shipping function-nature/coastal protection in estuaries**

> **Western Scheldt** (Netherlands): The dredging and dumping of sediment has to a large extent affected the morphology of the estuary, causing erosion at several locations. The dredging is carried out with the purpose of maintaining a navigable depth in the channels, in order to ensure the connection with Port of Antwerp. This connection is of major economic importance for Belgium.
>
> **Elbe estuary** (Germany): The morphology of the Elbe estuary has been altered in order to optimize its function as a shipping route. The depth of the navigation channel has been and is continuously adjusted to the increasing size of vessels. The canalization has resulted in a loss of intertidal and shallow sub tidal areas and in an irreversible increase of the tidal range.

The Wadden Sea area (Wadden case in the Netherlands, Elbe estuary in Germany and Sylt in Germany) has a high nature conservation value, especially the tidal flats and estuaries.

Box 2-7 **Examples of importance salt marshes for nature conservation and coastal protection**

> The island Scharhoern in the **Elbe estuary** is one of the most important breeding island for terns and other seabirds in the whole region of the Wadden Sea. The development of dune vegetation has been artificially supported and added by installing bush fences to catch the drifting sand next to the island since 1926. Since 1973, it has been shrinking rapidly. Following the sedimentation and erosion transport affected by wind and sea, the island has drifted 1.4 km eastward during the last century and got closer to the deep fairway of the Elbe. Because of the threatening loss of the breeding sanctuary Scharhoern, the environmental authority of Hamburg decided in 1989 to establish a new dune island by sand nourishment 1.5 km away in the southwest of Scharhoern but still situated on the Scharhoern reef: the artificial island Nigehoern.
>
> The loss of island Scharhoern has major effects for migratory birds, especially terns. Furthermore, the salt marshes in front of the dikes have a significant influence on the wave energy attacking the dikes. Because of the small depths above the salt marshes the wave will break and dissipate energy before reaching the dikes. Loss of salt marshes will increase the attack on the dikes. This will have effects on the safety levels of the area, protected by the dikes. The new dune island therefore serves two purposes: nature compensation and coastal protection.
>
> The **Humber Estuary**, UK, is home to a wide range of valuable wildlife habitats and species, the national and international importance of which have long been recognized through statutory site protection. The estuary is regarded by ornithologists as one of the five most important in Britain and one of the 10 most important in Europe. The estuary is of international significance for eight bird species. They have calculated that, over a five-year period, the average number of birds on the Humber flats, marshes and coast came to about 105,000, of which about 20,000 were wildfowl and 85,000 waders.

➢ Assessment of capital at risk

From Bryant et al (1995), it appears that most of the coastal areas in the North Sea region are at high risk. This also follows from the case studies, which are practically all at high risk.

Box 2-8 South West Netherlands, capital at risk

> The disaster in the South West Netherlands in 1953 claimed 1835 victims and caused a total damage of about 0.7 billion Euro. The total loss potential of the Holland coastal zone, is estimated to be approximately 300 billion Euros (Kok et al., 2002). Due to this high vulnerability there has been no flood insurance since the flood event of 1953 (due to possible bankruptcy of insurance companies). Currently, the Calamities Compensation Act' (WTS) compensates most of the possible flood damage, which cannot be insured.

The risk of flooding is present along low-lying sedimentary coasts, such as Belgium, the Netherlands and Germany at the North Sea coast. In these countries, the capital at risk can be of incredibly high value (see Box 2-8). In England, where the land is usually elevated (cliffs), the capital at risk consists only of the houses, investments or infrastructure that are directly affected by erosion (see Box 2-9). Therefore, the capital at risk at the English coast is much smaller. In estuaries in England however, a risk of flooding exists and capital at risk can be much higher.

Box 2-9 Holderness cliff coast (England), capital at risk

> In 1990, Mappleton was under threat from losing 30 houses and its main road. Even though erosion problems would arise 'downstream' of Mappleton, a coastal management scheme was set up and blocks of granite were imported from Norway to build two groins and a seawall. The costs of these structures were very high, maybe even higher than the costs of a compensation arrangement.

➢ Future impacts erosion in coastal zone

Climate change will induce an increase in the rate of sea level rise and possibly in an increase in storm frequency and intensity. Since all countries in the North Sea area suffer from land subsidence, relative sea level rise together with an increased storm frequency and intensity will have impact on the North Sea coasts. As a result, the capital at risk and thus the impact of erosion on socio-economic factors will increase.

The foreshore, which is the fundament for sea defence on the long term, is eroding due to the sea level rise. When the rate of sea level rise increases, continuing foreshore erosion will become more serious on the long term. It increases the expenditure needed to keep the sea defences in an acceptable condition. Ultimately, maintaining the sea defences could become so difficult or costly that it would be necessary to set them back to a new line or carry out other works elsewhere which would achieve the same effect.

For low-lying countries with sand and dune coasts, the flooding area will expand, and thus increase the capital at risk. For cliffs, the possible increase in storminess will increase the erosion rate and thus the capital at risk. In the tidal estuaries the risk of flooding will also increase as a result of higher river outflows.

In the next decades due to rising sea levels, a significant loss of valuable intertidal salt marshes and shallow water area is to be expected in the estuaries around the North Sea. In the Western Scheldt, for example, a loss of about 500 ha. of shallow water and intertidal areas is expected until 2020.These areas are valuable for both safety (wave dissipation) and nature (breeding/spawning).

Box 2-10 Humber estuary (England), increase of loss intertidal marshes

> Extensive studies suggest that if sea levels rise as expected, about 450 hectares of inter-tidal habitat of outstanding value for wildlife will be lost through a process called 'coastal squeeze' in the Humber estuary. Since there is some uncertainty about this figure, a loss of 850 hectares is anticipated, which will have to be replaced if the estuary's conservation value is not to be affected. Furthermore, foreshore erosion linked to the sea level rise will become more serious as the rate of sea level rise increases.
>
> Furthermore, the threat of flooding will increase significantly. It is clear that measures are needed to guarantee sufficient protection in the flooding area of the Humber estuary. As sea level rises, the cost of providing ever-bigger defences is escalating, with economic implications for the country as a whole. It is not economically viable to continue increasing the size of existing defences in every location. Therefore it is important to look at developing flood defence strategies, which are economically, socially and environmentally acceptable.

An assessment has been made for the changing flood risks with sea level rise, the capital at loss and possible adaptation costs to protect human environment in the SURVAS[15] project for five countries (Netherlands, Germany, Poland, Turkey and Estonia). The Netherlands stands out as having by far the largest impact potential in both absolute and relative terms. However, despite its high exposure, adaptation costs are relatively low in the Netherlands, and also in Germany, compared to economically less developed countries such as Poland and Turkey. From a financial point of view, the relatively rich countries in the North Sea should therefore be able to adapt to sea level rise relatively easily. However, these adaptation measures will do nothing to counteract the loss of coastal wetlands and may even accelerate these losses, particularly if hard defence options are used.

Thus, there is often a conflict between sustaining socio-economic activity and the ecological functioning of the coastal zone in the North Sea area under rising sea levels[16].

2.4 Atlantic Ocean

Economic situation

In the economic situation of the Atlantic Ocean there is a difference between the northern and the southern countries in the Atlantic (see Table 2-4). Ireland, United Kingdom and France are prosperous North-European countries (GDP/capita circa 25,000) while Spain and Portugal's GDP/capita (circa 12,500) is clearly lower.

[15] Proceeding of SURVAS Expert Workshop on European Vulnerability and Adaptation to impacts of Accelerated Sea-Level Rise (ASLR), Hamburg, Germany, June 2000

[16] Nicholls, R.J. 2000, Coastal Zones, in Parry, M.L. (ed.). Assessment of the Potential effects of Climate Change in Europe. Jackson Environment Institute, University of East Anglia, in press. [update]

Table 2-4 Economic information of Atlantic Sea region countries[17]

	Population 2001 [*1000]	GDP [million euro]	GDP/capita [euro]
Ireland	3,820	103,470	27,086
France	59,521	1,404,775	23,601
United Kingdom	59,832	1,547,903	25,871
Portugal	10,023	115,255	11,499
Spain	39,490	608,787	15,416

The northern countries (Ireland, United Kingdom and France) are more industrialized and developed than the southern countries. Furthermore, the awareness of environmental issues has grown sooner and faster among the public and politicians in the northern countries. In Spain and Portugal historically bad land use of the coastal zone has occurred. This has, in some places, destroyed the dunes. In France bad land use has also occurred in the past but the awareness of the importance of the dunes and the need to carefully plan urban expansion in the coastal zone started growing several decades ago. In Portugal and Spain this kind of awareness has only recently started to grow (see Box 2-11).

In Cavo do Vapor/Caparica Beach, the erosion problems are very serious and with repercussions in terms of patrimony losses and great socio-economical level impacts. For this reason it is important to defend the area with soft or hard interventions that could reduce the erosion rate. This site has a shortage of beach area in relation to the number of users.

The coastline is changing, and if measures are not planned carefully, it is possible that in the future important repercussions will occur. The urban area must be restricted to locations where the risk of overwashes and flooding are very small. It is not coherent to expand the construction of buildings or beach supports to areas where the risk of destruction is very high, and to build sea defences after that to protect these infrastructures. Therefore, urban expansion along vulnerable coastlines must be stopped. Local authorities and urban planners cannot continue to ignore the medium/long term physical dynamic and consequent constraints.

Between 1972 and 2000, during approximately 30 years and with the help of the groin field and the seawall, the beach and the coastline stayed more or less stable. In 2000/2001 however, persistent sea actions occurred, it was noticed that the area was vulnerable and that there is a possibility of destruction of the sea defences. It is essential to never forget that the area is very instable, with a great probability of change and with very high physical dynamics.

Box 2-11 Cavo do Vapor/Caparica Beach, coastal urban expansion in Portugal

erosion impacts in coastal zone

➢ Population density

Figure 2-5 shows the population density around the Atlantic Ocean area. The British coast is densely populated (>200 persons/km^2), while at the Irish coast population densities are much lower (<50 persons/km^2). Apparently the Irish coast is relatively sparsely populated, except for the area around the big cities such as Dublin. This might partly explain the lack of coastal zone management in Ireland. The French Atlantic and Spanish Atlantic coasts have an average population density of 100-200 persons/km^2. At the Portuguese coast, population densities are relatively high in Lisbon and Porto metropolitan area, whereas they are low south of Lisbon: about 80% of the coastal population lives north of Lisbon and only 20% south of Lisbon.

[17] EUCC, Coastal erosion policies: defining the issues, Scoping study, final draft report, September 2002

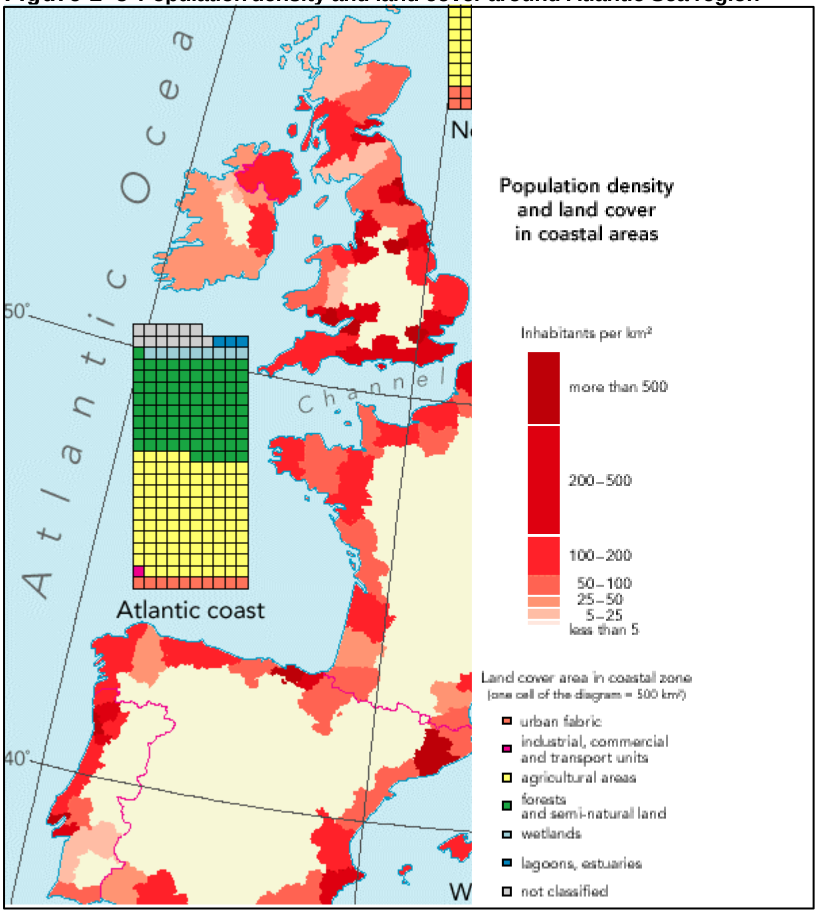
➢ Major function and land use

Apart from population densities, Figure 2-5 also shows the land cover around the Atlantic Sea region. The area is less developed than the North Sea region; more natural areas are left. About 45% of the area consists of agricultural lands, while still around 40% of the area is covered with forests and semi-natural lands (this is only 20% in North Sea region). About 5% of the coastal zone is urbanized and wetlands, lagoons and estuaries cover another 5%. The wetlands cover around 5,000 km^2, the lagoons and estuaries around 1,500 km^2.

Urbanization, the safety of human lives and investments, is of course of primary importance in the coastal zone. This function is especially important along densely populated coastal areas, thus the big cities at the Atlantic Coast (e.g. Lisbon, Porto, Bilbao, Bordeaux).

The main and most important industry in Spain, France and Portugal is tourism, especially in the coastal zone. In the United Kingdom and Ireland, tourism is also of importance but to a lesser extent than in the southern countries. This is not surprising, considering the fact that France and Spain are respectively tourist destinations number 1 and 2 in the world. Tourism and associated industries at the Atlantic coasts have the problem of seasonality.

Figure 2-5 Population density and land cover around Atlantic Sea region[18]



[18] Land use: CORINE Land Cover; Population data: EEA, 1996 (modified from GISCO 1996)

Nature conservation in most case areas is at least a secondary function in the coastal zone. Especially the dunes and submarine life are sources for nature development. Furthermore, in Spain, Portugal and France fishing and aquaculture are of great importance in the coastal zone (though this importance is reducing at present). In the United Kingdom and Ireland, a lot of agricultural land is found in the coastal zone. Ports and related industries are found along the entire Atlantic coast. Many river catchments areas in the Atlantic Ocean region are heavily industrialized (for example the Mersey and the Oria), while others (such as Loire and Shannon) are largely rural and agricultural.

An important threat to economic values of a coast, such as tourism, aquaculture and nature, are oil spills. The oil spill of the 'Prestige' tanker changed the general panorama. The oil spill influenced the French and Spanish coast with an important social impact. So far, the fishing and mussel-farming industry have been seriously damaged while the consequences on tourism cannot be assessed yet.

- Assessment of capital at risk

From Bryant et al (1995), it appears that most of the coastal areas in the Atlantic Sea region are at high risk. Low-lying coastal plains are at risk of flooding and therefore usually have to deal with a relatively high capital at risk.

Box 2-12 Capital at Risk at Isle of Wight

> Capital assets at risk in the Undercliff study area at the Isle of Wight comprise land, property and infrastructure as well as the lives of the 7,000 local residents and visitors. Bearing in mind that the whole of the Undercliff study area is a major coastal landslide complex with a resident population, it is vital that coastal protection measures are put in place where economically justifiable to reduce the impact of coastal erosion in terms of promoting ground instability.
>
> At this time, a major ground investigation is being undertaken in order to supplement geomorphological mapping done previously. This study forms part of a quantitative risk assessment for central Ventnor, which will further inform the planning process and assess whether there are any further engineering measures in addition to coast protection that can be undertaken to try and reduce the ground movement problem.

At cliffs, the erosion directly threatens houses or infrastructure but the consequences of erosion are smaller. If there is a possibility for big land slides however, the consequences of cliff erosion can be much greater than just the houses located at the edge of the cliff. For example, at the Isle of Wight a major landslide complex is present, threatening a large area and increasing the capital at risk (see Box 2-12).

An example of actual damage by the storm surge of 1999 is given for Châtelaillon; here 300 houses were flooded in the north of the bight. The north of the bight is the only section where coastal protection was not yet provided so far at this case study. The beach is narrow and flat and cannot protect sufficiently against flooding. Beach nourishment of this area is now provided for in 2003.

- Future impacts of erosion in coastal zone

Climate change will induce an increase in the rate of sea level rise in the future. Of course sea level rise will affect the coastline, increasing the erosion along the Atlantic coast. However, because of high tidal ranges and the highly energetic coast of the Atlantic, the relative impact of sea level rise will be much smaller than in the Baltic Sea and the Mediterranean.

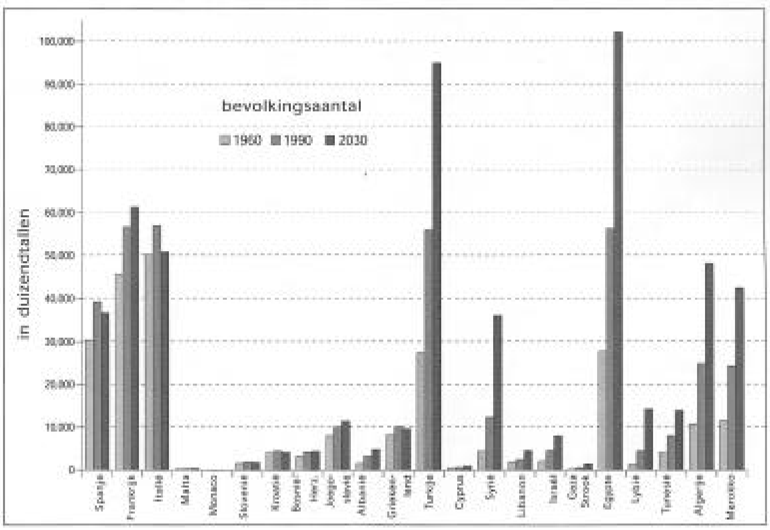
Increased Atlantic storm frequencies may have a great impact in the future also, however whether this is actually caused by climate change and whether this trend from the last decades will continue in the future is still uncertain.

2.5 Mediterranean Sea

Economic situation

In 1960 the total population of the countries surrounding the Mediterranean Sea was 246 million. In 1990 the population grew up to 380 million and in 2000 it is estimated at 450 million. According to the blue plan data base (see Figure 2-6) It is expected that the population shall grow to 520-570 million in 2030 and might even grow to 600 million in 2050. By the end of the 21st century, the population is believed to grow up to 700 million. A greater part of the population lives in the coastal area. In the past, the population of the countries lying in the North of the Mediterranean formed 2/3 of the total population. At present, they represent half of the population.

Figure 2-6 Population growth in the countries around the Mediterranean sea



Source: Blue Plan Database, United Nations, World Population prospect, The 1994 Revision

Tourism is presently the first source of income and contributes to about 22% of the Bruto National Product (BNP). The Mediterranean Sea areas contribute in total about 1/3 of the international financial returns from Tourism.

Impact of erosion in the coastal zone

Urbanization
Migration rate to the bigger cities is high and has lead to shortages of public services in these cities. These includes water supply, roads, sewage water treatments plants and housing.

Tourism
The Mediterranean sea area is famous for tourism and hosts about 30% of the international tourists. According to estimates, the number of tourists in the coastal area of the Mediterranean Sea is expected to grow from 135 million in 1990 to 235-350 million in 2025. Tourism is seasonal and is concentrated in the coastal areas. Nature Conservation areas in the coastal areas are affected due to the pressure of tourism.

Agriculture
Agricultural activities take place in the limited lowlands lying between the rocky coastal region of the Mediterranean Sea. Almost all types of agriculture and other land-use types are considered as diffuse sources for water pollution and are therefore very difficult to be quantified.
Agricultural activities are believed to facilitate soil erosion while increasing the supply of nutrient in the coastal waters of the Mediterranean Sea. Lakes found in the surrounding countries often receive high nutrient levels from the agricultural lands. The rivers Rhone and Po are often affected. The catchments that are seriously affected by high concentrations of nutrients from agricultural practices are found in the following countries: Italy, Sicily , Sardine, Greece, Turkey and Spain.

Fisheries
The total fish landings from the Mediterranean Sea is still higher. The total landings in the Mediterranean countries has increased from 1,1 million tons in 1984 to 1,3 milliton tons in 1995. The fishing techniques practiced have undergone very little changes in the last few years. The number of fishing boats has increased by 19.8 % between 1980 and 1992. The fishing techniques slightly shifted from the use of relatively high labor intensive equipments to capital intensive ones. Big trawlers and multifunctional boats are presently being used but the average number of trawlers has remained constant since 1982. The by-catches and the number of missing fishing nets at sea have however increased.

Aquaculture
Marine aqua cultural production has increased in some of the countries surrounding the Mediterranean Sea. The production has increased from 78.000 ton in 1984 to 248.500 ton in 1996. Aquaculture is a relative new activity is in the Mediterranean region and is mostly directed towards the farming of shelled animals (bivalves) and fish species including Bass and Red sea-bream. The effects of this activity on the environment is local and is relatively lesser when compared to the effects registered in Asia or South America.

Industry
Industrial activity (from mining to end production) around the Mediterranean Sea is very common. Especially in the North Western part where the hot spots are concentrated. Big industrial complexes and big sea ports are found in this region. Chemical pollution of the waters is caused by the chemical/petrochemical sector and the metal industries in the area. Other big industrial sectors in the coastal area are: sewage treatment plants and recycling of solvents, metal works, paper production, paint, plastic, textile, and printing companies.

Based on the Exports from the Mediterranean countries, three groups of countries can be classified:

1. Countries that are highly specialized and export very few items whilst the rest of the products are being imported. These are the oil producing countries eg. Algeria, Syrie, Egypt and Libya.

2. Less specialized countries that export similar goods exported by other countries in the region. These countries often export goods even under unfavorable market conditions. Some of these countries include: Turkey, Tunisia, Morocco, ex Joegoslavia, Cyprus en Malta. They export clothes, textile and leather. Next to these, these countries can produce specialized products for export.
   For example: Tunisia produces chemical products including oil and lubricants; Morocco produces chemical products including fertilizers whilst Turkey and ex Joegoslavia produce textile, wool, cotton, paper and cement.

3. Highly diversified exporters and less specialized group of countries. These include the countries of the European Union. They also form the biggest part of the petrolchical industry in the Mediterranean area.

The environmental effects of the industries can either be direct or indirect. Direct effects are found in the cases of sewage water pollution, sea ports and pollution from the industrial complexes which contribute to the formation of the hot spots. Indirect effects are related to the location of the industries. Industries call for a concentration of workers and urbanization along the coastal area. The industries also contribute to air pollution.

Sea transportation

Three main sea routes are known for going to and from the Mediterranean Sea area:

- Dardanellen/ Sea of Marmara/ Straat of Istanbul,
- Straat of Gibralter en
- Suezkanal

About 90 % of the oil transport is done from east to west (Egypt-Gibraltar), between Sicily and Malta and very close to the coast of Tunisia, Algeria and Morocco.

On average 60 accidents take place every year at sea and about 15 ships loose their cargo of chemicals at sea. Most of the accidents take place in the Streat of Gibralter, Messina, The Canal of Sicily and the routes leading to the Dardanellen. At some of the ports like Genua, Livorno, Civitavecchia, Venetia,Triest, Piraeus,Limossol/Larnaka, Beirut and Alexandria, accidents do occur.

Reference: Europees Milieu Agentschap (2000); " Toestand van en bedreigingen voor het milieu in de Middellandse zee en haar kustgebieden"; ISBN 929167190-8

2.6 Black Sea

Economic situation

The economic situation of Romania and Bulgaria is comparable. The GDP/capita of both countries is about one-tenth of the GDP/capita of for example a Northsea-country.

Table 2-5 **Economic information of Black Sea region countries**

	Population [million people]	Labour Force (million people)	GDP [biliard US$/year]	GDP/capita [US$/year]
Romania	23,17	10,9	71,9	3100
Bulgaria	8,86	4,3	36,4	4100

It has to be noted that this is the picture of the whole country. Economic activity in the coastal area is much higher than the average of the country.

Industry, agriculture and tourism are among the most important economic sectors in the Black Sea coastal region.

The impact of erosion in the coastal zone

Population density

The population densities of Romania and Bulgaria are represented in Table 2-6.

Table 2-6 **Demographic information of Black Sea region countries**

	Population [million people]	Pouplation density [people/km^2]	total area (km^2)
Romania	23,17	97,6	237500
Bulgaria	8,86	79,9	110910

It is important to note that the population density in the Black Sea region of Bulgaria and Romania is much higher than the national averages . This is a result of the trend that people have moved from inside the country towards the coastal zone. Bulgaria and Romania also have known a second trend, namely migration of the population toward the industrialized urban centers. Therefore the population density in the coastal zone is very variable as a large part of the coastal population lives in the urban areas (this is 82 % for Bulgaria (two large cities and 18 small towns)). In summer time the population densities of the tourist areas are even larger.

- Land use and major functions

Land use

The geography of the coastal areas of the pilot-sites can be best described as:

- Mamaia Beach: sandy beaches
- Danube Delta (Romania): delta plain, sandy beaches without much profile.
- Shabla-Krapetz: beaches (and cliffs)

Accurate figures about land use along the Romanian and Bulgarian coast were hard to obtain. To provide at least a rough indication, Table 2-7 contains the data for the coastal zone area of the Danube Delta.

Table 2-7 Land-use for the coastal zone of the Danube Delta

Land use Danube Delta	Part of total coastal area
urbanized and industrial use	ca. 2 %
Agriculture	ca. 30 %
semi-natural land, forests, lagoons, estuaries and wetlands	ca. 68 %

Major functions

In the Black Sea region the following economic activities have a relation with coastal erosion: agriculture, forestry, fisheries, tourism, urbanisation, harbour activities and nature conservation .

The negative impacts erosion has on these functions are:
- threatening human life;
- loss of monuments of culture and history as well as intellectual values - culture, history, local habits and traditions;
- loss of living resources and biodiversity;
- loss of natural resources (loss of landscape diversity, rocky coastal cliffs, lakes, limans, wetlands and protected areas), and
- loss of “resources” for economic activities (loss of beaches and dunes, loss of fertile land, damage on infrasctructure and loss of fish stock).

Based on an analysis of the case studies it can be stated that loss of fertile land (agriculture) and loss of beaches and natural resources (tourism / nature conservation) are the major issues concerning erosion.

Agriculture
Agriculture and forestry, semi-natural landuse etc. are the land use activities which cover the largest areas. They are both influenced significantly by erosion as well as that this type of land use influences the coastal erosion.

Tourism
Tourism and recreation are main all-year round income sources for the Black Sea regions of Romania and Bulgaria. It’s expected that large investments will be made to strengthen this function. Important features for tourism, affected by erosion, are:
- the sandy beaches of this part of the Black Sea coast ;
- infrastructure and accomodation, and
- nature conservation (which is a separate function as well). There is a great potential to develop ecological tourism activities in the natural areas of the Black Sea coast. This is a good opportunity as the tourism sector is under regression.

Nature conservation
The protection of natural ecosystems, such as the Danube Delta Biosphere Reserve, the dune system at Can Picafort, the Messologi lagoon area, etc., is of great importance for tourism and coastal protection (e.g. the protection of dune systems enables the self-regeneration of the beaches after storm events).

Box 2-13 Danube Delta Biosphere Reserve (ROMANIA)

The Danube Delta was declared a 'biosphere reserve' in 1990. It covers an area of 46,403 ha. According to the provisions of Act nº. 82/1993 the Danube Delta Biosphere Reserve, as an important national and international ecological zone, consists of the Danube Delta, the Saraturile Murighiol-Plopu, the Razim-Sinoie lagoon complex area, the maritime Danube as far as Cotul Pisicii, the Isaccea-Tulcea sector with the area liable to flooding, and the Black Sea coast from the Chilia Branch to Cape Midia. Inshore marine waters and the territorial sea as far as isobath –20m are included.

Compared to other protected areas (strict nature reserve, national park, natural monument, reserve for nature preservation, or, in other words – wilderness sanctuary, protected land or seashore landscape, resource reserve, anthropological reserve, areas of resource administration, areas of universal inheritance), the biosphere reserve is not intended for exclusive protection, but it has more goals:

- Preservation of the ecosystem and balanced use of regenerating natural resources.
- The maintenance of traditional forms of economic activity which do not cause ecological imbalance.
- The permanent research and monitoring of the component parts of the protected ecosystems.
- Informing and educating people about the scientific value and the necessity of preserving and protecting the plant and animal species as well as the landscape.
- Integration into the world network of protected areas and information exchange regarding their scientific value and condition.
- The integration of the economic activities on the DDBR perimeter so these should not produce ecological imbalance.
- The harmonization of the interests of the local population with the basic objective of preserving the biosphere reserve.

- Assessment of the total capital at risk due to erosion

The coastal areas in the Black Sea region of Bulgaria and Romania are considered to be under high / moderate/ low risk. An indication of the capital at risk is derived from the quantitative evaluations of Shabla-Krapetz . In this case it is estimated that the yearly overall capital loss due to erosion will be 4,5 % of the total capital of an area .

- Future impacts of erosion in the coastal zone

The erosion along the Bulgarian and Romanian coast is significantly induced by wind and storm conditions. Therefore it can be expected that in the future the impact of erosion will increase as a result of the changed storm conditions (increased frequency and intensity) due to climate change.

The sea level is also expected to change in the future. The estimated sea level rise for 2100 along the Bulgarian and Romanian coast will differ between 15 and 50 centimeters. This will result in an expected retreat of the coastline by 50 till 150 meters.

It's likely that the increased erosion due to more severe storm conditions and sea level rise will affect the different functions in the coastal zone of 70 – 80 % of the Romanian coastline although the actual impact isn't specified in the site reports. It's expected to be high moderate or low.

For the whole of Romania a trend is shown that people move from the country towards the coastal zone and from the rural areas towards the urban areas. 44% of the entire coastal population lives in the main coastal areas. Continuation of this trend will lead to more investments and a higher pressure on the space in the coastal zone and therefore to a higher impact of erosion on the functions.

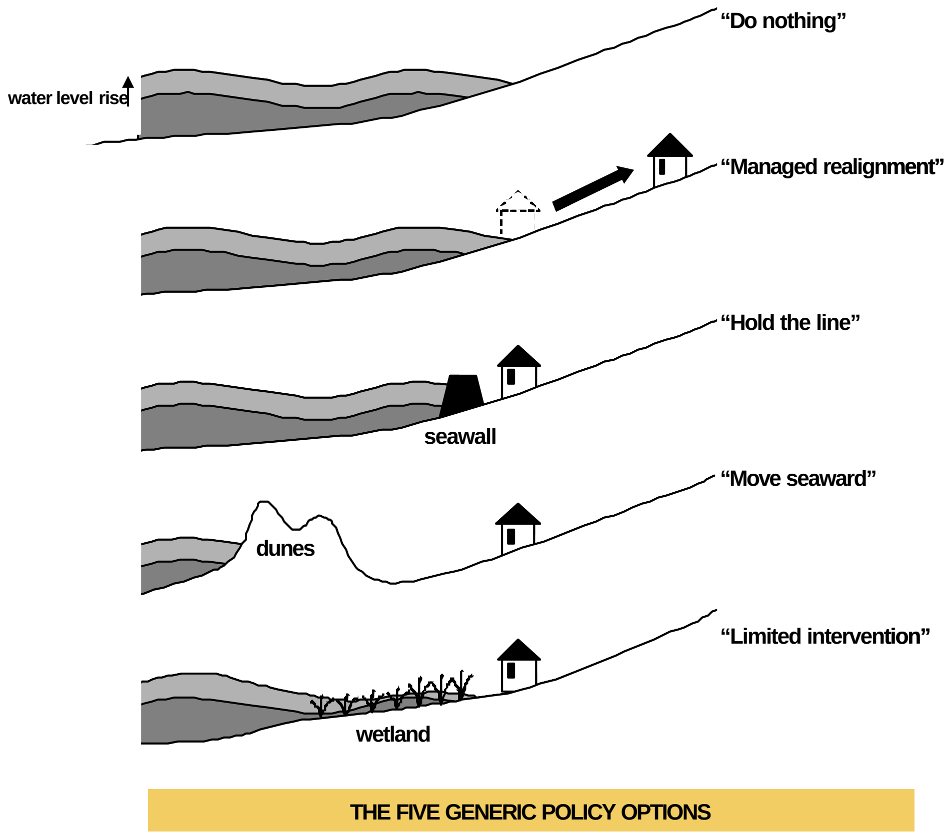
The tourists sector in Romania needs large investments. If not planned carefully it is likely that in the near future considerable investments are needed to protect newly built accomodations from coastal erosion.

3 POLICY OPTIONS

3.1 Introduction

For the purpose of the Eurosion project, the approach of generic policies as defined by the UK Department for Environment, Food and Rural Affairs (DEFRA) is adopted as shown in Figure 3-1 and explained Box 1-1.

Figure 3-1 The five generic policy options



Box 3-1 Policy options adopted for Eurosion project

Do nothing
There is no investment in coastal defence assets or operations, i.e. no shoreline management activity.

Hold the line
Hold the existing defence line by maintaining or changing the standard of protection. This policy covers those situations where works are undertaken in front of the existing defences to improve or maintain the standard of protection provided by the existing defence line. Policies that involve operations to the rear of existing defences should be included under this policy where they form an integral part of maintaining the current coastal defence systems.

Move seaward
Advance the existing defence line by constructing new defences seaward of the original defences. This use of policy is limited to those management units where significant land reclamation is considered.

Managed realignment
Identifying a new line of defence and, where appropriate, constructing new defences landward of the original defences.

Limited intervention
Working with natural processes to reduce risks while allowing natural coastal change. This may range from measures that attempt to slow down rather than stop coastal erosion and cliff recessions (e.g. nourishments), to measures that address public safety issues (e.g. flood warning systems, dune and forest maintenance, building restriction in coastal strip).

For each coastal system, the commonly applied policy options are given. It should be noted that more than one policy option may be present at the same case study. Besides this, the distinction between the policy options is not always crystal clear. Nourisment of a beach to compensate structural erosion can fit the policy option of limited intervention as well as hold the line.

After the policy options, strategies to execute these policy options are described. These vary from European level down to the local level. In some case studies coastal defence policies at a national level have not yet been adopted, leaving management of erosion problems often to local and/or regional authorities (e.g. El Medano, Canary Islands uses a regional approach).

A proactive approach refers to a policy of anticipating erosion processes. Technical measures or plans (management plans, flood warning systems etc.) are adopted to prevent erosion or minimize the expected effects of erosion. A reactive approach refers to the policy of performing coastal defence measures to reduce the effects of existing erosion processes. Another part of the strategy is to decide whether to use hard or soft measures to deal with erosion.

In the next step, the policy options and strategy are positioned within the framework of integrated coastal zone management, together with a description of the available legislation and responsible authorities in the coastal zone.

3.2 Integrated Coastal Zone Management (ICZM)

In this section the concept of ICZM will be briefly explained. After that this section will state the main questions on ICZM for the analysis of the regional seas.

the concept of ICZM

The EU coastline is 89 000 kilometres long, and about half of the population of those Member States with a coastline lives within 50 kilometres of the sea. Coastal zones already include the European Union most valuable habitats. The total ecosystem benefits generated by the EU coastal zones are worth more in economic terms than the national GDP of any of the smaller EU countries.

Integrated Coastal Zone Management (ICZM) is not just an environmental policy. While the need to protect the functioning of natural ecosystems is a core aim of the strategy, ICZM also seeks to improve the economic and social well-being of coastal zones and help them develop their full potential as modern, vibrant communities. In the coastal zone, these environmental and socio-economic goals are intrinsically interconnected. Important issues of Europe's coastlines are:

- Badly planned tourist developments
- Decline of fishing industry
- Poorly conceived transport networks
- Increasing urbanisation
- Erosion
- Pollution
- Habitat destruction

In September 2000 the European Commission adopted the document "Integrated Coastal Zone Management: a Strategy for Europe" based on the results and conclusions of the EC Demonstration Programme on Integrated Coastal Zone Management (ICZM). The EC Coastal Strategy highlights the importance of coastal zones, and also includes a proposal for European Parliament and Council Recommendations where eight principles of good coastal zone management have been identified[19]:

- *Take a wide-ranging view of inter-related problems (thematic and geographic) - a broad "holistic" perspective*
- *Use a long-term perspective; allow for unforeseen future developments*
- *Local specificity: base decisions on good data and information*
- *Try to work with natural processes*
- *Participatory planning: involve all stakeholders*
- *Support and involve all relevant administrative bodies*
- *Make use of a range of instruments (laws, plans, economic instruments, information campaigns, Local Agenda 21s, voluntary agreements, promotion of good practices, etc.)*

main questions on ICZM for the analysis of the regional seas

In principle, each of the five generic policy options can incorporate the concept of ICZM. This concept puts erosion in the perspective of other issues in the coastal zone. For instance, habitat protection and water quality recovery are other issues that could use ICZM as a tool.

Eurosion seeks to define sustainable solutions for managing coastal erosion. The ICZM sections of this chapter describe the policy options and strategies that are used in the regional seas in Europe against the background of ICZM. These sections aim to address the following questions:

1. Is ICZM explicitly used as a tool in organization/legislation?
2. Which principles of ICZM can be recognized?
3. How are policy options and strategies linked to ICZM principles?
4. What are the main conflicts between user functions in the coastal zone, how is coastal erosion involved?

These have been used as background to the description of ICZM, but are not explicitly treated in each of the relevant paragraphs.

When it comes to legislation specifically covering ICZM, at present no European country has developed explicit legal instruments. ICZM has, therefore, to be covered through existing legal means. Predominant national instruments are Planning and/or Building Acts. This is not surprising given the fact that the implementation of ICZM will always require planning decisions. However, the lack of environmental legislation that needs to be consulted will not always ensure that biodiversity and environmental issues will necessarily be covered in any ICZM planning applications. The legislation pertaining to ICZM is all recent, having been passed in the last decade.

3.3 Baltic Sea

3.3.1 Organization and legislation

In the past, coastal protection was often planned very locally. Local plot owners and municipalities took the initiative to protect their own coastal stretch. Since coastal protection measures can affect areas downstream and needs to prevent flooding of sometimes much larger areas, a national approach of the problem is necessary. Therefore, at present the responsibility for planning of coastal protection schemes usually is located at a **national level** (see Table 3-1).

Table 3-1 Responsible authorities in Baltic region[19]

Country	Ministerial Authorities	Local Authority Level
Denmark	Environment (ICZM); Defence (oil); Industry (tourism); Transport & Works (defence)	County
Estonia	Environment	County
Finland	Environment (planning); Transport & Comm. (shipping); Agric & Forest (water resources)	Municipality
Germany	Transport, Building & Housing	Municipality
Latvia	Environmental Protection & Regional Development	Regional, district and local
Lithuania	Environment; Transport	County & Municipality
Poland	Environment; Housing & Urban Development Office	Regional, district and local
Russia	Construction	None
Sweden	Environment; Agriculture (fisheries)	Regional & municipality

[19] EUCC, www.coastalguide.org

3.3.2 Policy options

Hold the line and limited intervention are the most frequently used policy options in the Baltic Sea area. When high population densities and high economic values are at risk of erosion or flooding, appropriate measures should be taken. Usually, a hold the line policy is opted in densely populated and economic valuable coastal areas, for instance when port facilities are in direct danger. Hold the line is often executed with the help of hard measures, though sometimes nourishments are applied to try and keep the coastline in the same position. In contrast to other functions, such as nature and tourism, the loss of human lives cannot be compensated for in any way. Nature and tourism can be compensated for either by creating nature or recreational areas at other locations, or by applying mitigating measures. The latter is done to minimize the impacts on and damage to these functions.

Hence, safety of human lives and protecting the economic value of a coastal area are usually the main reasons for the need of coastal protection. However, sometimes other functions threatened by erosion are of such great importance that measures against erosion are taken, even though human lives are not at stake. For example at Hyllingebjerg (Denmark), where only summer cottages and recreational beaches are present, a large coastal protection scheme has been executed because of the high recreational value of this coastal stretch.

Furthermore, functions like nature or tourism can determine in which manner a coastal protection scheme is executed. For example, if tourism is the main function at the coast, wide beaches, easy access and recreational facilities are of importance. If nature is the main function, the objective is to maintain the coast as dynamic and natural as possible (within the safety limits), for instance by choosing for limited intervention.

Limited intervention is applied through forest and foredune maintenance. Restoration of dunes and revegetation can be very effective in limiting the damage by storm activity. This is especially cost effective in countries with low labour costs like in Latvia, Lithuania and Estonia. Nourishments can also be used for limited intervention, to slow down the retreat of the coastline and to limit the damage when a storm hits the coast by offering an extra sand buffer. Furthermore, building restrictions are also part of the limited intervention policy option. Most of the Baltic region countries have building restrictions in the coastal strip varying 100-300 m from the waterline. Only in Germany and Finland, these restrictions are not present (yet) on a national level.

The policy option do nothing is sometimes applied when the occurring erosion does not pose any problems to the coastal stretch because no buildings, infrastructure or recreational facilities are threatened. In this case, a dynamic coastline is accepted where erosion and accretion can occur alternately. This is often possible in Finland and Sweden (because of land uplift and low population density). The policy option move seaward is very rare; an example of move seaward is seen at Køge Bay in Denmark where land was reclaimed in order to protect the hinterland from flooding. The policy option managed realignment was not seen in the case studies at the Baltic Sea. However, in literature[20] information was found that two large realignment schemes have taken place at Germany's Baltic Sea Coast creating a total of 700 ha of new flooded areas and dozens more realignment schemes are planned in the future.

[20] Susanne Rupp, Robert J. Nichols, Managed realignment of Coastal Flood Defences: A Comparison between England and Germany prepared for Proceedings of "Dealing with Flood Risk", 4 March 2002

3.3.3 Strategy

Approach to combat erosion

The strategy in coastal protection in the Baltic Sea area has so far usually been a reactive strategy. After a flooding or when a building, road or other construction is obviously being threatened, measures are taken. However, at present pro-active strategies are being developed in some areas especially to prevent problems with climate change in the future. For example, in Sweden at Falsterbo a lot of studies are presently carried out to find out the effects of sea level rise at the Peninsula and to identify the best measures to be taken to prevent negative effects. Also problems with a possible future increase of storm frequency and intensity are foreseen, and should be taken into account in the design of coastal protection schemes. In the Baltic States (Estonia, Latvia and Lithuania) where a negligible sea level rise is expected due to land uplift, this potential effect of climate change is clearly mentioned but a pro-active strategy has not yet been developed. Further study of the effect is needed first.

In the past usually hard measures like seawalls, revetments, and groins have been applied. At most places in the Baltic Sea area these constructions have been built starting from the beginning of the 20th century. After time had passed, most of these constructions turned out not to be effective. The constructions had to be repaired or reconstructed in order to be effective again (at least for some time). Another problem that rose was the fact that these hard measures tend to move the problem further downstream and disturb the natural equilibrium at the coast. In some cases the erosion problem was even worsened by applying hard measures.

After the problems with the hard measures, experiments with soft measures at the coast started. The first nourishments took place in Germany in 1950 and since then there has been a gradual change from hard to soft protection in Germany. In Denmark this change took place starting from 1980. Especially the last decade the use of nourishments as coastal protection has increased and spread to all the other Baltic Sea area countries as well. In Sweden however, beach nourishments are still very unusual for coastal protection. The volume of the nourishments is of the order of a few thousands up to 15,000 m^3 maximal.

At present, structural erosion problems caused by longshore transport are usually tackled with soft measures. When the longshore transport is interrupted, nourishments have also shown to be the best solution downstream. When roads, buildings or other structures have to be protected against storm events however, hard measures are still applied at several places in the Baltic Sea area. In Sweden, in almost all coastal erosion cases, hard measures like revetments or groins are being used.

In some countries, such as Denmark, Finland and Sweden, coastal landowners are responsible for the protection of their property, while in Germany and Poland for example it is the governments' duty to protect coastal areas from erosion and flooding. This difference in the governments' obligation will influence partly determine the strategy in coastal protection.

Measures concerning safety of hinterland

Besides measures to protect the coast, measures can be taken to mitigate the consequences of flooding and if damage does occur due to failure of the coastal protection scheme. Evacuation plans for a flooding are usually available at a municipality level. These plans include emergency mitigation of the erosion and/or flooding disaster effects and for evacuation of people.

In the case of a big flooding or erosion, in the Baltic States (Estonia, Latvia and Lithuania) municipalities are supposed to provide a limited subsidy for those who have suffered the most. For the bigger aid for a compensation of damage caused by erosion, municipalities apply to the national government. Furthermore, most of the expensive houses in the coastal area in the Baltic States are insured against damage.

3.3.4 Integrated Coastal Zone Management

In the last decades the conditions for planning in the coastal zone have changed significantly. Many interests like tourism or environmental concerns have gained importance. Well-developed countries, with fairly large cities, a variety of industries, and modern agriculture and forest management, surround the Baltic. Ever since industrialization started here in the latter part of the nineteenth century, the Baltic Sea receives steadily increasing amounts of pollutants. It takes about 35 years for all the Baltic water to be refreshed by ocean water. Foreign substances entering the seawaters will remain there for over a quarter of a century, often long enough to have strong effects. Therefore, all coastal areas in the Baltic Sea are threatened by pollution and eutrophication, caused by dense population, industry and tourism.

Conflicts can occur between these functions and the main function of coastal protection: safety. Furthermore, between these functions mutually conflicts can arise (for example between tourism and nature conservation). Therefore, besides safety other functions have to be considered in coastal defense planning. To do so, integrated coastal zone management is necessary.

When it comes to legislation specifically covering ICZM, no country in the Baltic has developed explicit legal instruments. This, in fact, reflects the situation throughout Europe. ICZM has, therefore, to be covered through existing legal means. Predominant national instruments are Planning and/or Building Acts. This is not surprising given the fact that the implementation of ICZM will always require planning decisions. However, the lack of environmental legislation that needs to be consulted will not always ensure that biodiversity and environmental issues will necessarily be covered in any ICM planning applications. The legislation pertaining to ICZM is all recent, having been passed in the last decade.

In the Baltic Sea area, several ICZM programs (see Box 3-2) have been initiated. Every country in the Baltic area is somehow engaged in ICZM and ICZM projects are being undertaken everywhere. However, integrated coastal zone planning is still in a very early stage in the Baltic Sea area and in most countries the implementation of ICZM is experimental.

Box 3-2 Coastal Zone Management Plans in Baltic region

HELCOM

Issued to protect the marine environment of the Baltic Sea, the first Convention on the Protection of the Marine Environment of the Baltic Sea Area was signed in 1974 by the coastal states of the Baltic Sea at that time. It was the first international agreement to cover all sources of pollution, both from land and from ships as well as airborne. In 1992, a new Convention was signed including a new article (Art. 15) on nature conservation and biodiversity, which entered into force on 17 January 2000. The present contracting parties to HELCOM are Denmark, Estonia, European Community, Finland, Germany, Latvia, Lithuania, Poland, Russia and Sweden. The Helsinki Commission has established a system of more than 60 Baltic Coastal and Marine Protected Areas and established management plans for five large coastal lagoons and wetland areas along the south and south eastern Baltic coasts (for further information see www.helcom.fi). HELCOM gave recommendations on the protection of the coastal strip or the preservation of natural coastal dynamics. Most of the Baltic Sea Region countries have adopted these recommendations. The protected coastal strip (building restriction) ranges from 100-300 meters landward and seaward in the different countries. Only Finland and Germany have not nationally adopted the HELCOM-recommendations. However, in Germany for example the region Schleswig-Holstein has adopted a protected strip.

VASAB 2010

VASAB 2010 (Visions and Strategies around the Baltic 2010) is an intergovernmental program of the Baltic Sea Region countries on multilateral spatial planning, giving "common recommendations for spatial planning of the coastal zone in the Baltic Sea Region".

Interreg IIC, Baltic Sea Region: Procoast

The objective of Procoast is the implementation of HELCOM- and VASAB recommendations into coastal management. This implies the step from common recommendations to practical solutions in daily work. The focus of the project was on integrated coastal zone management issues. Another specific object of Procoast was to bring together different stakeholders in the coastal zone with coastal management experts from different countries and regions around the Baltic.

Baltic 21

In 1996, the Prime Ministers of the Baltic Sea Region took the initiative to develop an Agenda 21 for the Baltic Sea Region aiming at sustainable development encompassing economic, social and environmental aspects. The Agenda 21 for the Baltic Sea Region was adopted in 1998 and is a joint, long-term effort by the 11 countries of the Council of the Baltic Sea States (CBSS). The emphasis is on regional co-operation, and the work is focused on seven economic sectors, spatial planning and, since spring 2000, also on education. The Baltic Sea Region is the first region in the world to adopt common regional goals for sustainable development. Implementation is in progress (see further www.ee/baltic21/).

On a project scale, integrated coastal zone management is being applied in different ways.

First of all, different functions are taken into account. In some projects, an attempt is done to manage the coastal zone in the most natural (examples: vegetation at Køge Bay, coastal dynamics at Rostock) and visually acceptable manner (example: at Hyllingebjerg the sight of the coastal protection scheme has been of great importance in the design). Furthermore, at Køge Bay the recreation function was combined with the coastal defense function by building a Beach Park that also protects the hinterland from flooding. In most cases, the importance of tourism is acknowledged by maintaining the necessary beach width.
Secondly, an integral approach can be seen in the planning process, the stakeholders taking part in this planning process and the financing. In a recent project in Denmark at Hyllingebjerg, plot owners, the municipality and the county financed the project together (see Box 3-3).

Box 3-3 Hyllingebjerg, Denmark: example of integral financing coastal protection project

> The Hyllingebjerg case shows how a coastal defence project can be financed integrally. The coast of Frederiksborg County has been classified in three categories regarding the need for coastal protection: category 1 contains coastal stretches that have a need for action and that are of public interest (e.g. areas with recreational or transport functions). In this case the costs can be divided between landowners and public authorities. Other coastal areas with a need of protection fall within the second category, where landowners have to take over all the costs of coastal defence measures. The third category contains all other coastlines with no need for coastal defence measures.
>
> Dividing the costs for coastal protection between the county, municipality and landowners has advantages and disadvantages. An advantage might be that landowners take a higher responsibility and do not build houses very close to the sea. On the other hand, a risk exists that the landowners may not have enough financial means if the costs for coastal protection are too high and that they are not willing to join a common project. Maybe also they can be excluded to own land close to sea, due to these costs. For example for farmers who own a lot of land this could cause problems.
>
> In the Hyllingebjerg case, landowners are organized in a private organization to represent their interests. When a local organization like this is absent, there is a risk that the money is spread to many small projects, meaning that the problem can, in the worst case, be moved to another location or that areas where the problems are worst are not dealt with. These problems might also occur if landowners are not willing to join the common organization. Therefore, it is very important to get all the interested parties (especially the landowners) to join the common project. This was nearly successful in the presented project at Hyllingebjerg-Liseleje coast.

The land reclamation at Køge Bay was executed in the 1970s, this project also had a complex planning and financial process and some lessons learned are described in Box 3-4.

Box 3-4 Køge Bay, Denmark: lessons learned about planning coastal protection project 1970s

> Interesting things about the Køge Bay project are the planning process (the authorities, municipalities etc. that have been involved and how), how the "Strandparken" was financed (Copenhagen city and some of the surrounding municipalities etc. have contributed to the costs) and how at least two main problems (recreation facilities combined with coastal defence measure) were solved by co-operating.
>
> In the planning phase there have been several complaints against the project by local residents as well as by environmentalists. While environmentalists feared the loss of biotopes for sea birds, local inhabitants were afraid to loose their free access to the beach. The project has been planned since the thirties and was conducted during the seventies. Maybe today, more participatory planning instruments would have been used which could have avoided some complaints. Especially for large projects like Strandparken, participatory planning tools or at least an early information about the consequences of the project are recommended in order to achieve an early acceptance of planned measures.
>
> It seems important to consider environmental aspects at an early stage in order to avoid conflicts with nature conservation goals. However - regardless if it is a result of the complaints or of wise planning - after two decades it now turns out that the park has become a recreational area as well as a nature reserve with many different nesting and migrating birds.
>
> Another important aspect at Køge Bay is the management of the vegetation. Only typical vegetation from very similar locations was planted at Køge Bay and managed in a way that keeps the park in a most nature-like manner. However, looking back, leaving some parts of the park over to nature in order to let free succession of the vegetation take place might have been another option.

Furthermore, the importance of informing the public and creating good will with the public has been acknowledged. An example is shown in Box 3-5.

Box 3-5 Hyllingebjerg, Denmark: the importance of informing the public

During the coastal protection project Liseleje - Hyllingebjerg it became clear that it is important to keep the public fully informed about the process and to provide easy access to the information - you can't overinform in anyway. The web-site made by the County of Frederiksborg (http://www.fa.dk/natur/projekter/) is a very good example, and people who live there are very satisfied with it. The county has put a lot of work in it, but they feel that it has definitely paid off.

Something else noticed (e.g. in Latvia) was the apparent shortfall in the exchange of information related to coastal management among public institutions. There is not a single institution in Latvia, which contains a coherent picture of what is going on in the coastal zone of that country, or possesses all relevant information, which were important for sound and integrated decision-taking related to the coast. E.g., although the geographers at Latvian University have a rather long monitoring record of coastal dynamics in Latvia, they are rarely asked for advice regarding coastline management. At the same time, private or semi-public companies, who take active efforts in coastal development and defence, hardly ever share their knowledge with public institutions and authorities.

3.4 North Sea

3.4.1 Organization and legislation

Spatial planning issues are generally well developed in the North Sea region countries on the landward side of the coastline. However, in the marine area, many (often national) sectorial agencies regulate different issues with little reference to integrative thinking and public involvement. At the same time, the traditional terrestrial-based planning system often lacks mechanisms for dealing with issues, which overlap the marine and terrestrial zones [21].

Table 3-2 Responsible authorities in North Sea region[22]

Country	Ministerial Authorities	Local Authority Level
Denmark	Environment (ICZM); Defence (oil); Industry (tourism); Transport & Works (defence)	County
Germany	Transport, Building & Housing	Municipality
Belgium	Agriculture; Environment; Public Works, Transport and Town and Country Planning	Regional
Netherlands	Ministry for Transport, Public Works and Water Management	Regional
United Kingdom	Environment, Transport and the Regions; Environment Agency	Regional & County

[21] NORCOAST – Recommendation on improved Integrated Coastal Zone Management in the North Sea Region, County of Jutland, 2000

[22] EUCC, www.coastalguide.org

A short description of planning and legislation aspects for coastal areas in the different European countries in the North Sea region is given below.

Belgium
For a long time the seacoast has been the domain for sectoral planning mainly serving tourism and recreation. Due to the small length of the coast and heavy population pressures most of the seacoast became urbanized and half of the coastal dunes disappeared. However, Vlaanderen adopted a *Duinendecreet* (Dunes Act, protecting the remaining dunes) in 1995 as well as an *Ecosysteemvisie* (ecosystem management strategy) for the dunes. A new plan for the coast *(Kust 2002 Pla*n) has been prepared which fully integrates conservation objectives with economic developments. Projects are also ongoing to improve the conservation and management of coastal dunes.

Denmark
Denmark has an elaborate spatial planning, especially in the coastal zone, with a high level of horizontal (cross-sectoral) integration and participation. The Danish Planning Act stipulates communication between the state, the counties and the municipalities. Regional plans (to be renewed every 4 years) usually provide guidelines for the rational use of coastal areas including planning of recreational activities. A national ICZM policy does not exist. All coastal counties are more or less actively involved in coastal zone management and planning.

Germany
The organizational structure for decision making and planning in Germany involves three different political levels of decision making: community, state and federal government. The States *(Länder)* are the first responsible bodies for spatial planning and for coastal and water management. Planning in the German coastal zone has a predominantly sectoral character, with little integration of land and sea. All natural ecosystems in the coastal zone ale protected. National Parks play an important role in the German coastal zone. Three National Parks cover almost the entire German Wadden Sea. The North Sea coastlines of Schleswig-Holstein and Niedersachsen are involved in the Life-project "Integrated co-operation on the development of sustainable tourism and recreation in the Wadden sea area".

Netherlands
There is a long tradition of integrated planning in the Netherlands as a result of the population density and high economic development pressures. Planning frameworks for all sectors are made at a national level and they are usually tuned to each other because their development is a long process involving many stakeholders, ministries and the Parliament. Cicin-Sain and Knight (1998) consider the Netherlands to be the world leader in ICZM for coastal defence and in harmonization of national coastal and ocean policies. Coastal ecosystems (Wadden Sea, all marine foreshore zones, sand dunes and salt marshes) are all given a high protection status as key elements of the *Ecologische Hoofdstructuur (EH*S, a national ecological network). Already for fifteen years, the Dutch Wadden Sea (part of three provinces) has a special status as a separate planning area with a special Council *(Waddenadviesraa*d) for horizontal and vertical integration. The planning and management of the Dutch Wadden Sea has developed as an international model of ICZM.

England
Sectoral national policies and regional strategies form the framework for coastal management in the UK. In England and Wales coastal management is strongly determined by instruments such as National Parks, *Heritage Coasts* and properties of national NGO's (e.g. National Trust, RSPB, local trusts). Management initiatives are locally based, non-statutory, cross-sectoral plans, implemented through voluntary partnerships. Local management initiatives often feature strong public consultation. Examples of this are the various *Estuary Management Plan*s. Primarily based upon sea defence interests, also many *Shoreline Management Plans* are currently developing (in principle for all "coastal cells"). Various sources conclude that the complicated and strongly sectoral legal framework will hamper effective ICZM. As a result of extensive EC-funding for UK-projects in the context of the EU Demonstration Program for ICZM and the Estuary Management Plans the UK is quickly developing local experience.

3.4.2 Policy options

In the North Sea, historically the most frequently used policy option has been **hold the line** when safety of human lives and of economic investments are in question, for instance in the urbanized areas. Historically this was mainly achieved using hard measures. The last few decades the emphasis is shifting in the direction of soft measures (nourishments).

Besides the function of urbanization, other functions are becoming increasingly important in the North Sea region. For example, the awareness of the importance of ecological values and nature conservation is growing. In coastal areas, environmental values become more important in coastal zone management. This brings the opportunity the choice for limited intervention or even do nothing.

Limited intervention consists of mitigating measures to reduce risks while allowing natural coastal changes. Nourishments are becoming more common in the North Sea. Creating a sand buffer in front of the coast (for example the feeder berm at De Haan, Belgium) slows down the erosion of the coastline. Furthermore, vegetation techniques are being applied in the North Sea area more often for the stabilization of dunes and cliffs.

Do nothing has historically been applied when no investments or human lives were threatened. Later, the option ‘do nothing’ is also suggested when a coastal protection measure would cause too much negative effects at adjoining coastal stretches. In that case, the general interest of the entire coastal cell is put above the individual interest of local landowners. Especially in Great Britain, where cliff erosion supplies sediment for downstream beaches and estuaries, this has shown to cause large conflicts between landowners/local inhabitants and the councils that are responsible for the coastal protection scheme. Up until now, the councils have usually given in to the objections of inhabitants and landowners (see Box 3-6).

Box 3-6 Example of conflict with policy option do nothing

At Hornsea, the local council promised landowners facing the loss of their land or property to build a stone groyne at the base of the cliffs to trap sediments and reduce the power of the waves. The inhabitants, however, were infuriated by the decision of the council not to take this action until the cliff edge was 30m from their front doors. The main concern of the council had been to protect the British Petroleum oil and gas terminal further towards the south at Easington. Furthermore the Countryside Commission had argued that protecting the cliffs at Hornsea reduces the flow of sediment down the coast and into the Humber where it protects the riverbanks. Their research shows that this increases the risk of flooding in Hull. But following protests from the local Hornsea population, the stone barrier was anyhow extended to protect the village.

In the estuaries, no further retreat of the coastline can be accepted at the locations where the channels have migrated towards the sea-dike. The policy option is to hold the line at these locations. Another measure, setting back the defence line, managed realignment, can compensate for the expected loss of tidal marshes and flats in estuaries (and thus of nature functions) because of sea level rise (coastal squeeze). Complementary advantage of this measure, when applied in the inner estuary, is the lowering of water levels in the estuary, decreasing the risk of flooding.

Managed realignment is applied in the United Kingdom, for lands that lack dense economic use (e.g. agricultural land). The loss of habitat, changing perceptions of the implications of sea level rise and cost on maintaining hard defences have all contributed to the choice for managed realignment, which accepts that some land will be lost to sea. Combined with 'softer' engineering techniques this policy option provides a flexible approach to coastal protection. Managed realignment allows for the compensation of the loss of ecologically valuable habitats by creating new intertidal areas. These provide the hinterland with extra protection against wave attack. A possible problem with managed realignment in an estuary may be the increasing tidal volume and increasing currents in the outer estuary.

In the other North Sea countries, the choice for managed realignment is less accepted for different reasons.

Move seaward is not observed in any of the case studies. An existing example of 'move seaward' can be found in the Netherlands: the Maasvlakte has been built to provide primarily in the space needed for the expansion of the economic activities of Rotterdam-Harbour.

3.4.3 Strategy

Approach to combat erosion

In the past, hard engineering options were commonly applied. These were constructed only when erosion became a serious problem. As such, a reactive strategy was adopted in general. Nowadays, however, authorities responsible for the coastal zone management along the North Sea, are very much aware of the need to develop sustainable national coastal policy plans, focusing on the short to medium-long time horizon (50 years), in which sea level rise is taken into account. Thus, they are anticipating problems, creating pro-active strategies.

Box 3-7 Changing approach of coastal protection in the Netherlands[23]

The Netherlands are amongst the few countries that have elaborate national coastal policies. The Dutch government periodically issues Coastal Plans (Kustnota's), primarily from the viewpoint of coastal defence. The main goal is maintaining security regarding floods together with the maintenance or even the enhancement of natural processes. Generally, a premise for Dutch coastal policy is the consolidation of the existing sea defence ('hold the line') and solving only the most acute erosion problems. This strategy is called dynamic preservation.

This policy has developed through the following plans:

- 1st Coastal Plan (Eerste Kustnota, 1990): changed the emphasis of the policy from hard towards soft engineering, i.e. permanent beach nourishment; as of 1990, all structural erosion will be counteracted.
- 2nd Coastal Plan (Kustbalans, de Tweede Kustnota, 1995): assessment of five years of dynamic preservation of the coast; possibilities were presented for integrated coastal management.
- 3rd Coastal Plan (Derde Kustnota, 2000): confirms the policy of maintaining the coastline and combating structural erosion, primarily with soft engineering.

Projects involving four ministries have resulted resulting into two government papers: Principles for integrated coastal management (Kust op Koers, 1999) and Policy agenda for integrated coastal management (Naar integraal kustzonebeleid / Beleidsagenda voor de kust, 2002)

In the Netherlands (e.g. cases Holland coast and Waddenzee), for example, the main goal as defined in the national policy, is to guarantee a certain level of security regarding floods together with the maintenance or even the enhancement of natural processes. Besides, Integrated Coastal Zone Management becoming a more important issue constantly (see Box 3-7).

Historically and especially in the 20th century, hard constructions were built to hold the coastline at its existing position and to protect the infrastructures and polders against flood. This holds for all case studies considered.
At present, the general policy with regard to coastal protection tends to use the natural processes along the coast. A soft approach is often adopted and coastal defence actions are merely based on sand nourishments. This is a relatively cheap method and it fits with the natural characters of the coast. An example is given in **Fout! Verwijzingsbron niet gevonden.**.

In the early 1930's a sloped seawall was constructed at **De Haan** in order to stabilize the dune belt and to allow for touristic expansion. The fixed seawall made natural movements of the dune/beach system clearly visible.

After the 1990 storm attack, the foundation of the seawall was put into jeopardy. The sea wall was protected by nourishments, consisting of a combination of a profile beach nourishment with a subtidal feeder berm. The decision to choose this system was based upon economical, technical and ecological considerations.

The purpose of the nourishments is to prevent the seawall from being exposed to direct wave attack by the first following storm. Soft measures protect the hard measures that were constructed in the past: the seawall (storm) is protected by the sediment of the nourishment.

Box 3-8 Protection of a seawall by beach nourishments at De Haan

Box 3-8 shows that engineering solutions have changed from a hard to a soft approach. This is the case since the beginning of the eighties. Apart from economical reasons, this is partly due to

[23] Eurosion Scoping Study

the growing awareness among the general public and among politicians of environmental issues. A rehabilitation of the natural sea-land environment, new technical potentialities and political accents have made that since the seventies preference is given to “soft”, eco-friendly measures, i.e. beach nourishment, taking into account the natural dynamics of the shoreline (coast or estuary). An example of the growing awareness of the natural behaviour of the Westerschelde estuary is given in Box 3-9.

> Since the 1970 the Flemish government has deepened and widened the navigation channel to Antwerpen in the **Westerschelde**. As a result, the yearly amount of dredging has increased from 4 Mm3 (1970) via 8-10 Mm3 (1995) to an expected amount of 14 Mm3 in 2002. Most of the dredging was done in the eastern part of the estuary.
>
> A dredging and dumping strategy is adopted in which the dredged material is dumped in the Western Scheldt. Dredging and dumping of sediment can have various consequences, such as the loss of the dynamical behaviour of the morphology as well as the loss of diversity of habitats for plants and animals (e.g. intertidal mud flats/salt marshes or shallow water zones). These effects were noticed especially in the eastern part of the estuary.
>
> The present strategy is to prevent a further reduction of these valuable habitats. At locations, where a further migration of the navigation channels may cause undesired effects, such as erosion of dike toes or intertidal salt marshes, revetments are constructed. Since migrating channels are characteristic for the natural dynamical behaviour of an estuary, it can be argued that these revetments cause a less ‘natural’ behaviour of the estuary.

Box 3-9 Maintaining the natural behaviour of an estuary (Westerschelde)

Managed realignment is applied in the United Kingdom, for lands that lack dense economic use (e.g. agricultural land). Private landowners do generally not accept the option “managed realignment” or “do nothing”. An example can be found in the Holderness case, where in the past, private ad hoc sea defences have been put in place to protect assets. While these provide a short-term protection to the properties directly protected, their general nature and design is of concern. For any private scheme to be considered it would have to be deemed by the Planning Authority to be technically sound and have no negative impact on the environment. Conditions relating to maintenance and eventual removal should also be considered.

In the other North Sea countries, the choice for managed realignment is less accepted for different reasons, for example Germany[24]:

- Coastal morphology

In England, low-lying areas are often backed or alternated with rising grounds. This means that a shorter dike line or no dike line at all (and thus lower costs) will result from realignment. At the North Sea coast of Germany the flood plain is flat, continuous, extensive and many kilometers wide. Therefore, this advantage is not present at these locations.

- Importance of intertidal habitats

In Great Britain, the concern for the loss of salt marshes seems to be greater than in Germany because salt marshes have traditionally been more valued (especially for flood defence purposes) and considerable amounts of money have been and still are being spent to build up and sustain salt marshes in front of dikes.

[24] Rupp, S. and Nicholls, R.J., Managed realignment of Coastal Flood Defences: A comparison between England and Germany, March 2002.

- Coastal management approach

In Germany lots of lives were lost due to floodings. Therefore, there is a strong sense among the public that the sea is a bitter and cruel enemy and giving land back to the sea is not popular with the public.

- Current state of coastal defences

Most of the coast in Germany is heavily defended with high dikes (that are in good condition) with recent investment to claim land from the sea. In England, a smaller portion, about one third, of the coast is protected in some way but the protections are often in poor condition and usually provide much less safety in the current situation than in Germany.

- Coastal defence responsibilities

German federal states have the duty to maintain and build coastal defence structures they took responsibility for in the coast protection masterplans. The defence standards are the same along the entire German North Sea coast and are not related to the land use of the hinterland. The defences are in excellent condition. In England, no one has the automatic right to be defended; defence structures are built and maintained strictly according to benefit-cost analysis. In areas where defences are not viable, the landowner will not receive compensation.

For practically the same reasons as in Germany, managed realignment is probably also less popular in other North Sea countries such as Belgium and the Netherlands. Only when sea level rise should be greater than expected and one would no longer be able to reinforce or heighten the existing dikes, a retreat of the defence line is possible in the far future. In England, managed realignment is expected to be practiced increasingly in the near future.

Measures concerning safety of hinterland

Besides measures to protect the coast, measures can be taken to mitigate the consequences of flooding and if damage does occur due to failure of the coastal protection scheme. In the Netherlands for example, the safety standard of the dikes is so high (see Table 3-3) that a flooding is very improbable. However, in England, safety standards are varying and can be very low at areas that lack economic value (e.g. agricultural lands).
The Environment Agency in England has a flood warning system which uses a special telephone number which can be dialled to provide guidance on where warnings are in operation. Access via the Internet provides a similar service. This is backed up by the provision of maps available on the Internet.
In Denmark, the "Kystdirektorat" is responsible for providing a storm tides warning. Evacuation plans for floodings are usually available in the different countries on a local scale.

Any land in the floodplain is liable to be flooded, whatever standard of protection is provided, since there is always a risk that an event capable of overwhelming the defences will occur. Current legislation in England does not (except in special circumstances) require the Environment Agency either to provide or to maintain a particular standard of protection. As a result, there is no general provision for compensating anyone whose land or property is affected either by flooding or by erosion in England. In the Netherlands and Germany, safety standards are legally required and have to be maintained. In Denmark, apart from the 200-year return period for the major dikes at the tidal Wadden Sea Coast, there are no national rules for safety assessment of dikes or dunes.

Table 3-3 Required safety levels at North Sea countries

	Legally required or locally desired return period (in years)	Observations
Netherlands	4.000 Zeeland 10.000 Holland Coast 2.000 Wadden Islands 4.000 Wadden Sea Coast	Legally required Legally required Legally required Legally required
Germany	200 Wadden Sea Coast	Legally required
Denmark	200 Wadden Sea Coast 100 West Coast dunes	Legally required -
Belgium	1.000 only for current repairs and constructions	-
England	Ranging from 5-200, extremities: 5 agricultural land 200 high density urbanized	Return period is differentiated for economic value of hinterland

The total potential loss of the Holland coastal zone is estimated to be approximately 300 billion Euros[25]. Due to this high possible impact there is no flood insurance since the flood event of 1953 (due to possible bankruptcy of insurance companies). Currently, the Calamities Compensation Act (WTS) compensates most of the flood damage, which is not to be insured.

3.4.4 Integrated Coastal Zone Management

In the North Sea area, most countries have a long tradition of coastal management and of integrated strategies. Compared to countries in Europe, these countries have therefore made most progress in establishing ICZM. National legislation concerning ICZM is yet not present in any of the North Sea countries. However, in England and the Netherlands national ICZM discussion papers have been produced by the government. ICZM has to be covered through existing legal means. Predominant national instruments are Planning and/or Building Acts.

From NORCOAST[211], the following recommendations concerning the regulatory framework for ICZM followed for the North Sea region:

- Legislate for a clear statutory responsibility for spatial planning – land and sea;
- Appoint authorities as lead agencies to initiate ICZM;
- Define a national framework for ICZM;
- EU should provide practical support for the development of ICZM.

It is clear that there are moves to develop ICZM – either on a statutory or non-statutory basis – in all the North Sea countries. But at this moment, the picture is by no means uniform.

Table 3-4 Status of ICZM in coastal regions of countries bordering the North Sea[26]

	Total coastal regions entire country	Fully established	Partially established	In progress	Little/ no progress
Belgium	1	0	0	1	0

[25] Kok et al., 2002

[26] Salman, A., Perez Valverde C. and van Elburg-Velinova D., Progress of ICZM Development in European Countries: a pilot study, Leiden, November 1999

Denmark	14	0	0	14	0
Germany	5	0	0	2	3
Netherlands	5	2	1	2	0
UK	49	1	0	11	37

Table 3-4 gives an overview of the status of ICZM on a regional scale. In most coastal regions some progress is made in the North Sea countries. For Germany, the 3 coastal regions where no progress is made are located at the Baltic Sea. Apart from that, only in a large part of the coastal regions in England no progress is made. In Belgium, Denmark and Netherlands in every coastal region some kind of progress is made. ICZM is established in a complete region in the North Sea: Wadden Sea in the Netherlands.

Two large ICZM projects in the North Sea area are described in
Box 3-10 Box 3-10 Large ICZM projects in the North Sea area; NORCOAST and the Trilateral Wadden Sea Cooperation. Furthermore, some ICZM projects in the framework of the European Union ICM Terra project and the LIFE project are executed in the North Sea area.

Box 3-10 Large ICZM projects in the North Sea area

NORCOAST: Recommendation on improved Integrated Coastal Zone Management in the North Sea Region
The NORCOAST project (1998 – 2000) aimed to investigate and promote good practice in Integrated Coastal Zone Management in the North Sea area. The project was based on the experience and knowledge of practitioners in coastal planning and management with particular focus on the regional level. The project set out to assess the status and effectiveness of coastal planning and management systems in the North Sea area and included study visits to the 7 participating regions. From this the project group has developed general and issue-specific recommendations for the development of ICZM.

Trilateral Wadden Sea cooperation
Since 1978, the responsible ministries of the Netherlands, Denmark and Germany have been working together on the protection and conservation of the Wadden Sea covering management, monitoring and research, as well as political matters:
-Minister of Agriculture, Nature Management and Fisheries, The Netherlands;
-Federal Minister for the Environment, Nature Conservation and Nuclear Safety, Germany;
-Minister of Environment, Denmark.

The Trilateral Governmental Conferences, which are held every 3 - 4 years, is the highest decision making body in the framework of the collaboration. In the periods between the Governmental Conferences, the Trilateral Working Group (TWG), as a permanent working group, meets on average four 3 - 4 times a year. The TWG is composed of civil servants of the responsible ministries and other relevant ministries as well as regional authorities. The Common Wadden Sea Secretariat (CWSS) was established in 1987 in Wilhelmshaven, Germany, as the secretariat for the trilateral cooperation. Its primary task is to support, initiate, facilitate and coordinate the activities of the collaboration. (Administrative Agreement, 1987)

The case studies show the importance of the integrated approach of coastal zone management. Possible conflicts between functions and between responsibilities of legislative bodies (at ministerial and local authority level) require an integrated approach. Box 3-11 shows an example of the integration of the different functions around the Essex estuary.

Box 3-11 Integrated Coastal Zone Management in Essex

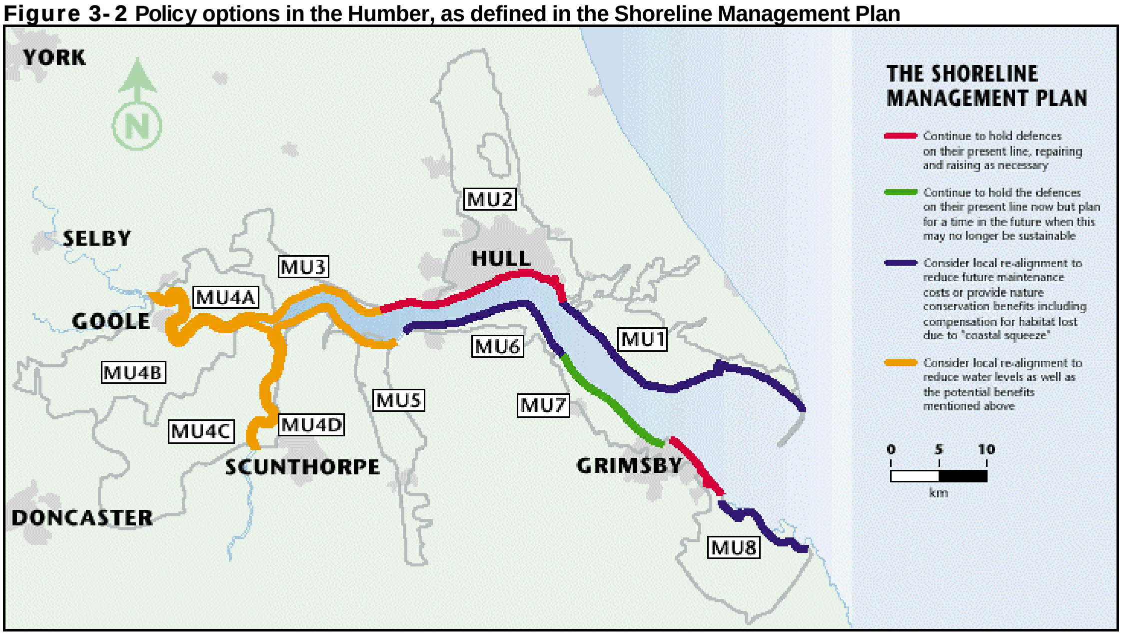
The **Essex** Estuaries Initiative (EEI) is a strategic approach to coastal management, which aims to coordinate the activities affecting the Essex estuary. This is a statutory designation, which involves a wide range of authorities, from local authorities to fisheries regulators, from nature conservation agencies to harbour authorities.

The main purpose is to ensure the nature resources of the coast, both on sea and land, in order to continuing support business, wildlife, and the sustainable development of coastal populations and nature areas. The development of appropriate management will facilitate the attainment of different goals of conservation whilst at the same time maintaining and enhancing the socio-economic development of the area.

The initiative initiates coastal and estuary management with specific reference to sustainability and supported decision-making. It aims to implement the Habitats Directive by developing a management plan in partnership with relevant authorities, users and interest groups.

Another example can be found around the Humber estuary, where various functions are present, such as industry, transport and energy, fishery and aquaculture, nature, agriculture and forestry, tourism and recreation. The long-term policy options for the protection of the hinterland around the estuary were given in the Humber Shoreline Management Plan in which the different functions have been taken into account (see Figure 3-2).

Figure 3-2 Policy options in the Humber, as defined in the Shoreline Management Plan



The number of people and the value of property within the floodplain make it essential to provide a line of defences around the estuary. It may however be worthwhile moving the line locally, if this will provide benefits (such as reduced costs). The defence strategy depends upon the balance between the costs and the benefits of moving the defences. Costs and benefits are related to economic, social and environmental considerations.

Moving the defences in the Humber may lead to savings if the new line is cheaper to build or maintain, for example if it is shorter or lower or if it avoids the need for costly erosion protection measures. Any decision to move the line will take into account the loss of land or property that will result and the need to provide compensation for habitat losses due to flood defence works elsewhere in the Humber.

3.5 Atlantic Ocean

3.5.1 Organization and legislation

A short description of planning and legislation aspects for coastal areas in the different European countries in the Atlantic Ocean is given below [27].

Portugal
The whole coastal zone of Portugal is subject to the Coastal Zone Management Plans (Planos de Ordenamento da Orla Costeira – POOCs) 6 of the 7 plans are already approved. The local authority level – municipalities - are responsible for the local implemenatation of the plans. Despite the fact that they do not cover all ICZM elements, these plans can be good instruments for horizontal and vertical integration. Public participation is not yet strongly developed in Portugal.

Spain
Between 1960 and 1990 the coast has been the domain for strongly sectoral planning mainly serving international tourism. A national ICZM policy does not exist in Spain. However, because the Autonomous Regions are responsible for spatial and environmental planning, most coastal Regions have developed cross-sectoral land planning for coastal areas over the last 5-10 years. With respect to management of the coastal zone, there exists an overlap of jurisdiction among national, regional and local authorities. Although the bulk of resource management jurisdiction is vested in the regional government, the national government has claimed exclusive competence over the coastal strip determined as Coastal Public Domain through the Shores Act (Ley de Costa 1988). Local governments participate in coastal zone management through the development of land use plans in beach and foreshore areas. Vertical integration and public participation are not yet strongly developed.

France
France has a tradition of central planning, with an important government service (Conservatoire du Littoral) that purchases natural coastal areas and a national Coastal Law (1986) that stipulates a narrow (at least 100 m) protected zone along the undeveloped coastlines. A nation ICZM policy does not yet exist in France, but a very interesting prototype already exists since 1983. This is a management tool for primarily marine use conflicts, zoning the adjacent marine environment and introducing a system of plans for enhancing and exploiting the sea. Problems in making these plans concrete are the complexity of the instrument, lack of funding and conflicting interests of stakeholders.

Ireland
The Irish legislative framework is strongly sectoral, complex and intricate. Legislative measures serve one of two principal purposes – the administration of activities or the protection of the environment. Spatial planning is rather decentralised. As a result, the coastal zone is administered by a range of authorities, agencies and bodies. ICZM is quite a new phenomenon

[27] Salman, A., Perez Valverde C. and van Elburg-Velinova D., Progress of ICZM Development in European Countries: a pilot study, Leiden, November 1999

in Ireland. However, a ICZM working paper was produced in 1997 by the Irish Government as a first initiative.

United Kingdom
Sectoral national policies and regional strategies form the framework for coastal management in the United Kingdom. In England and Wales coastal management is strongly determined by instruments such as National Parks, *Heritage Coasts* and properties of national NGO's (e.g. National Trust, RSPB, local trusts). Management initiatives are locally based, non-statutory, cross-sectoral plans, implemented through voluntary partnerships. Local management initiatives often feature strong public consultation. Examples of this are the various *Estuary Management Plan*s. Primarily based upon sea defence interests, also many *Shoreline Management Plans* are currently developing (in principle for all "coastal cells"). Various sources conclude that the complicated and strongly sectoral legal framework will hamper effective ICZM. As a result of extensive EC-funding for United Kingdom-projects in the context of the EU Demonstration Program for ICZM and the Estuary Management Plans the United Kingdom is quickly developing local experience.

Table 3-5 Responsible authorities for coastal planning in Atlantic region

Country	Ministerial Authorities	Local Authority Level
France	Environment; Agriculture and Fisheries; Planning and administration of navigable waters	Municipality
Spain	Environment	Regional & Municipality
Portugal	Environment and Natural Resources	n.a.
Ireland	Marine and Natural resources; Environment and Local government	County
United Kingdom	Environment, Transport and the Regions; Environment Agency	Regional & County

Table 3-5 gives an overview of the responsible authorities in coastal planning on a national and on a local level. The final responsibility for coastal management is usually located at a **national level** in these countries.

3.5.2 Policy options

At the end of the 19th century and in the beginning of the 20th century, the Atlantic coastline was stabilized using primarily hard engineering techniques. In general, a **hold the line** policy was adopted. At that time, mostly ports and auxiliary industries were protected. Since 1970, in France, Portugal and Spain, tourism has increased rapidly, but also in the southern part of the United Kingdom and Ireland tourism is important. Most of the protected ('hold the line') areas within the case studies consist of seaside resorts or other recreational facilities. Furthermore, high population densities (urbanized areas) and economic investments are protected by applying 'hold the line'. Like in the United Kingdom, Ireland and Portugal. At present, 'hold the line' is still applied at many sites along the Atlantic coastline where high economic values and/or human lives are directly at risk.

As was demonstrated above, socio-economic factors influence the coastal strategy chosen. In turn, the coastal strategy can have a great impact on the socio-economic situation of a coastal zone. In Box 3-12 (Châtelaillon) and Box 3-13 (San Sebastian) examples are given of the impact of a coastal protection scheme. At Châtelaillon, the new beach width created new possibilities for tourist development and accompanying measures. At Gross Beach in San Sebastian, different functions were taken into account during the design. In the end, this strategy has clearly paid off.

> Before the first beach nourishment, the economy of the seaside resort decreased, like the numbers of inhabitants (the numbers of inhabitants had decreased to less than 5,000 inhabitants in 1990 to raise to about 5,800 in 2000).
>
> After the beach nourishment, a policy for the development of the seaside resort and the improvement of the touristy attraction has been developed, based on the image of a large beach with:
>
> - The building of properties
> - The building of a marine hydrotherapy
> - The rehabilitation of the casino
> - The building of hotels
>
> The numbers of tourists-days have increased from around 600,000 in 1984 to 870,000 in 2000. The chosen strategy for the protection of the beach apparently is working. The erosion seems to be controlled and the seaside resort is in a growth period.

Box 3-12 Châtelaillon, France: positive impact coastal strategy on local economy

Box 3-13 Gross Beach, Spain: integration beach regeneration in city plan San Sebastian

> The beach regeneration that has been carried out at San Sebastian satisfies the original goals set for the project; incorporating a new leisure space and economic zone related to the sectors that boost the economic development of the area. In addition, the environmental aspect in the surroundings of the beach has changed, its influence being notable in the city as a whole.
>
> The project is considered to be effective and a success, as it has combined an appropriate solution from a technical viewpoint with a solution with little visual impact and preserving the natural beauty of this area.
>
> Finally, the importance the project has had in its projection and integration with the general planning of the city clearly justifies the actions taken. The project is valuable not only from a technical viewpoint as far as the chosen alternatives are concerned, but also aesthetically, environmentally and socio-economically. It has been completely integrated within San Sebastian's development strategies.

In recent decade a shift towards other policy options, like do nothing can be observed in several areas. Do nothing is generally applied when no economic values are at risk (e.g. undeveloped lands, forest lands, sometimes agricultural land). 'Do nothing' is usually applied at cliff coasts where no flooding risks are present and therefore the capital at risk is relatively low. At present 'do nothing' is sometimes applied in coastal areas where in the past 'hold the line' would have been applied. This shift mainly results from a cost-benefit approach along the entire 'coastal cell'. When protection against erosion at one point increases the erosion further downstream, it might be profitable to apply the policy option 'do nothing' instead of providing protection. In that situation the individual interests of the threatened properties are considered to be inferior to the general interest related to the larger coastal cell.

In the United Kingdom, this is possible because the government is not legally obliged to protect the civilians living at the coast and the British government indeed has accepted this policy change officially (see Box 3-14). The policy change causes great conflicts with affected local inhabitants and in some cases the government still gives in to the demands of the inhabitants.

> Over the last few years, the British government has adopted a changing policy. The government has accepted the fact that coastlines change and that sometimes these changes should be allowed (do nothing). This decision was made for various reasons, such as the inevitability of coastline changes, the benefits these changes can bring, and the damage that might be caused by trying to prevent these changes. The government argues that there are aesthetical reasons for allowing coastline changes instead of applying defence works; some defence works are ungainly and entirely out of place on unspoilt stretches of coast. Furthermore, for technical reasons doing nothing can sometimes even be more profitable: coastal defences at cliffs cut off the supply of sand and shingle which is vital to maintain features along other parts of the coast and in this way the defences displace the effects of erosion from one point to another. The government's stance is not always popular and can obviously cause great conflicts with local occupants.
>
> Of course, the English government accepts that in some places coastline changes cannot be accepted, for example at large towns, ports or nuclear power stations. It realises that different strategies will be needed in different places, implying a case-by-case approach.

Box 3-14 United Kingdom, shift in policy option towards 'do nothing'

In France, expropriation of local inhabitants is possible through the Bamier Law (1995). The most vulnerable premises are subjected to this expropriation order. A fund was also started to finance these measures. For example, at Criel, Haute-Normandie, 7 families were expropriated when the erosion could not be stopped. Because the costs of the measures to protect these houses would have risen to unjustifiable heights, it was chosen to do nothing and give up on these houses.

Another shift in policy options, observed at the Atlantic coastline, is from 'hold the line' to managed realignment**.** Managed realignment policy option consist of identifying a new line of defence and, where appropriate, constructing new defences land ward of the original defences. In some cases 'managed realignment' is being considered for the future, because costs to hold the line increase with accellerated sea level rise. At certain time the option managed realignment is a more rewarding solution (based on a cost-benefit analysis).

'Managed realignment' is considered for the future at several case study areas in the United Kingdom, France and Portugal. The arguments against 'managed realignment' that were shown for some of the North Sea countries (Germany, Netherlands and Denmark) apparently are not valid for these Atlantic Ocean countries. Box 3-15 describes the considerations for possibly applying 'managed realignment' in Portugal.

Box 3-15 Portugal, consideration towards policy option 'managed realignment' in the future

> There is a generalised retreat of the Portuguese coastline, which is of worrying proportions in some areas. Erosion is progressing with great intensity on several known stretches of coast and, despite the existence of seawalls and groins, the situation is critical. Several urban waterfronts (Esmoriz, Cortegaça, Furadouro, Costa Nova, Vagueira) currently appear as small "capes" that enter the sea, surrounded by coastal defence structures of considerable dimensions. In these situations, it sometimes has become necessary, or will become necessary in the medium term, to proceed with the resettlement of the inhabitants more landward.

An example of a recent choice for managed realignment in Portugal is given in Box 3-16

Box 3-16 ***Vagueira–Mira (Portugal), application of hold the line and managed realignment***

This area is located in the central region of Portugal, in the Aveiro district, south of the inlet of the Aveiro lagoon and distinguished by the dune system along its whole extent, starting in Costa Nova village and ending on Mira beach. The length of the study area is 15km, with a NNE-SSW coastal orientation, and it could be characterised by a long beach with extensive flat areas, with low relief.

The policy adopted in the Ovar–Marinha Grande coastal management plan, approved in 2000, was to **hold the line**, with some **managed realignment**. The first policy is for urban areas and the second for non-urbanised areas, above all downdrift of the groynes, in order to establish a new line of equilibrium.
One of the main measures set out in the coastal management plan is reconstruction of the dune system between Costa Nova–Vagueira beach and Vagueira beach–Mira beach. This artificial dune is parallel to a coastline predicted to be in a static equilibrium.

This is justified by the risk of a breaktrough of the dune cordon together with the costs to reconstructe the dune after stormdamage. In stead the construction of an artificial dune cordon in a retreated position behind the present dunes might be a more coast effective measure on the long term and give space to natural processes.

In some cases <u>limited intervention</u> is applied. This policy option has become more popular as a result of the increase in public and political awareness for the environment in the Atlantic coast region. The coastline is maintained in a dynamical way, allowing as much changes as possible within the present situation. 'Limited intervention' measures observed in the case studies are beach nourishment to slow down coastal retreat, restoration of destroyed dunes to increase the strength of the coastline and implantation of dune vegetation to decrease wind erosion.

Box 3-17 Canary Islands (Spain): Application of limited intervention policy option

The Montaña Roja Special Nature Reserve (Canary Island Natural Areas Act 12/1994, 19 December) has a surface area of about 166ha and extends along approximately 3km of coast in the municipality of Granadilla de Abona to the west of the population centre of El Médano, in the southern part of the island of Tenerife.
The strategy followed in the management plan goes for **limited intervention**, leaving the natural processes of the area themselves to produce its self-regeneration from specific actions, while at the same time it reduces the pressure on the environment using the legal regime it is provided with.
This attempts to improve the quality of the reserve's landscape by restoring areas of land affected by mineral extraction or uncontrolled tracks, eliminating existing infrastructures generating this kind of impact and rehabilitating constructions that might form part of the public use of the reserve.
Aimed at restoring the Roja plain and the eastern base of Montaña Roja from its northern flank to the side that links with the base of Bocinegro mountain, encouraging the dune formation process and the gradual establishment of potential plants and animals

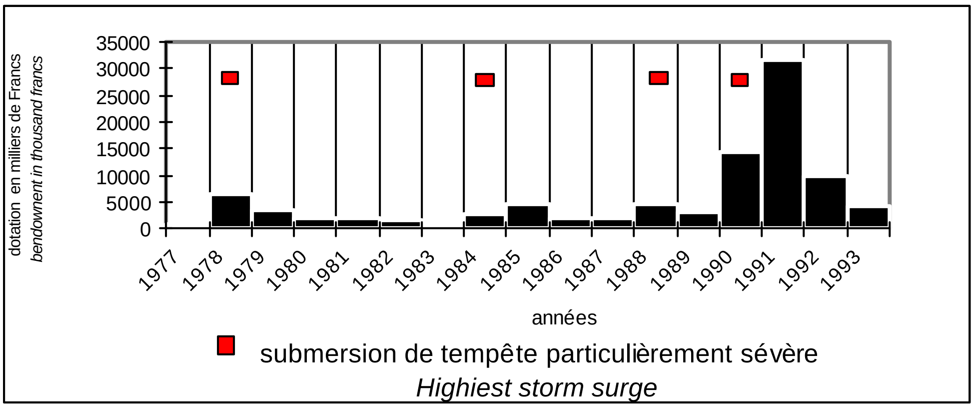
In Ireland, coastal policy has just become an issue in recent decades. Because of the land uplift in the last centuries, Ireland is almost unprepared for any serious erosion and has no clear strategy for the future. With increasing sea levels, higher tides and more violent weather conditions, coastal erosion will become an important issue in Ireland. Should Ireland try to protect its shores or allow the loss of (some of) its shores? At present, these decisions have to be made locally. No general policy option is available yet.

3.5.3 Strategy

Approach to combat erosion

In the past, as in any other region, the strategy in coastal protection at the Atlantic coastline has mainly been **reactive**. Figure 3-3 shows the expenses in coastal protection for the Haute-Normandy coast in France together with the occurred storm surges. The figure shows that the expenses historically were realised during or after the catastrophes: a reactive post-crisis management. However, since the last decade, this kind of post-crisis management rarely occurs anymore and the strategy has shifted towards a **pro-active** one. Nowadays, the socio-economic development of the seafront and the development of physical processes (for example relative sea level rise and possibly increased Atlantic storm frequencies) are considered before taking measures.

Figure 3-3 Expenses and occurring catastrophes at the coast of Haute-Normandy, France



Until 1980, usually hard measures such as seawalls, groins, breakwaters and dikes have been applied to secure the coastline and protect the hinterland from flooding. These structures were usually built without any study about their interaction with the environment and have often modified the coastal landscape in the affected areas. As a result, the landscape was often changed and degraded and coastal zones were transformed into artificial coastlines. In this way, the original maritime and terrestrial ecosystem as well as the natural resilience of the coast have been modified to sometimes even disappear completely. The current trend is therefore to work with the dynamic nature of the coastal environment as much as possible; this change in policy has induced the shift towards the use of soft measures to combat erosion.

In the past decade soft measures have been executed at a regular scale in the Atlantic region. However, in this highly energetic coastal region, soft measures are often not sufficient to combat erosion, therefore a combination with hard measures is often applied (for example groins with nourishment to increase the beach width in between the groins). Soft measures applied in the Atlantic region include beach nourishment (shingle or sand), dune regeneration, dune vegetation and beach drainage. Different considerations and reasons led to the application of these different soft measures at different times. Some examples are given below.

- Beach nourishment

The first great beach nourishment scheme in France was executed at Châtelaillon in 1989, after the example of American beach nourishments (see Box 3-18). In Portugal and Spain sand beach nourishments have been applied since the 1990s.

Box 3-18 Châtelaillon: first large beach nourishment scheme in France

The Châtetaillon coast suffers from erosion that has mainly a structural character, continuously reducing the beach width and lowering the beach profile. As a result, the risk of severe damage (also: flooding) during storms is increasing as well. In order to protect the village the first seawall was built in 1925. Since then, the beach profiles have begun to lower. The reflection of the waves on the seawall, as well as the cross-shore transport due to the action of the waves have increased the erosion. In the 60's the beach disappeared at high tide. The foot of the seawall had to be protected by rocks in order to keep the city of Châtelaillon safeguarded from flooding.

In 1989, after having seen the results of American beach nourishments, the *mayor* of the city decided against the opinion of all public authorities, to execute the first large beach nourishment in France. The nourishment project consisted of 330.000 m^3 on the south and middle of the site. In order to reduce erosion on the northern beach, each year between 10.000 to 30.000 cubic meters are taken from the south of the beach and brought on the north by using power shovels and dumper-trucks.

The aim of this soft solution was to create a large beach for tourists even at high tide, and to protect the city against flooding. This first beach nourishment was possible by dredging on an offshore sand bank (north to Oleron Island). The success of the solution has led to a second nourishment, which was carried out in 1998, at the middle of the beach. A third is provided for 2003, in order to protect the north of the site against flooding and offer a wider beach to the tourists.

In the United Kingdom, the shingle beaches in front of cliffs have been artificially maintained since the 1980s. Besides shingle nourishments, a study was done into the protective values of submerged rock platforms in front of the cliffs (see Box 3-19). These kinds of studies create more knowledge on soft measures that work with natural processes. With this knowledge these types of soft measures can possibly replace hard measures.

In Portugal beach nourishments have been applied in very limited cases and mainly at the south coast of Portugal.

- Dune regeneration and vegetation

Tourist pressure, especially since the 1930s/40s, has led to destructive coastal land use in the Atlantic region. Especially dunes have suffered from the tourist pressure in Portugal, Spain and France. Dunes were destroyed to be able to expand tourism, and natural dune vegetation was often trampled and destroyed by the presence of tourists. Also private ownership of dunes (as was usually the case in beginning of the 19th century) has caused a lack of maintenance in dunes.

During the past decades, the importance of dunes has been recognized more and more and therefore dune regeneration and vegetation projects have been started throughout the entire region. For example, the State Agency in France has been buying coastal sites since 1975 to protect these areas from visitors and provide the required maintenance. Nowadays, in Portugal and Spain, some coastal areas like public domain ones or natural areas are being developed for dune system developing.

Current trends in Europe focus on the concept of shoreline management, working with the dynamic nature of the coastal environment rather than fighting against the forces of the sea. This is best exemplified by the widespread move away from hard engineering methods of

coastal defence acting to restrain coastal processes, towards soft engineering approaches which recognise the dynamic nature of the coastal environment by utilising these processes to take advantage of them. Soft engineering methods usually have a lesser impact on the environment and may require less maintenance.
For these reasons, innovative techniques must be implemented to safeguard coastal heritage as well as possible.

Box 3-19 Risk of Cliff Collapses (ROCC) project about soft measures for cliffs at Sussex coast

> During the last seventy years, all except those sections of coast backed by high cliffs have been groined and immediately to the east of Brighton groins have been installed even in front of tall cliffs to help reduce coastal retreat that threatens cliff-top properties and the coastal highway. However, faced with the prospect of climatic change and possible sea level rise this century, there is concern that the erosion rate will increase. To anticipate this, the ROCC (Risk of Cliff Collapses) project was set up. Its main aim is to try to find out which areas may be most vulnerable to such future changes, so that planners and engineers can make appropriate decisions.
>
> Instead of seeing the sea as a force, which must be stopped by a solid wall, the researchers investigated the protective value of the submerged natural rocky platforms that lie just underneath the cliffs. These platforms have a significant impact on the rate of cliff erosion - a wide platform will reduce the rate enormously, whereas a narrow platform will imperil the cliffs. Up until now, a seawall has been seen as the most effective form of defence.
>
> It has become clear that sea defences have only been effective for a limited time before they have had to be rebuilt. This is often because the rocky shore platform that forms their foundation has been eroded from around and beneath them. Through research, smaller amounts of money may be used to combat the problem by protecting or building up the intertidal platforms and saving the Sussex coastline.
>
> Today, the "hard" defences of concrete seawall and timber breastworks are being replaced with the "soft engineering" of shingle beach management systems and rock structures, where appropriate. Whilst the rock used is in itself hard, the defence systems constructed with it and the wider shingle beaches are considered "soft" because they absorb wave energy, rather than reflecting it with seawalls, as in the past. Wave reflections encourage scour and thus the removal of beach material from the shoreline.

Measures concerning safety of hinterland

Besides measures to protect the coast, measures can be taken to mitigate the consequences of flooding and to mitigate the damage due to failure of the coastal protection scheme. For example, in Sussex residents are being warned through a ‘Flood defence’ and a ‘Flood Warning’ system. Both systems have teams with a detailed knowledge of how rivers and low-lying coastal areas respond to the rain and the tides. When necessary, the teams issue flood warnings. In other case studies, unfortunately no information was found on similar measures.

Some information was found about the existence of risk maps. Risk maps can give a clear overview of capital at risk and thus of the most vulnerable areas for erosion and flooding. In France a PPR (Plan de Prevention de Risques) is currently being formulated for the entire coastal zone. In Portugal, a first version of the Risk Map has already been set up for the coastal zone.

3.5.4 Integrated Coastal Zone Management

Integrated Coastal Zone Management is still in an orientating phase in the Atlantic region; about half of the regions has developed some kind of progress in ICZM. A large European ICZM project covering the Atlantic region is OSPAR, although this project mainly concerns environmental issues. Furthermore, many Terra and Life projects have been initiated at the Atlantic coastline, of which several focus on coastal erosion issues. For Portugal 6 projects have been approved and 1 is under discussion. Box 3-20 gives some examples of these projects given for this water system.

Box 3-20 Examples of ICZM Terra and Life projects in Atlantic Sea region

- TERRA projects

-Algarve (Portugal) and Huelva (Spain): Sustainable management of coastal areas, COASTLINK.
-Algarve (Portugal): Local cooperation in the management of the coastal areas, TERRACZM.
-Vale do Lima (Portugal): Development of medium sized cities in coastal areas, CONCERTCOAST.
-Aquitaine (France).
-Devon and Cornwall (United Kingdom): Integrated management of a Living Atlantic coastline.

- LIFE projects

-Central Portugal: MARIA.
-Azores: Integrated Management of Coastal & Marine Zones in the Azores.
-Donegal (Ireland): Involvement in sustainable coastal development.

Table 3-6 shows an overview of ICZM on a regional scale. Established ICZM is only present in France and the United Kingdom. Spain and Portugal show some progress while in Ireland little progress is noticed in ICZM in most coastal regions. In Ireland coastal policies have just recently become an issue.

Table 3-6 Status of ICZM in coastal regions of countries bordering the Atlantic region[28]

	Total coastal regions entire country	Fully established	Partially established	In progress	Little/ no progress
Portugal	7	0	0	5	2
Spain	10	0	0	5	5
France	11	0	2	3	6
Ireland	14	0	0	2	12
United Kingdom	49	1	0	11	37

Examples of Integrated Coastal Zone Management in the case studies show the local implementation of ICZM and the fact that, although national ICZM policies are not yet present in any of the Atlantic Ocean countries, on a local scale it is already being executed in several ways. An example of interregional cooperation with respect to coastal erosion is demonstrated in Box 3-21.

[28] Salman, A., Perez Valverde C. and van Elburg-Velinova D., Progress of ICZM Development in European Countries: a pilot study, Leiden, November 1999

Box 3-21 Normandy and Picardy: Inter-regional co-operation

Normandie and Picardy erosion coastal management, based on restrictive administrative division and not on the scale of the natural phenomena, can be summed up as rigid and restricted coastal defence policies responding to crisis periods. Realising this, the territorial institutions of the two districts have recently been encouraged to think about handling coastal erosion as an overall partnership. This was initiated within the framework of the "Contract de Plan Interrégional du Bassin Parisien" and continued by an Interreg II programme: "Beach erosion of the Rives-Manche". Because of problems of reliability and spatial and temporal representative problems of previous studies, the first step in this inter-regional co-operation project was to establish a reliable and homogeneous quantification and monitoring method for the coastal dynamics. The second step in this co-operation is the establishment of an inter-regional coastal observatory which must concentrate on past and present information to propose future co-operative management.

3.6 Mediterranean Sea

3.6.1 Organization and legislation

Administrative bodies dealing with different aspects of coastal management in Southern Europe evolve from port authorities to public works and land planners (tourist administration bodies) to environmental bodies as the coastal policies gain weight.

Table 3-7 shows three major issues concerning coastal administration and management: land use planning (frequently on the hands of local authorities), coast management (which includes coastal defence when mentioned) and Integrated Coastal Zone Management.

Table 3-7 Administration framework and legislation for major coastal policies throughout Southern and Eastern Europe (source: IIMA)

Country	Land Use Planning	Coast Management	Legislation	ICZM	Comments
Cyprus	Ministry of Communications and Works and local authorities	Ministry of Communications and Works ; Cyprus Ports Authority (pollution)	n.a.	n.a.	
France	Conservatoire du Littoral. Ministère de l'Équipement, des Transports et du Logement, la Direction du Transport Maritime, des Ports et du Littoral (DTMPL). Local authorities.	Secrétariat Général de la Mer, under Premier Minister. It coordinates the National Policy on the Sea. It promotes a *Comité Interministériel de la Mer*.	Conservatoire du Littoral/Loi no 86-2 du 3 janvier 1986 relative à láménagement, la protection et la mise en valeur du littoral (1975)	n.a.	The objective of the C*onservatoire du littoral* is currently to keep one third of the coast without any kind of urbanization ("tiers sauvage")
Greece	Ministry of the Environment, Physical Planning & Public Works - Directorate of Physical Planning. Local authorities	Local authorities (cleaning, restoration). Ministry of Mercantile Marine under the National Contingency Plan.	Law 2344/1940 "On the foreshore and the wasterfront" (1940)	Ministry of Environment, Physical Planning & Public Works - Directorate of Physical Planning, and Department of Nature Protection.	

Country	Land Use Planning	Coast Management	Legislation	ICZM	Comments
Italy	Local and regional authorities	Erosion control is promoted by regional goverments and financed by national budget.	Legge 31 dicembre 1982, n. 979, Disposizioni per la difesa del mare (1982)	Not implemented although regional programmes	
Malta	n.a.	n.a.	Developement Protection Act (1992)	n.a.	
Slovenia			In 1993 the Office for Physical Planning organised a planning workshop for the entire coastal area entitled 'Physical Planning of the Coastal Area' (1993)		
Spain	Ministery of the Environment, D.G. Costas (500 m strip) and local authorities	Minstry of the Environment, D.G. Costas	Ley 28/1969, de 26 de abril de Costas (1969)	Minstry of the Environment, D.G. Costas	ICZM has been estated as apolitical willing (April 1992). DG Costas is to lead the process.

3.6.2 Policy options

Throughout the information in the cases of the Mediterranean Sea in 17 situations a policy option is mentioned. In most of them examples of <u>Hold the Line</u> are found (9). In most of these 9 situations the problem is an eroding beach that is being used for tourism. Also, Hold the Line is found where economically valuable activities/structures are found (roads, industry).

For the Mediterranean Sea situations, the <u>Do Nothing</u> option was found 4 times. It is found where the policy is to "preserve and improve the conditions for the natural coastline" (Cyprus – Dolos Kiti). In Malta the coastal engineering works are constructed for maritime related activities and transport services rather than for the purpose of combating erosion. That is why Malta classifies this as Do Nothing (Xemxija Bay). In the French Mediterranean Rhône Delta there is a policy for doing nothing on stable beaches in a nature reserve area.

<u>Limited Intervention</u> consists of mitigating measures to reduce risks while allowing natural coastal changes. In the case studies only 2 examples could be found. In Mallorca nourishments are done when a significant retreat is observed. In Ghajn Tuffieha (Xenxija – Malta) the precautionary measures of prohibition of extraction of dead posidonia oceanica leaves is classified there to be Limited Intervention.

Only in one case study the policy was classified as <u>Move Seaward</u>. In Lakkopotic (Greece) constructing engineering works resulted in beach width increase. A good example of moving seaward can be found in Monaco (no case study).

<u>Managed Realignment</u> is also a rare policy option in the Mediterranean Sea. In the Ebro Delta case study managed realignment is mentioned. There are examples of removal of infrastructure located on the shore (La Marquesa and Pal beaches).

3.6.3 Strategy

Approach to combat erosion
In the past (until about 1980), hard engineering options were commonly applied. These were constructed only when erosion became a serious problem. As such, a <u>reactive strategy</u> was adopted in general, see examples in Box 3-23. Nowadays (from about 1980), however,

authorities are more aware of the need to develop sustainable policy plans. This anticipation on the future problems, a pro-active strategy, is shown in Box 3-22..

Box 3-22 Example of proactive approaches

Coastline Malta

At the beginning of the 90s the Maltese Government has started to elaborate some Structure Plan Policies in order to control and reduce the impact of the coastal areas. The principle Structure Plan Policies are the CZM1, CZM2 and CZM3 which manage and plan the use of the coastal areas taking into account the preservation of the environment. There are some more concrete Structure Plan Policies as RCO21 and RCO22 that control directly the erosion in the coastal areas of the Maltese Areas.

Box 3-23 Example of reactive approaches

Ebro delta (Spain)

Some measures have been directed at protection against rising sea levels and over-washing without taking erosion processes into account. These measures were taken as a consequence of the breaking of Trabucador Bar in October 1990 because of a storm. The volume eroded was about 70,000m^3 (Sánchez-Arcilla *et al*., 1997[21]). This event led in January 1991 to the beginning of emergency works, building a 5km dune 1.5m high, 12m at the crown and 24m at the base, fixing it using cane stakes and dune vegetation (Amophila Arenaria, Othanthus Marítima and Elymus Factus). This action was completed in 1992 with the "Trabucador Bar Protection Scheme", which consisted of extending the above solution along the whole bar, positioning the dune in the interior, beside the bay, with the aim of preventing over-washing by water from the open sea when high waves were produced. The fixing system consisted on one hand of constructing 10 x 10m stake "corrals" of *spartina versicolor*, and on the other hand of planting dune vegetation (Montoya *et al*., 1997[22]). The works done on the Trabucador spit were considered two years later as a non-sustainable solution because dunes and vegetation have no dynamic stability (Serra, 1997[23]).

hard and soft measures

Until about 1980 coastal erosion used to be treated as a problem that could be stopped. There are a lot of examples of major structures built to protect property or a beach. In some cases the effect was positive (Lakkopotic – Greece), but in most of the cases the erosion continued at a somewhat lower rate, but in some cases even increased. Generally, hard measures can be succesful if there is a solid understanding of the coastal system. Also due to lack of monitoring data, the level of understanding is often not enough to find the optimal solution right away.

In Marina di Massa for instance, a lot of hard measures were taken to combat erosion. At the point where the coastline was absolutely full of structures, soft measures (beach nourishment) were applied. Still now the soft measures have to be carried out periodically to combat erosion. See Box 3-24.

[21] Sánchez-Arcilla, A. *et al*., 1997. El problema erosivo en el Delta del Ebro. Revista de Obras Públicas, n.3368; pp.23-32.

[22] Montoya, F., Galofré, J., 1997. El Ebro en el Delta. Revista de Obras Publicas, n.3368;pp.33-46.

[23] Serra, J. 1997. El sistema sedimentario del Delta del Ebro. Revista de Obras Públicas, n.3368; pp. 15-22.

Box 3-24 **Artificialised shoreline at Marina di Massa (Toscana, ITALY)**

Until 1850 the shoreline of Marina di Massa was in equilibrium, however, after this date the erosion process became a severe problem leading to shoreline retreat for approximately 500m. At the beginning of the 20th century the defence action adopted was the construction of 9.3 km of hard engineering structures: detached breakwaters, seawalls and groynes. These structures were useful to protect the stretch of the coast immediately in front of them, but at the same time they interrupted sediment transport along the coast, exporting the erosion southwards and requiring the construction of new defence structures. The coastline in front of Marina di Massa is now totally artificialised by these structures. Every year it is common to carrying out periodic nourishment operations to improve the beach for tourism.

*Photo source: Report on Marina di Massa-Marina di Pisa (Italy). See appendix.

Sometimes however, hard structures seem to be a very good solution for a densely populated area that is aimed to be protected for flooding (see Box 3-25).

measures concerning safety of hinterland

Coastal defence is the general term covering all aspects of human initiated defence against coastal hazards such as flooding and erosion. Coastal defence efforts may be small scale involving relatively small structures or may involve extensive land claims, e.g. by establishing buffer zones.

Box 3-25 ***Storm surge danger on Castellón plain (Spain)***

Sudden variation in sea level is an important phenomenon on the Castellón coast because, in the pre-littoral area of the 'La Plana' region, there are large areas close to sea level. This is because they were formed from coastal bars and filled-in former marshes. Any variation in sea level can therefore have an effect on the future development of the coast and if any variation in sea level coincides with a big storm, the risk of the sea invading the low-lying coastal areas behind the beach is increased. This variations of extraordinary level can be produced by tides, very low atmospheric pressure (e.g. storms) or the effect of intense winds and waves. This is why a longitudinal seawall was built on Serrallo beach, just beside the Port of Castellón, in order to protect the seafront from erosion and to prevent lowlands from flooding.

**Photo source: Aeroguía del Litoral de Valencia[13]

[13] Aeroguía del Litoral de Valencia y Castellón. Ed. Planeta. 1997.

The relative sea level rise can have important implications for the future of the deltas of the Mediterranean Sea. However here the pattern of change is much more complicated with tectonic movements caused by a variety of influences (e.g. volcanic activity and earthquakes). When this is coupled with human influences which exacerbate sea level rise, significant problems of erosion, salt water intrusion and flooding can occur. These effects are especially important in the major deltas where a decrease in sediment availability and subsidence due to water pumping or the sheer weight of infrastructure may be some of the factors which give rise to substantial problems of erosion and flooding as is being experienced in several of the major Mediterranean deltas.

Box 3-26 Po Delta (Italy): flooding problem

Several works to defend from flooding the inner lands of Po Delta were done. In the 2002 springtime new integrate soft measure starts. To improve the navigability at the Goro Po mouth, the sands are taken from the submerged bar in front of the lighthouse beach, and, these sediments (about 80.000 m^3), are used for the beach re-nourishment, for about 600 meters of length. At the external boundary of the new beach a little groin has been built to stop the moving away of beach sands toward the sea, induced by the circular hydrodynamic cell.

Only these measure do not allows to save the inner lands from flooding and to keep the Goro spit survival. To achieve also these results, a coastal dunes rebuilding plan have been made, based on morphological surveys on nearest natural coastal dunes. Data have been collected regarding winds, waves and historical coastline evolution. These data have been used as input for mathematical models to project the news beach and dune morphologies.

These coastal dunes rebuilding can work better than natural costal dunes, because their core is armed with gabions filled with stones covered by a permeable geotextile. To favour the artificial dunes bodies capability to adapt them to any future possible new beach profile changes, the gravel mattresses have been placed over a wood poles structure done by vertical poles fixed in the bottom of the beach and connected among them trough horizontal poles. This system will consent adjustment movements of the gravel mattresses that could assume the better position in relation to any new beach profile.

3.6.4 ICZM in the Mediterranean Sea

Integrated Coastal Zone Management principles are not commonly used in Mediterranean pilot zones. Only few sites have coastal management, which is different for each area. These principles have been adopted by Cyprus, Marina di Massa, Sicily, Marina di Sarzana, Goro Po mouth, Marina di Ravenna (Italy), Malta, Sitges (Spain), Mar Menor (Spain). Some examples are given in Box 3-27, below.

Box 3-27 Examples of ICZM practices at UAB pilot sites

Ghajn Tuffieha (Malta)

ICZM principles have only been recently introduced in the Maltese Islands, primarily within the spatial planning system. The Scheduling of Ghajn Tuffieha bay is part of an extensive area of coastal cliffs that has been scheduled under the planning system. The goals of the Conservation Order have taken into consideration the recreational potential of the site for tourism purposes and in effect do not prohibit recreational use of the area. It is envisaged that once the management plan for the site is in place it may serve as an example of sustainable coastal management where conservation and tourism goals can be reached harmoniously within a highly sensitive area.

Po delta (Italy)

The integrated approach to mitigating coastal erosion and inland flooding allows a proposal for a rebuilt ecosystem that is capable of evolving without negative environmental impacts. This makes it possible to combine coastal defence works with an ecologically sustainable approach, providing guarantees for inhabitants and economic activities. Furthermore, it highlights the possibility of using coastal dunes or rebuilding them to maintain the fragile ecosystem, without conflict with coastal management plans in areas of high natural value.

Mar Menor (Spain)

The Mar Menor has been marked by the political absence of ICZM practices, verified by an environmental diagnosis and by the tendencies observed, which will mark the next few years of the development of the lagoon, if preventive measures are not considered. However, part of the local community is calling for the protection of the Mar Menor. In response, Indicative Plans for Coastal Uses, Protection and Harmonization of Uses in the Mar Menor, with specific designations for protected areas and evaluations of the environmental impact, have been have been drawn up.

The Mar Menor and its area of influence are currently being proposed as a pilot site for the CAMP (Coastal Area Management Programme) promoted by PAP/RAC (Priority Action Programme), which is aimed at implementing practical coastal management projects in selected Mediterranean coastal areas, applying Integrated Coastal Area Management (ICAM) as a major tool. Source figure: RAMSAR [20]

3.7 Black Sea

3.7.1 Organization and legislation

Even though coastal zone management has not yet been identified as a separate issue, elements of ICZM has been incorporated into the legislative framework of the physical planning system.

Table 3-8 Responsible authorities in the Western Black Sea region

Country	Ministrial Authorities	Respective Laws	Local Authority
Romania	Spatial planning Ministry of Regional Development and Construction	The Law of Landfund (no. 18/1991)	County
	Environment The main central administrative power for environmental policy is the Ministry of the Environment (and Water).	The Environmental Protection Law, (no. 137/1995). The Water Law, (no. 8/1974). Law no. 17/1990; the Law contains the juridical organisation of Romania inner waters, territorial waters and the contiguous zone.	
	Nature Protection Central authority: The Ministry of Waters,Forests, and Environmental Protection (MWFEP) represents the Central Environmental Authority (CEA	Law no. 2/1987; concerning maintenance, protection and development of forests. Law no. 81/1993; stipulates compensation fixing for damages brought of forestry fund, forestry vegetation on the private or public estate and hunting economy. Law no. 8/1991; ratification of the Convention on long distance transboundary air pollution	
Bulgaria	Spatial planning Ministry of Regional Development and Construction	Law for Urban and Land-use Planning (for urban and territorial arrangement), (1973). Law for the Administrative and Territorial Division, (1995). Regulation no. 2 for the norms and rules for the land-use planning of the Black Sea, (1994).	County

[20] RAMSAR (http://www.mma.es/ramsar)

	<u>Environment</u> The main central administrative power for environmental policy is the Ministry of the Environment (and Water). This Ministry is responsible for the environmental management of the Bulgarian Black Sea coast	Water Law, (1961), (a new Water Law is on the way). Law for Protection of the Air, Waters and Soil, (1963). Law for the Environment, (1991). Law for the Purity of the Atmospheric Air, (1996). Law for the Solid Wastes Treatments, (1997). Law for the Bulgarian Maritime Territory, (1987).	
	<u>Nature Protection</u> Ministry of the Environment	Law for the Protection of the Air, Waters and the Soil, (1963). Law for the Protection of the Nature, (1967). Regulation no. 4 for the buffer zones around the reserves, (1988). Law for the Environment, (1991). [6] Nature Protection Act, (amended and supplemented in 1998).	

3.7.2 Policy options

In the western Black Sea area (Romania and Bulgaria) no general, common coastal defense policy esists. However, in the 3 Black Sea pilot cases, different policy options exist to defend local economically valuable coastal areas. Here, <u>Hold the line</u> is quite common to counteract negative (local) impact of erosion on tourism developments, e.g. at Mamaia beach (Romania).

Box 3-28 Mamaia Beach (Romania): "hold the line"

Another case is Mamaia beach that is one of the most famous beaches of the Romanian Black Sea littoral. It is located close to Constanta city, on a narrow sand bar, 250 – 350 m width. It is formed by Danube originating sandy material.

Coastal erosion is a particular problem at Mamaia, due to the Midia harbour extension dikes (5 Km long) which act as a barrier to long shore currents running from north to south. This dike is deflecting the long shore sediment drift offshore, to the south-east, and thus Mamaia beach was transformed in a bay, almost totally lacking of natural sediment supply. General decreasing of the sediment supply into the littoral zone after Danube river damming should be added to that.

The policy option adopted is "hold the line". The strategy adopted by the communism regime (before 1990) was to solve the problem of coastal erosion which destroy the Mamaia beach in 1988. Both the "hard and soft" coastal protection were developed to reduce the effects of wave attack on the beach in the stormy weather. Due to the different grain size the soft solution was not effective as the dredged sand and from the lake was washed up in short time seaward.

Considering the Danube delta (Romania), hold the line policy is relatively rare compared to the <u>do nothing</u> option that prevails here. According to the Danube delta pilot case, considering only 2% of the total delta littoral is being protected by hold the line measures, although without proper maintenance, at the town of Portita. Additionally, a monitoring programme for coastal erosion is carried out by the Romanian national institute for Marine Research and Development.

Box 3-29 Danube Delta (Romania): "Do nothing" and "Hold the line"

In the Danube Delta zone, the policy option is **do nothing**. Under the communism regime, actions to protect the coast against erosion have been carried out in the Danube Delta littoral only at Portita (**Hold the line**) Only 2% from the entire Danube Delta coast is protected against erosion with "hard" protection measure at Portita (the protection structures at Portita have been undertaken in three stages: in the first stage three groins have been built and in the next two stages two protection dykes have been settled consisting of concrete tetrapods, stones and concrete platforms). This measure proven stability of the shore but it was a solution only for this part of the coast which was very vulnerable to erosion. The solution adopted in a communismtime did not take into consideration the cost of the maintenance of this defence structure and also its effect in the vicinity. The erosion phenomena is present now in the southern part of Portita

Even so, combinations of policy options are possible, as is the case at Shabla-Krapetz (Bulgaria) where a hold the line policy option is combined with managed realignment. Last decade, this combination was chosen with respect to the tendency of tourism being a powerful driving-force in coastal development and investments on coastal protection.

Box 3-30 Shabla-Krapetz (Bulgaria)

Cape Shabla is one of the symbols of this community with its specific lighthouse, more than 250 years old, picturesque bay, two traditional fishermen's villages - North and South, and the oil production trestle. Erosion is threatening excellent beaches in Krapetz bay, the village at the coast, the coastal lands and parcels used for recreational purposes, for agriculture, for infrastructure services, the landscape values. The erosion process consists of abrasion, demolition and landsliding of the cliffs and dilution of the material and washing it into the sea.

No direct evidence of the move seaward option was found on the western Black Sea shores, even though in two cases (Shabla Krapetz, Bulgaria and Mamaia beach, Romania) local attempts of artificial nourishments have been implemented, there is no suggestion of a move seaward policy.

3.7.3 Strategy

Approach to combat erosion

In the last decade, the Black Sea Environmental Programme (BSEP – started 1993) has played a very important role in environmental policy developments in the region. The main problems in the region are eutrophication, competition for water and severe (oil) pollution. Coastal Zone Management is one of the six components of the BSEP programme.

In Bulgaria different solutions were used to fight coastal erosion. The tendency for the last ten years show that the local managers were forced to develop tourism as one of the best alternatives for coastal development. This can be seen as a pro-active strategy to find multifunctional solutions to enrich multiplied effect out of the inevitable investments on coastal protection. However, generally speaking, reactive strategies prevail in coping with coastal erosion in the Black Sea region. Both stategies commonly include hard engineering measures, such as groynes, jetties, (attached or non-attached) breakwaters and dykes. These measures are normally only partially effective, and maintenance is often poor. Soft engineering measures, such as the artificial nourishment at Mamaia beach (see above) are so far less effective due to lack experience and knowledge. Moreover, deficits in potential (quality) sand supply for artificial nourishments are quite common at the Black Sea shores.

Measures concerning safety of hinterland

In Bulgaria, wind waves with mean wave height of >200cm are characteristic for the March - October period. Extreme wind waves are the main cause of flooding in low-lying coastal land. These also cause increased salinity in most coastal firths, the activation of erosion, landslides.
Salinisation in low-lying coastal land is the result of periodical flooding caused by storms. This leads to degradation of agricultural lands as a result of repeated cycles of inundation-evaporation. The central sectors of the Bulgarian Black Sea coast are affected by salinisation (Bourgas region).
Long-term sea-level fluctuations of the western Black Sea have been studied for different time periods and the estimate of sea-level rise is 2.386 mm/yr. Natural and anthropogenic factors are pointed out as the main causes for sea-level rise. The natural factors involved include changing river discharge into the Black Sea, rainfall-evaporation balance and water exchange through the straights linking the Black Sea to the Mediterranean.
Anyway, the coastal policies adopted for dealing the erosion in Bulgaria can be sumarised in the construction of some hard engineering works along the Danube Sand Banks, that aren't enough to fight the strong erosion affecting the interland.

3.7.4 ICZM in the western black sea

When it comes to legislation specifically dealing with Integrated Coastal Zone Management, no (western) Black sea country has developed explicit legal instruments. Predominant national instruments are Planning and/or Environmental Acts.

The Danube and the Black Sea constitute the largest non-oceanic body of water in Europe. Having in mind the fact that the Black Sea is a "Special Area", Bulgarian and Romanian environmental policy includes additionally some strict local and national rules and requirements mainly for pollution prevention. Many of the Danube countries will become members of the European Union (EU) and the Black Sea will become a coastal area of the EU. As the environmental situation in the region is extremely critical, a strategy is required to rectify it. If this strategy is to be effective, there has to be cooperation between all the countries of the Black Sea region.

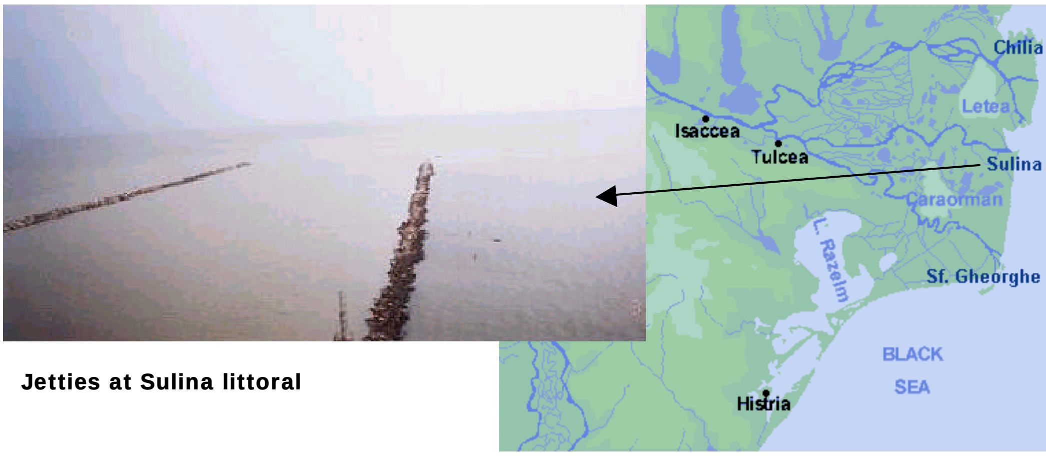
In the nineties, the Western Black Sea countries (Bulgaria and Romania) have gradually started to outline coastal policies, although major concerns are focused on water pollution. The way in which the national plans will be implemented depends on the legal system of each country. The Action Plan states that “Each Black Sea coastal state shall endeavour to adopt and implement, in accordance with its own legal system, by 1999, the legal and other instruments required to facilitate integrated coastal zone management”. Some countries have already started to take the necessary actions. New laws have been developed in Bulgaria, for example, and coastal zone management is already embodied in a Presidential Decree in Russia. The Action Plan also foresees the development of a Regional Black Sea Strategy for ICZM by December 1998. Most of the preparatory work for this strategy is already complete.

One rather serious problem affecting the coastal zone of all Black Sea countries is erosion and land degradation. Beaches are supplied with sand and pebbles from rivers but the construction of dams on many rivers has reduced this supply (see Box 3-31). On the other hand, deforestation has caused land erosion and increased the loss of soils to the sea in some places. Erosion results in very large economic losses and may result in conflicts between countries where changes in river flow affect the interests of the neighbour. The Action Plan calls for this problem to be studied and for countries to work together to solve it. The coastal zone does not stop at national boundaries and management plans should take into consideration the cross-border issues.

The European Union's PHARE and TACIS Programmes have initiated a training programme in five of the Black Sea countries. Participants from Bulgaria, Georgia, Romania, Russia and Ukraine are receiving training in integrated coastal zone management, environmental impact assessment and environmental audit. Throughout the training programme the trainers and facilitators are helping participants develop an understanding of ICZM as a process. Coastal management tools such as conflict resolution, policy making, etc. will be highlighted. The role of individual scientific parameters and the need for and means of, their integration within the terms of sustainable resource use is also being identified and developed in a suitable manner for each country and the region as a whole.

Box 3-31 Technical works applied in the Danube delta (Romania)

Human made structures are strongly affecting the shore. The permanent extension of commercial activities led to the necessety of building enlargements to several harbours on the Romanian seashore (Constanta, Midia, Mangalia and Sulina).



Jetties at Sulina littoral

The coastline has been strengthened and protected in part, and further construction aimed at reducing erosion includes the building of a 32km canal (35m wide and 6-7m deep, with a dam at its eastern end to stop sea surges) connecting Sulina and Sf Gheorghe which will transport delta water into the sea at Cherhana Rosulet (Arhire, 1990). Some degradation can be attributed to water regulation through canal, dyke and channel realignment and agricultural intensification within empoldered areas. Nearly 80% of the lower Danube flood plain has been drained and converted to agricultural land resulting in the virtual elimination of floods within the delta itself.

Even though some efforts have been put forward through both international support and national initiatives to improve coastal zone management and to integrate the management of coastal areas, it is of high importance to implement these results and recommendations. Practical experience gained through the implementation of ICZM pilot projects will surely help the development of institutional capacity on the field of ICZM.

4 TECHNICAL ANALYSIS

4.1 Introduction

The selection of the technical measures to deal with any erosion or flooding problem depends partly on the value of the land or property threatened. The values at stake in coastal areas – people, property and associated economic values; ecological and cultural values – determine the need for intervention. Once these values are assesed, the selection of the most appropriate solution(s) can be made.

Coastal protection measures can generally be divided between hard and soft measures, as described in Ch2. The hard engineering measures involve the construction of solid structures designed to fix the position of the coastline while soft measures are designed to work with the natural processes. They allow the natural dynamic behaviour of the coastal area and thus the coastline may change over time.

Application of possible measures will vary according to the local situation or "Geodiversity" (type of coast, physical circumstances), but it's the desire to identify the best option(s) (efficient and cost effective). In order to achieve this, a good knowledge is needed of the scale of the problem and the causes of erosion/flooding under which the optional measures are to be applied.

For example, when the erosion problem is caused by a net longshore transport, a seawall is generally not a sufficient solution. The seawall would be undermined by the longshore transport and fail. Such a seawall would not stop longshore transport, while groins for example could. When the problem is caused by cross-shore transport, a seawall could be efficient. Another example, concerning cliff protection: the geology and location and orientation of the bedding planes will determine the type of erosion (rock fall, toppling failure, wedge failure, slide, rotational slump or flow) and thus the appropriate type of protection required.

Succes- and failfactors of technical measures depend on Geodiversity and the combination of the type and causes of erosion, the measures itself and the surrounding physical conditions. Furthermore, succes or failure depends on the choice of policy and sometimes the way the measures are performed.

In the next paragraphs for each of the coastal systems the most commonly applied technical measures will be described, the locations where they have been applied and the observed success and fail factors. This information is drawn from the case study descriptions. A more detailed description of measures and their effects can be found in the case studies themselves.

The scheme below (Figure 4-1) illustrates the decision process of finding a suitable technical solution in case of sedimentary coasts, dealing with either acute or structural erosion.

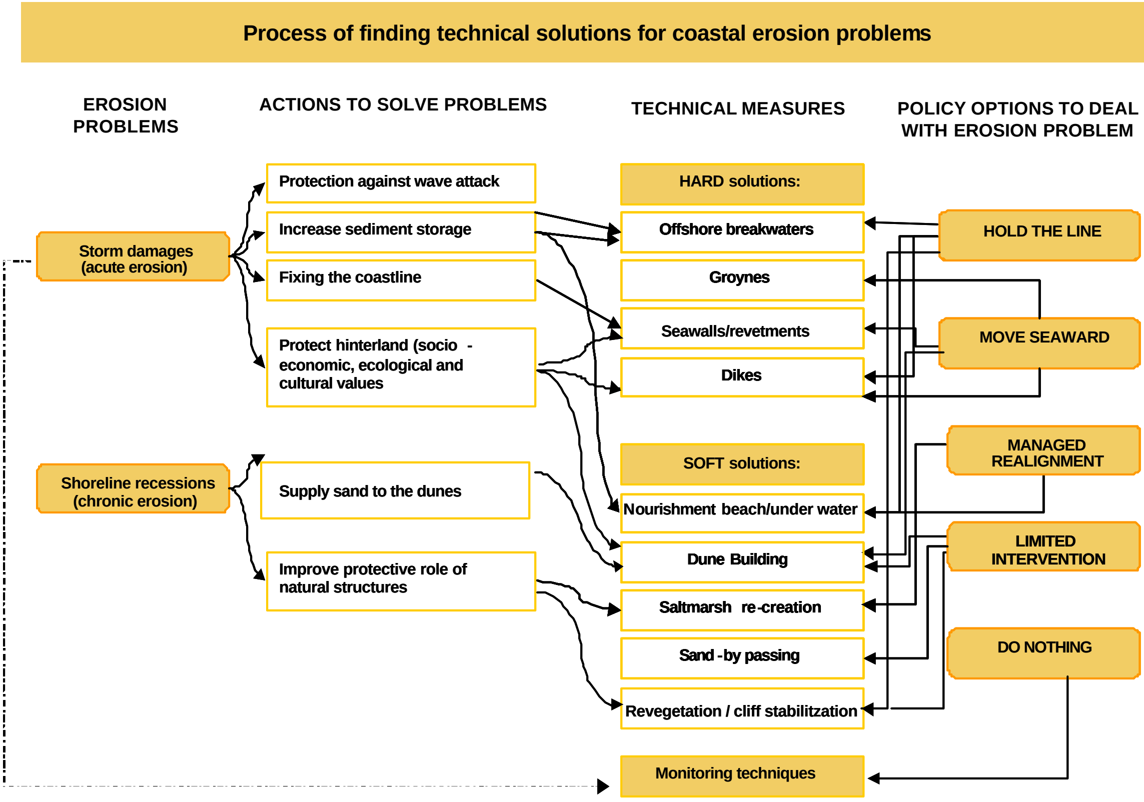


Figure 4-1 Flow diagram technical solutions

A summary of the most commonly used measures to prevent coastal erosion is given in Box 4-1 (hard measures) and Box 4-2 (soft measures). For every type of measure a short definition or general description is given.

Box 4-1 **Description of common hard measures**

Seawalls (shore parallel)
A seawall is a massive structure, designed primarily to resist wave action along high value coastal property. Seawalls may be either gravity- or pile-supported structures. Common construction materials are either concrete or stone. These structures are often pile supported with sheet pile cutoff walls at the toe to prevent undermining. Additional rock toe protection may also be used. The seaward face may be stepped, vertical, or recurved. A seawall usually forms a physical barrier between land and sea.

Revetments (shore parallel)
A revetment is a facing of erosion resistant material, such as stone, tetrapods, geotextiles or concrete. It is built to protect a scarp, embankment, or other shoreline feature against erosion. The major components of a revetment are the armour layer, filter, and toe. The armour layer provides the basic protection against wave action, while the filter layer supports the armour, provides for the passage of water through the structure, and prevents the underlying soil from being washed through the armor. Toe protection prevents displacement of the seaward edge of the revetment. A slope protection is rather similar to a revetment; a slope protection consists of an enforced toe of a dune or cliff, usually in the form of piled stones or boulders.

Groins (shore perpendicular)
Groins are narrow structures, often of rubble-mound or sheet-pile construction, usually built perpendicular to the shoreline. Groins may be used to: (i) build or widen a beach by trapping longshore drift, (ii) to stabilize a beach that is subject to severe storms or to excessive seasonal shoreline recession by reducing the rate of sand loss by longshore transport, (iii) to reduce the rate of longshore transport out of an area by locally reorienting the shoreline so that it is more nearly parallel with the predominant incoming wave crests, (iv) to reduce longshore losses of sand from an area by compartmenting the beach, and (v) to prevent sedimentation or accretion in a downstream area (harbour, inlet for example) by acting as a barrier to longshore transport.

Detached breakwaters (shore parallel)
Offshore breakwaters are generally shore-parallel structures that effectively reduce the amount of wave energy reaching the protected stretch of shoreline. They can be built close to the shoreline they are intended to protect, in which case they are called near shore breakwaters, or they can be built further offshore. When used for beach stabilization. Breakwaters function to reduce wave energy in their lee and thus reduce the sediment carrying capacity of the waves there. They can be designed to prevent the erosion of an existing beach or a beach fill, or to encourage natural sediment accumulation to form a new beach.

Box 4-2 Description of common soft measures

Beach and dune nourishment
Beaches and dunes form a natural system of shore protection for coastal lowlands and associated development. When the natural protection system provides inadequate protection from large storms, the first solutions frequently chosen are quasi-natural methods such as beach nourishment or artificial sand-dune construction. Such solutions retain the beach as a very effective wave energy dissipater and the dune as a flexible last line of defense.

Submerged nourishment
Submerged nourishments can be viewed as extension of beach and dune nourishment. The general idea is to take advantage of the natural shore directed sand transport. Submerged nourishments can be cheaper than beach or dune nourishments, because they don't have to be profiled and create less hinder to beach tourism.

Both beach and submerged nourishments include stockpiling of suitable beach material at the updrift end and allowing longshore processes to redistribute the material along the remaining beach. Beach nourishments require a storm i to bring the sand into the transport zone. When conditions are suitable for stockpiling, long reaches of shore may be protected by this method at a relatively low cost per linear meter of protected shore. It is important to remember, that the replenishment of sand eroded from the beach does not in itself solve an ongoing erosion problem. Periodic replenishment will usually be required.

Nourishment could be applied to recreate a beach, but also to create a sand buffer, which can serve to lower wave attack on dunes or cliffs. Furthermore, nourishment could supply a buffer from which sediment can be drawn during heavy storm surges, decreasing the rate of erosion.

Revegetation techniques
Revegetation techniques use natural sources to stabilize cliffs, dunes or slopes. Examples are:
- marram grass planting
- foredune maintenance
- forest maintenance

Cliff stabilization
Several soft techniques are available to stabilize a cliff:
- Grading: reducing the angle of cliff slope, by cutting and/or filling the cliff;
- Drainage: reduce pore water pressure or amount of water flowing along planes of weakness;
- Vegetation: increase the strength of the surface layers;
- Pinning: bolting the rock layers (bedding planes) together to avoid slips.

For each of the measures in the boxes common success and fail factors can be found in the case studies throughout Europe. Most of the success and fail factors exist in all regional seas. In the paragraphs on the different regional seas some specific factors for that area will be discussed. In the tables 4-1 to 4-4, common success and fail factors can be found. Similar measures have been grouped in the following tables to give a more compact overview on success and fail factors.

Table 4-1 Success and fail factors for seawall, revetment and slope protection

Hard measures (1)	Seawalls	Revetment and slope protection
Success factor ☺	✓	✓
Protecting local infrastructure, buildings on sedimentary coast against storms, at least temporarily. A sea wall can be applied to protect high value hinterland	✓	✓
Stopping erosion when it is caused by cross-shore transport only	✓	✓
Protecting dunes and/or cliffs against wave attack and thus erosion	✓	✓
Impeding aeolian sediment transport from the beach towards dunes	✓	
Fail factor ☹		
If erosion is caused by a net longshore transport gradient, seawalls are not effective	✓	✓
Loss of beach in front of seawalls caused by wave reflection.	✓	
Increase of erosion further downstream (moving the erosion problem to another loaction)	✓	✓
Wave attack during storm events can damage and even destroy seawall, high maintenance costs possible	✓	✓
Unprofessional approach towards slope protection (stone dumping by individual landowners): inadequate designs, lack of maintenance, thereby increasing the problem on the long run		✓
Hard points prevent the coast from adapting to sea level rise	✓	
Beaches are less easily accessed and this can discourage tourism	✓	
Although revetments can play an important role during severe conditions, maintenance of the beach (nourishments) is still required		✓
Protection is only locally	✓	✓

Table 4-2 Success and fail factors for groins and breakwaters

Hard measures (2)	Groins	Detached breakwaters
Success factor ☺	✓	
Stopping or slowing down erosion at a sedimentary coast when it is caused by net longshore transport gradient. Trapping sediment can even result in accretion over a significant coastal stretch	✓	
Protecting cliffs against erosion by trapping sediment that provides a protection against waves	✓	
Groins can be effective in reducing or stopping the migration of tidal channels	✓	
Length and distance in between groins need careful design to enable sand retention	✓	
Formation of tombolos		✓
Areas with low wave energy are created, thus reducing (longshore and cross-shore) sediment transport locally		✓
Colonization of salt marshes is stimulated		✓
Protection of sedimentary coast by accumulating sediment	✓	✓
Reduction of coastal erosion and of amount of nourished sand locally	✓	✓
Fail factor ☹		
If erosion is dominated by cross-shore transport, groins are not effective	✓	
Increase of erosion further downstream, the problem is only moved. The protection is only locally.	✓	✓
Sometimes unexpected results were seen, such as an increase of erosion and a return to the original situation (groins not effective or even worsening the erosion)	✓	
Constructions can be damaged and therefore require maintenance	✓	✓
Possible local erosion in bays between groins (especially, in case of large bays and thus large gaps between breakwaters)		✓
If tombolos are formed, longshore transport is fully interrupted increasing the erosion downdrift		✓
Structures may be unattractive	✓	✓
Structures are often costly, since constructions are built in relatively deep water		✓

Table 4-3 **Success and fail factors for sand nourishment**

Soft measures (1)	Beach, dune nourishments	Submerged nourishments
Success factor ☺		
Beach is extended instantaneously	✓	
Stopping or slowing down the retreat of the coastline	✓	✓
Longshore bars may be formed after cross-shore sediment transport; thus reducing wave attack.	✓	
Stopping or slowing down erosion of cliffs by creating a sand buffer that decreases the wave attack at the cliffs	✓	
Mitigating the effects of interruption of the longshore sediment transport	✓	✓
Executing the beach nourishment to fill up to the expected equilibrium profile as much as possible to obtain a stable coastline	✓	✓
No negative effects further downstream, unless presence of harbours or posidonia oceanica fields.	✓	✓
Most natural solution possible; less disturbance than hard constructions and the coastline keeps its natural resilience	✓	✓
On the long term, nourishments can be relatively cheap	✓	✓
Successful in mitigating negative impact caused by interruption longshore transport		✓
Using dredged sediment from port or river inlets can safe costs	✓	✓
Decreasing flood risk by creating a sand buffer seaward of the coastline		✓
Reducing wave attack		✓
Relatively cheap compared to beach and dune nourishments		✓
Stopping or slowing down erosion at sedimentary original coastline by creating a sand buffer offshore		✓
Obtaining a stable new coastline with nourishment: 1. Use the original morphology as much as possible to create a new coastline; 2. Application in a sheltered area; higher sediment transports mean that it is more difficult to maintain an artificially created coastline (higher maintenance costs)		✓
Choosing an optimal grain size		
Fail factor ☹		
Erosion at sedimentary coasts is not stopped	✓	✓
Heavy storm events can destroy dune and beach nourishments by transporting the sediment to deeper water; in combination with a net longshore transport the sediment can be removed from the cross-profile preventing beach build-up during calmer conditions	✓	
Nourishments have to be repeated frequently	✓	✓
Large amounts of sand excavation required at deeper water	✓	✓
Sediment does not directly contribute to the safety of the beach		✓
Relatively large quantities of sediment are required		✓
Less applicable for beaches with coarse sediment (pebbles/cobbles)	✓	
Presence of near shore posidonia oceanica fields. If covered with sediments from a nearby nourishment, the posidonia oceanica fiels disappear. Shells sometimes provide a significant part of the sediment supply. Shells inhabit the podisonia oceanica fields	✓	✓
Beach is less attractive for tourist purposes when the nourished sediments contain mud and have a dissimilar colour (dark)	✓	

Table 4-4 Success and fail factors for vegetation techniques and cliff stabilization

Soft measures (2)	Vegetation techniques	Cliff stabilization
Success factor ☺		
Mitigating the damage done by storm activity	✓	✓
Stabilizing dunes, cliffs and saltmarshes	✓	
Vegetation techniques are cost effective, as long as they succeed in mitigating the damage done to the coast by storm activity, and as long as the costs are reasonable (for example due to low manual labour costs in Baltic States)	✓	
Increased security for protected area		✓
Fail factor ☹		
Erosion at sedimentary coasts or cliff coasts is not stopped	✓	
Maintenance is required	✓	
Reduced sediment supply to beach in front of cliff can enhance further wave attack with erosion as a result		✓
It takes time for the measure to become effective	✓	
Effect of the measure depends on the growth of the vegetation	✓	

4.2 Baltic Sea

4.2.1 Introduction

There is a concentration of case studies in the western part of the Baltic Sea area, since the vulnerable and progressively eroding coasts of Germany, Poland, Denmark and south Sweden are located here (see Figure 1-2). Along the remaining parts of the Swedish coast as well as along the Finnish coast erosion problems are very uncommon, because of the prevailing land uplift. Various erosion case studies have been selected in the eastern area of the Baltic Sea. Here, the erosion problems are mainly related to heavy storm surges (especially during the last decade).

Different mitigating measures have been applied at the various case studies, as shown in Table 4-5. The table shows that hard measures, including seawalls, revetments, slope protections and groins, have been applied on a regular basis (often dating from the past and still applied today, but in a less regular manner). Detached breakwaters were only applied in Hyllingebjerg. With regard to soft measures, in almost every case study vegetation techniques were applied in some form. Beach nourishment has also been applied on a regular basis (especially during the last few decades), while submerged nourishments seem to have been applied less frequently. It is noted, that in Sweden, during the last decade, the normal strategy to combat erosion was to execute hard measures instead of using (additional) nourishments. Cliff stabilization in some form (mainly vegetation) was actively applied at the cliffs in Klaipeda, Riga, Talinn and Rostock, thus at practically all case studies dealing with cliff erosion.

Table 4-5 Overview technical measures at the case study areas Baltic Sea

	Hard measures				Soft measures			
	SW	RV	GR	DB	BN	SN	VT	CS
Ystad	✓	✓	✓				✓	
Falsterbo			✓					
Hyllingebjerg		✓		✓	✓		✓	✓
Koge Bay			✓		✓	✓	✓	
Rostock	✓	✓	✓		✓		✓	✓
West Poland	✓		✓		✓		✓	✓
Klaipeda						✓	✓	✓
Gulf of Riga	✓	✓				✓	✓	
Talinn	✓	✓			✓		✓	✓
Finland								

SW *- Seawall*
RV *- Revetment/ Slope protection*
GR *- Groins*
DB *- Detached breakwaters*
BN *- Beach- and dune nourishment*
SN *- Submerged nourishment*
VT *- Vegetation techniques*
CS *- Cliff stabilization*

In order to interpret the effects of the applied measures and the success- and fail factors of the measures, the dominant physical processes at the coast should be considered. These processes were discussed in Chapter 2 and are summarized as follows:

- In the Baltic Sea the tidal influence is negligible (tidal range<0,25 m)
- So the coasts are wave dominated, while the wave climate is moderate:
  Common wave heights: 2-3 m (185/1000 chance),
  Extreme wave heights: 5-6 m (3/1000 chance)[29]

4.2.2 Hard measures

Striking is, that most of the seawalls in the Baltic Sea have been erected before the 1980's. Apparently the observed fail factors have caused a tendency not to construct seawalls on a regular basis anymore.

In Box 4-3 it becomes clear that seawalls can in Baltic area can work well, but can easily be destroyed in a storm. A good technical design therefore seems to be necessary.

Box 4-3 Examples of effects of seawalls applied in Baltic area case studies

Talinn (sedimentary coast): the net longshore transport is negligible, the main erosion problem is caused by a cross-shore transport and the coastal seawall (1970s) is effective in stopping this erosion. The seawall is functioning up until now.

Riga (sedimentary coast): a seawall (1969) was erected as a base for a newly raised foredune after the 1969 storm. The seawall was exposed after the destruction of the foredune in the November 2001 storm; then, the seawall functioned as an emergency coastal protection.

West Poland (low soft cliffs): different kinds of seawalls (1900 until 1998) have been applied mainly at low soft cliffs. Light seawalls (from concrete blocks) did not work; the concrete block was covered by sand and the remains of wooden or concrete piles pose a danger to users of the beach. The hard seawalls did succeed in stopping the erosion. The downside is the observed loss of beach in front of the hard seawalls because of wave reflection and an increase in erosion further downstream.

Falsterbo (sedimentary coast): a seawall made of wooden poles was erected a long time ago. The seawall is not effective anymore; apparently erosion has destroyed it.

[29] Liverpool/Thessaloniki network as a part of the ERASMUS project, European Coasts, an introductory survey, August 1996.

Box 4-4 shows that cooperation and common strategies are necessary factors for a working erosion defense.

Box 4-4 Examples of effects revetments/slope protections applied in Baltic area case studies

Rostock (sedimentary coast): revetment (1968) stopped erosion locally, but downstream the erosion has increased.

Ystad (sedimentary coast): rock dumping by owners has occurred since the 1950s. This temporarily saved the buildings, but in the long run the (unprofessional) manner of dumping resulted in much graver damages and more problems. Dumping still occurs on a smaller scale.

Talinn (low soft cliffs): strengthening of the coast with boulders (2000) was relatively effective in this case, with an indented and sheltered study area with negligible longshore transport.

Riga (sedimentary coast): a dike with concrete revetment (1960s) was built to protect adjacent port facilities and reconstructed with geotextile later (1999). The November 2001 storm however, has destroyed the revetment.

Hyllingebjerg (soft cliffs): in the past a great variety of more or less separately functioning revetments has been constructed by individual landowners and local coastal protection groups., Inadequately designed structures and a lack of maintenance have led to deterioration of the slope protection. Therefore, a common approach was needed; the deteriorated or disfigured slope protections were replaced or fronted by a new rubble mound protection to obtain an aesthetic appearance. The new slope protection is functioning in a satisfactory manner.

Box 4-5 shows that groins have been wrongly applied in the past because of lack of knowledge of coastal erosion processes. Groins do not stop erosion in some cases on the long term.

Box 4-5 Examples of effects groins applied in Baltic area case studies

West Poland (sedimentary coasts): normal and T-shaped groins have been constructed from 1870 to 1980. The groins often did not have the expected result, returning to the original situation or enhancing the erosion process. Therefore, in Poland the Maritime Office now has abandoned this kind of protection and is eliminating destroyed groins. The groins cannot stop cross-shore transport during storms; this most probably causes the observed failure.

Ystad (sedimentary beach): the groins (1995) up until now seem successful in holding the line in the case area.

Rostock (sedimentary beach and cliffs): about 150 groins have been built between 1967 and 1992. At the area downstream of the harbour inlet and the breakwater, the groins turned out to be slowing down the erosion but not sufficiently for the protection of the coast: extra beach nourishments were needed.

Box 4-6 shows that the first couple of years a combined measure was successful.

Box 4-6 Example of effects detached breakwaters applied in Baltic area case studies

Hyllingebjerg (soft cliffs): in combination with beach nourishment, detached breakwaters were constructed here in 2000. For aesthetic reasons it was preferred to minimize the number of breakwaters with large gaps. The breakwaters were constructed in such manner, that tombolos would form behind them (length breakwater=distance from coast). In this way the recreational beach has been widened successfully. The large tombolos cause a deficit of sand locally in a few of the bays and some landowners have been critical about this. Further downstream a large tombolo was already present, so the new detached breakwaters do not cause an increase of erosion in adjacent coastal stretches. In general, the beach surface in front of the cliffs has increased and the cliff protection has been improved.

4.2.3 Soft measures

Besides hard measures, soft measures were widely applied in the Baltic area as well, see Box 4-7 and Box 4-8. The soft measures have positive effects though maintenance might have been unexpected. In a single case the effect was very positive, it should be mentioned that the shoreline was already slowly accreting at this location.

Box 4-7 Examples of effects beach and dune nourishments applied in Baltic area case studies

Talinn (sedimentary coast): in 1970 foreshore and beach nourishment was executed in the case study area. The beach was relatively stable until the 2001 storm event, after that the beach was not replenished naturally so a re-nourishment is needed.

Hyllingebjerg (soft cliffs): nourishment was executed to fill up the beach between the new detached breakwaters to the expected equilibrium profiles and to avoid a retreat of the coastline in the new bays due to sand trapping behind the breakwaters. Locally this retreat took place anyway, but in general the nourishment is stable (mainly because the expected equilibrium profile was constructed) and offers protection to the cliffs.

Rostock (sedimentary coast): this is the largest beach nourishment scheme seen in the case studies of the Baltic area; between 1970 and present approximately 1,3 million m^3 of sand has been dumped. Directly downstream from the inlet and breakwaters, the nourishment has to be repeated every 2-3 years (100-400 m^3/m^1) while a bit further downstream the nourishment is repeated every 10 years (100-150 m^3/m^1). The nourishments succeed in slowing down the rate of retreat of the coastline, however erosion still continues.

Box 4-8 Examples of effects submerged nourishment applied in Baltic area case studies

Klaipeda (sedimentary coast): submerged nourishment of 500,000 m^3 of sand was executed in 2001; the sand was dumped at a depth of 4-6 m. The sediment was dredged from the Klaipeda Seaport gate. Preliminary investigations have so far raised hopes that the submerged nourishment might effectively mitigate the negative impact caused by interruption of the longshore transport. The measure however is relatively costly in the Baltic States.

Riga (sedimentary coast): submerged nourishment at 4 m depth has been taking place since 1998 with about 30,000 m^3/year. The fine sediment is dredged from the adjacent Lielupe River. No information on the performance of this nourishment is available.

Køge Bay (sedimentary coast): 5 million m^3 of sand was used to create a new artificial coastline with as basis the existing sandy barrier islands. Beach, dune and submerged nourishment was executed to realize a new recreational area by creating beaches, dunes and ports and a new flood defence system by creating a sand buffer in front of the existing coastline. The success of this scheme (executed in 1970s) was mainly due to the fact that the original morphology was enhanced but not changed.

Vegetation techniques, see Box 4-9, are usually supplementary measures to give some extra protection. However, in Estonia, Latvia and Lithuania the foredune and forestry maintenance is the main coastal protection strategy (limited intervention). The measures have to mitigate the damage done by storm activity; because of low labour costs this measure is cost efficient in these countries.

Box 4-9 **Examples of effects vegetation techniques applied in Baltic area case studies**

At Køge bay, Ystad, Rostock, West Polish Coast, Riga, Klaipeda and Talinn foredune maintenance has been executed in the form of dune vegetation to protect dunes against wind erosion en to give the dunes more strength during storms. This is usually executed with marram grass planting.

At Køge bay and Rostock forestry was also planted behind the dunes as a protection from wind and as a wave breaker at times of flooding of the dunes.

At Riga, Klaipeda and Talinn forestry is used to stabilize cliffs. By planting and managing of forestry on the cliff (slope) the strength of the surface layer is increased. Forestry maintenance is executed through cleaning, selective cutting and replanting.

Different possibilities have been mentioned for cliff stabilization. In the Baltic area case studies, mainly vegetation techniques have been used to stabilize cliffs (as was already described in the previous section). In addition, at Talinn grading of a cliff took place: to stabilize the cliff the cliff was cut and brought to a more stable angle. No information was found with regard to pinning and drainage of cliffs; probably, these measures have been taken, but usually as supplementary measures, which may explain why little information has been found.

Box 4-10 **Examples of effects cliff stabilization applied in Baltic area case studies**

Talinn (soft cliffs): grading of a sandstone cliff (1,5 km) has taken place at Kakumae in 2000. The effectiveness of this measure is still to be examined but so far during the storm of 2001, the cliffs have shown resistance to the wave action, though a few places at the beach were washed off.

4.2.4 Combined measures

In order to circumvent problems related to the application of hard or soft measures, a mixture of these measures is often applied. In the Baltic area case studies, an example of combined measures that were planned as one coastal protection scheme is found at Hyllingebjerg.

At Hyllingebjerg a combination of hard measures (detached breakwaters and slope protection) and soft measures (beach nourishment to fill up the bays behind the detached breakwaters to the equilibrium profile) has been executed. This coastal protection scheme was very successful; it created a stable coastline, the widening of recreational beaches, protection for the houses on the cliffs and an aesthetic view of the coast (including the coastal protection measures).

In other cases, due to the (insufficient) effects of hard measures soft measures were added to the coastal protection scheme in time. An example is Rostock, where about 150 groins were built to protect the coast. When it turned out that this was not sufficient to stop the erosion at some locations of the coast, a beach nourishment scheme was started.

4.2.5 Costs

Within the case studies some information can be found about costs of measures.

Table 4-6 Types of measures and related costs in the Baltic sea

BALTIC SEA	Type of measure	Costs
Hyllingebjerg-Liseleje (Denmark)	Coastal protection plan	1,700,000 € (1999)
	- Construction new breakwaters	520,000 €
	- Beach nourishment 80,000 m^3	465,000 €
	- Slope protection	350,000 €
Køge bay (Denmark)	Beach park construction	21,000,000 € (1980)
Tallinn (Estonia)	Coastal forest maintenance	2,500 €/ha/year
	Seawall (2.5 km)	70,000 (1998-2000)
Western coast of Finland (Finland)	-	-
Rostock (Germany)	Dune reinforcement (800m)	300,000 € (future)
	Beach nourishment (60.000 m^3)	200,000 € (future)
	Beach nourishment (180.000 m^3)	750,000 € (future)
Gulf of Riga (Latvia)	Foredune maintenance	3,000 €/ha/y
	Forestry maintenance	1,500 €/ha/y
	Revetment (600 m)	150,000 € (1999)
	Submerged nourishment	2 – 2.5 €/ m^3 (1998-2001)
Klaipeda (Lithuania)	Forestry maintenance	3,000 €/ha/y
	Foredune maintenance	1,500 €/ha/y
	Submerged nourishment	1,260,000 € (2001)
Hel peninsula Poland	-	-
Western Coast of Poland Poland	Construction of seawalls and nourishment 1996 and 2000 (67.000 m^3)	1,550,000 € (1995-2002)
Falsterbo peninsula Sweden	-	-
Ystad Sweden	-	-

In Table 4-7 the costs of nourishments recalculated to € per m^3 are presented. Apparently the nourishment costs are comparable in the different countries: €4 -5 per m^3 for a beach nourishments and €2-3 per m^3 for submerged beach nourishments.

Table 4-7 Costs of nourishments (€ per m^3), from case studies and general information

	Beach nourishments	Submerged nourishments
Case studies		
Klaipeda		2,5
Riga		2,0-2,5
Hyllingebjerg	5,5	
Rostock (estimate)	4,0	
Countries		
Denmark	4,2	2,6
Germany	4,4	

4.3 North Sea

4.3.1 Introduction

This section gives an analysis of the technical measures that were taken to combat erosion in the countries around the North Sea. **Fout! Verwijzingsbron niet gevonden.**13 shows the location of the case study sites. The selected sites are located at eroding parts of the North Sea coasts and include a number of estuaries (Humber, Wester Schelde, Elbe), cliff coasts (Holderness and, locally, Sylt and Essex) and sandy beaches and dunes (Zeebrugge, De Haan, Holland, Waddenzee, Sylt and West Jutland).

Especially for estuaries, sea level rise is a continuous problem. Although in many places hard measures are required to ensure the safety of urban areas, in other areas a managed realignment strategy has been adopted, in places where the original defences are set back. In these cases, although erosion *is* a problem, the erosion is accepted (locally) and no measures are taken to combat erosion. Along the sandy dune coasts at the North Sea, the hinterland may be threatened when severe erosion occurs. This is the case in Holland, where about 30 percent of the country lies below average sea level. In this case, the need to combat erosion is urgent.

Table 4-8 Overview technical measures at the case study areas North Sea

	Hard measures				Soft measures			
	SW	RV	GR	DB	BN	SN	VT	CS
De Haan	✓				✓	✓	✓	
Zeebrugge	✓		✓		✓		✓	
Westerschelde		✓	✓				✓	
Holland Coast	✓	✓	✓		✓	✓		
Waddenzee		✓	✓		✓	✓	✓	
Elbe	✓	✓			✓		✓	
Sylt	✓	✓	✓		✓	✓		
West Jutland		✓	✓	✓	✓	✓	✓	
Essex			✓	✓	✓		✓	
Holderness	✓	✓	✓					✓
Humber	✓	✓						

SW *- Seawall*
RV *- Revetment/ Slope protection*
GR *- Groins*
DB *- Detached breakwaters*
BN *- Beach- and dune nourishment*
SN *- Submerged nourishment*
VT *- Vegetation techniques*
CS *- Cliff stabilization*

Table 4-8 gives a summary of measures that were taken against erosion for the case studies considered. Basically, two types of coast are given in the table: tide-dominated estuarine coasts (Westerschelde, Elbe, Essex, Humber) and sedimentary beaches with dunes or cliffs (De Haan, Zeebrugge, Holland Coast, Waddenzee, Sylt, Jutland, Holderness). The measures have to be seen in relation to the type of coast. For example, revetments are often used in estuaries to slow down the migration of tidal channels causing erosion near sea defences, whereas nourishments are applied less frequently in estuaries but are more commonly executed at beaches.

A summary of the success and fail factors, as described in the cases is given in tables 4-1 to 4-4.

4.3.2 Hard measures

At many places along the coastline hard sea defences have been built to stop the erosion in places, where the sea threatens lives or important installations. However, these sea defences have a downside; they are unsightly, can be inefficient and in the long term can be found to encourage local erosion and erosion in other places. Furthermore, sea walls make access to the beach more difficult and can discourage tourism.

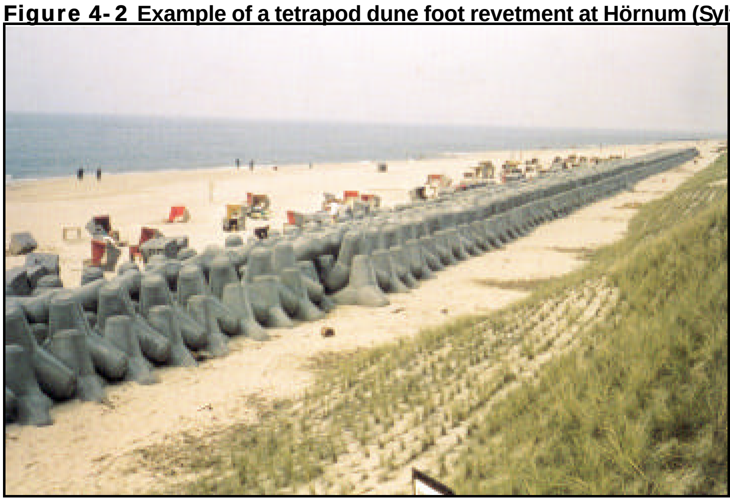
Box 4-11 Examples of effects of seawalls applied in the North Sea area case studies

Sylt (sedimentary coast): the seawall at Westerland failed on the long run, much damage to the seawall occurred. The seawall needs to be protected at the toe by nourishments to prevent the seawall from collapsing. Furthermore, the seawall causes erosion downstream of the seawall.

Holderness (sedimentary coast): At Withernsea, the stability of the beach depends on the effectiveness of trapping material between groins established 120 years ago. These were built when the promenade was established. However, storms during the winter of 1992/93 caused the removal of most of the beach fronting the wall. In some places up to more than 4 m of sand was stripped away by the sea, exposing the foundations to the sea wall. This has led to cracks appearing in the wall and houses along the sea front experiencing shock waves large enough to be measured on the earthquake scale.

De Haan (sedimentary coast): Historically and especially in the 20th century, hard constructions were built to hold the coastline at its existing position and to protect the infrastructure and hinterland against flooding. In the early 1930's a sloped seawall was constructed at De Haan in order to stabilize the dune belt and to allow for tourist expansion.
After the 1990 storm attack, the foundation of the seawall was put in jeopardy. At present, beach nourishments maintain the beach in front of the sea wall. These measures have created a wide beach at De Haan (function tourism and recreation). Furthermore the wide beaches and thereby the protection of the seawall assure the safety of the people and investments in the hinterland of the coast.

Figure 4-2 Example of a tetrapod dune foot revetment at Hörnum (Sylt)



In Box 4-12 it is shown that revetments are successfully applied to prevent channel migration. Erosion might still take place on other locations like the tidal marshes.

Box 4-12 Examples of effects of revetments/slope protections applied in North Sea cases

Westerschelde (macro-tidal estuarine coast): Natural meandering of channels locally causes erosion of saltmarshes in the order of several meters per year. At several locations, meandering may cause critical situations. At these locations, the channels have migrated towards the sea dikes and a further migration would cause damage and thus a threat to the dikes. Channel revetments were successfully constructed in the Westerschelde at several locations to stop the migration of the main channel.

Humber (macro-tidal estuarine coast): In the estuary human interference is of great importance. Embankments with revetments have fixed the coastline over a large stretch; this influences the response of the estuary on relative sea level rise. The natural landward movement of the coastline is made impossible, this causes erosion of the tidal marshes and erosion of the foreshores.

Figure 4-3 **Groins at Vlieland**

In the North Sea area groins and detached breakwaters have been successfully applied, especially in cases where channel migration had to be prevented. Erosion rates have been slowed down at the cases in Box 4-13 and Box 4-14.

Box 4-13 Examples of effe cts of groins applied in the North Sea cases

Sylt (sedimentary coast): The central part of Sylt at Kampen and Westerland has always been strongly protected in the past and still is (because of the high economic values) by hard coastal protection measures, such as groins. Because of the high erosion rates at the northern and southern spit and the reasonably stable situation (because of the heavy protections) at the central part, the coastal line is forming more and more into an arch shape. If the coastline had not been fixed by hard structures, the island would have wandered towards the east.

Westerschelde (estuary): In the Westerschelde, salt marshes erode with rates of several meters per year due to wave attack. The increased wave attack is the result of channel migration, resulting in a shallower foreshore. 6 groins of about 100 to 150 m were constructed at a salt marsh with an orientation perpendicular to the shore, at distances of 500 m. The works were finished in 1992. An evaluation (1997) showed that sedimentation had occurred between the groins and that the erosion rate had reduced from about 5 to 2 m/year.

Zeebrugge (sedimentary coast): The seaward extension (to a distance of 3,5 km from the coast) of the harbour of Zeebrugge in 1970's intersected the easterly longshore tidal flow and locally disturbed the morphological equilibrium. As a result, the local tidal trench called "Appelzak" shifted ground and re-established itself just in front of the groins before the coast of Knokke. Breaking storm waves transport the beach material offshore tot the seaward limit of the foreshore, into the tidal gully "Appelzak" from where it is carried away by the predomininantly northeasterly-flowing tidal current. In this way a structural erosion problem of the Knokke-Zoute beaches was created.

Box 4-14 Example of effects detached breakwaters applied in North Sea cases

Western Coast of Jutland (sedimentary coast): The effect of using low detached breakwaters has been studied. The results were based on 10 years of monitoring of a group of breakwaters. The purpose of the study was to confirm the design theory used, which was based on theoretical computations. The paper confirmed that the use of breakwaters in this group had reduced the need for nourishment landward of the breakwaters by 50%.

4.3.3 Soft measures

In the North Sea area nourishments are often a good option because of the large sediment availability. Large quantities are put on the beaches and foreshores. Results have been thoroughly studied because of successful monitoring programmes and research that is in some cases co-funded by the EU.

Box 4-15 Examples of effects of beach and dune nourishments applied in North Sea cases

Sylt (sedimentary coast): For a long time, the entire coast of Sylt has suffered from severe erosion, while accumulation of sand does not occur at any part of the coast. The high erosion rates are mainly caused by heavy storm surges from the west, affecting the westerly-orientated coast of Sylt to a large extent. Nourishments are executed on a large scale, with average amounts of 1,000,000 m^3 per year for the entire coast of Sylt (length is about 40 km.) Although locally, hard constructions were built to defend valuable assets during storm conditions, the nourishments seem to be effective in stopping the recession of the coastline.

Holland (sedimentary dune coast): In 1990 the Dutch government decided to stop further coastal retreat and to maintain the coastline of 1990 by means of beach nourishments. After almost 10 years an evaluation of this strategy has been carried out. The results of the evaluation are satisfactory. The task, which the national government undertook in 1990, the fighting of structural erosion, can be carried out successfully with sand nourishment. The only locations where the effect of beach nourishments is questioned, is at a few beach locations in the province of Zeeland that have very steep underwater slopes as a result of the presence of tidal channels.

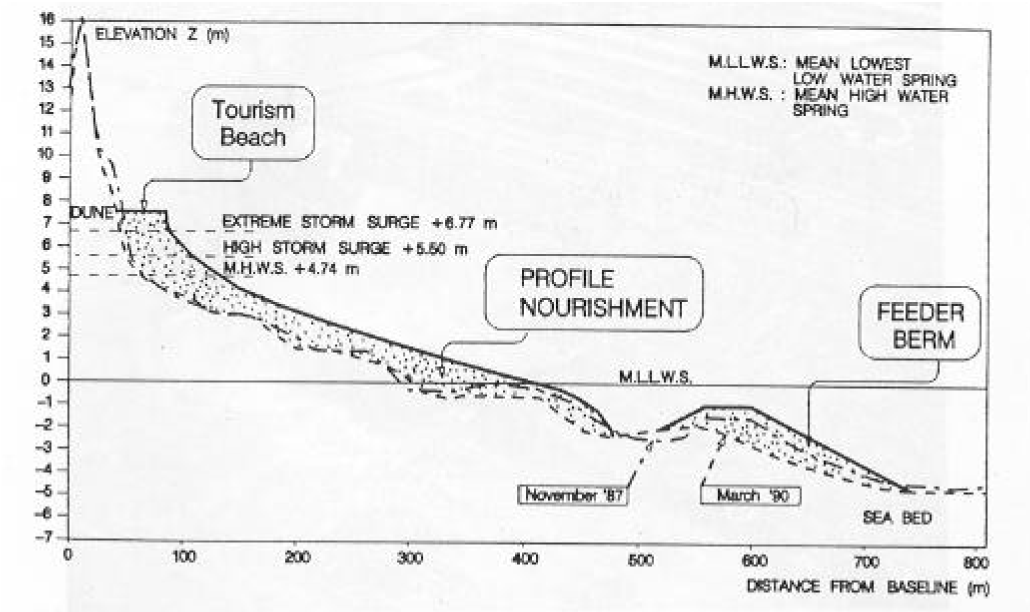
Box 4-16 Examples of effects submerged nourishment applied in the North Sea cases

De Haan (sedimentary coast): In 1991 works were executed, which combined profile beach nourishment with a sub-tidal feeder berm (see). During one year, the feeder berm acted on its own as coastal protection. Within this period, no significant losses of sand were registered and a progressive natural nourishment of the intertidal beach could be observed. Some lateral spreading of the feeder berm's sand equally to the West and East was observed.
Compared to classic beach nourishment, the behaviour of the profile nourishment combined with a feeder berm appears to be a better solution.

Waddenzee (sedimentary dune coast): Terschelling is a barrier island (30 x 4 km) situated in the Wadden Sea. The effectiveness of shore nourishment has been studied within the NOURTEC project (Innovative Nourishment Techniques Evaluation), as part of the MAST-II program of the EU. The objective of the Terschelling nourishment was to prevent, for a period of 8 years, the retreat in a 4.5 km long stretch of the coastline in the center of the island. Most of the 2 million m^3 of sand was dumped in the trough between two breaker bars.

The nourishment was supposed to compensate for the natural losses of 8 years (approximately 20 m). However, the results show a much greater gain of already 30 m at the end of 1996, which is still increasing. The nourishment acts as a submerged breakwater trapping sand. Further advantages of this solution are reduced costs (since some handling and the installation of, e.g. pipelines, are avoided), while any ongoing recreation is no longer hindered. So far, the experiment is declared a great success.

Figure 4-4 **Typical cross section of feeder berm with profile nourishment at De Haan**



Box 4-17 and Box 4-18 show that in two cases in the UK various soft measures are apllied to slow down erosion. These examples do not show negative side effects.

Box 4-17 **Examples of effects vegetation techniques applied in the North Sea cases**

> **Essex** (estuarine coast): The method of *gripping* is applied at the Essex coast. Gripping is a process where mud flats are excavated in parallel lines and the sediment placed to one side. Enhanced accretion rates and subsequent consolidation of the mud are achieved by various methods of "gripping". A series of ditches and ridges and brush wood groins increase drainage rates allowing the mud to dry for longer periods, and also to act as siltation traps. In addition, this method is to encourage earlier colonisation by plants and is often combined with planting e.g. *Spartina* in the 'gripped' areas. Regular maintenance of the ditches and ridges is essential.

Box 4-18 **Examples of effects cliff stabilization applied in the North Sea cases**

> **Holderness** (partly cliffs): Local authorities have tried various measures to tackle the problem of cliff erosion. Where storm waves undermine cliffs, physical barriers have been used to resist the waves. Sometimes large boulders are placed at the top of a beach to gradually reduce wave energy and to reduce the backwash by encouraging percolation. Where cliffs are likely to collapse because they have become saturated, drainpipes are placed in the cliff to lower the water table and reduce the likelihood of failure.

4.3.4 Combined measures

The island of Texel (Waddenzee case) suffered from severe erosion because of a net northward sediment transport. Therefore, at the NW side of Texel, a combined measure was chosen of hard and soft solutions and a dam with a total length of 800m was constructed. This was combined with nourishments. First, in 1994, a volume of 2Mm3 was nourished onto the beach.

Then in 1995, the dam was constructed in 4 months. Building costs of the dam amounted to 8M€.

The effect of the cross-shore dam is currently (2002) still under discussion. It is very clear that since construction strong accretion took place. The striking result is that the accretion takes place at both sides of the dam. The original expectation was accretion at its SW only (see Figure 4-5)

Figure 4-5 Accretion at both sides of a cross-shore dam at the island of Texel (Waddenzee)

In Essex a number of sites have become the recipient of recharge material. Much of this material is derived from the dredging of the Harwich Harbour. The method used comprises of dumping of sediment on the foreshore of the estuarine coasts. Often, this is combined with ‘offshore breakwaters’, for which sunken barges are used. The gaps between the barges are filled to reduce wave attack; tidal action will disperse the material dumped.

4.3.5 Innovative measures

A very unusual, and therefore possibly innovative, measure was taken in the Elbe estuary. The island Scharhoern, which is situated within the estuary, is drifting towards the nautical channel and is rapidly shrinking. The island Scharhoern is one of the most important breeding island for terns and other seabirds in the whole Wadden Sea region.

Because of the threatening loss of this breeding sanctuary, the environmental authority of Hamburg decided in 1989 to establish a new dune island by sand nourishment 1.5 km away to the southwest of Scharhoern, but still situated on the Scharhoern reef: the artificial island Nigehoern.

Using a 2.5 km long pipeline, 1.3 million m³ of sediment was pumped up the Scharhoern-plate within a time span of 5 weeks. When sculpturing the topography of the surface, the typical look of a low dune island in the estuary of the river Elbe was imitated: the initial form was a circle covering about 30 ha. This was supported by concentric bush fences at the periphery, a double circle of bush fences at the edge and three parallel bush-fence lines in the centre of the island. Latter ones were built to promote the development of primary dunes. The mean height of the new island was 4.25 m above sea level, reaching 5.2 m on the top of the dunes. In late summer of 1991, a kidney shaped reef was constructed in the northwest of the island to protect it from strong sea erosion. To support the sand nourishment and the effect of the bush fences, and to minimize aeolic sediment drift on the island, a large quantity of dune vegetation has been sowed and planted.

A major success was reached when the artificial island Nigehoern was colonized by migrating birds in the first year after it was built. This island has more or less taken over the role of the rapidly shrinking island Scharhoern. The loss of the tidal marsh island Scharhoern was compensated.

Another innovative measusere is the “drainage system” that was developed by the Geotechnical Institute and applied for the first time in the west coast of Denmark (see paragraph 4.4.5 for a general example).

4.3.6 Costs

Some information about costs is found in the case studies.

Table 4-9 Types of measures and related costs in the Baltic sea

NORTH SEA	Type of measure	Costs
De Haan(Belgium)	-	-
Zeebrugge-Knokke Heist (Belgium)	-	-
Western coast of Jutland (Denmark)	-	-
Elbe estuary (Germany)	-	-
Isle of Sylt (Germany)	Nourishment (29,350,000 m^3)	114,581,000 € (1963-2000)
Holland coast (The Netherlands)	-	-
Wadden Sea Islands (The Netherlands)	Nourishment	3,2 – 4,5 €/ m^3
	Cross-shore dam (800m)	8,000,000 € (1995)
	2 Groynes (180m-200m)	2,600,000 € (1995)
Western Scheldt estuary	Revetments	65,000,000 € (1998-2001)
(The Netherlands)	Maintenance dredging (14,000,000 m^3)	90,000,000 €
Essex estuaries (United Kingdom)	Thames Barrier &	£600 million (completed 1982)
	maintenance	£4,000,000/y
	Thames tidal defences	£400.000.000
	Sea defence 1990-1996 &	£95,000,000 (1990-1996)
	Sea defence maintenance	£41,000,000 (1990-1996)
	Coastal protection	£41,000,000 (1990-1996)
	Coastal protection maintenance	£100,000,000 (1990-1996)
Holderness coast (United Kingdom)	-	-
Luccombe- Blackgang (United Kingdom)	-	-
Norfolk United Kingdom		

Soft solutions are more often applied. An example is given for the Danish coast. Because of the small volumes and the lack of experience of the Danish contractors regarding pumping of sand directly on shore on the North Sea coast, the mobilization costs were quite high in the beginning and, consequently, the unit costs were high. With increasing volumes and experience, a better approach to nourish the different parts of the profile has been developed.

4.4 Atlantic Ocean

4.4.1 Introduction

This section gives an analysis of the technical measures that were taken to combat erosion in the European countries bordering the Atlantic Ocean. The sites selected for the analysis are located in the countries Ireland, United Kingdom, France, Spain and Portugal. Additionally, sites in the Azores (Portuguese) and the Canary Islands (Spanish) are included in the analysis. Figure 1-6 shows the locations of the case study sites.

The cases include various coastal types, such as sedimentary coasts with dunes (Aquitaine, Estela, Vageira) or without dunes (Châtelaillon, Sables d'Olonne),
cliff coasts with sandy beaches (Cova do Vapor/Caparica Beach, Vale do Lobo) or pebble beaches (Haute-Normandie, Isle of Wight) and volcanic sedimentary beaches. In the Azores, the latter are backed by cliffs and in El Médano (Canary Islands), the beach is backed by dunes. In some sites, pocket beaches are found, enclosed by headlands (e.g. Playa Gross).

Table 4-10 gives a summary of measures that were taken against erosion for the case studies considered. It shows that the measures taken are biased towards the hard solutions. Various types of hard solutions were applied in all cases considered. Although applied in almost all cases, beach nourishments are executed on a much smaller scale (in terms of m^3) than in the North Sea and the Baltic Sea regions. Whereas in the latter regions soft measures are often taken to combat erosion, along the Atlantic Ocean coasts the soft solutions are often combined with hard measures, probably due to the high energy conditions of the coast.

Examples of soft solutions and combinations of hard and soft solutions can be found in the Atlantic coast of France (e.g. Aquitaine region), where beach nourishments and dune regeneration are considered as the best solution for stopping the erosion problems. At various sites in Spain, United Kingdom, Ireland and Portugal (e.g. Vagueira) a mix between hard and soft engineering solutions was adopted for dealing with the erosion issues

A summary of the success and fail factors, as described in the cases is given in tables 4-1 to 4-4.

Table 4-10 Overview technical measures at the case study areas of the Atlantic Ocean

	Hard measures				Soft measures			
	SW	RV	GR	DB	BN	SN	VT	CS
Aquitaine	✓	✓	✓				✓	
Châtelaillon	✓	✓	✓		✓			
Haute-Normandie		✓	✓		✓			
Sables d'Olonne	✓				✓[30]			
Azores								✓
Cova do Vapor	✓		✓		✓			
Estela		✓[31]			✓			
Vagueira	✓		✓					
Vale do Lobo		✓			✓			✓
El Médano					✓		✓	
Playa Gross	✓		✓		✓			

***SW**- Seawall*
***RV**- Revetment/ Slope protection*
***GR**- Groins*
***DB**- Detached breakwaters*
***BN**- Beach- and dune nourishment*
***SN**- Submerged nourishment*
***VT**- Vegetation techniques*
***CS**- Cliff stabilization*

[30] In Sables d'Olonne a beach drainage system has been installed (see also section 4.4.5).

[31] 'Soft' revetments were applied, in the form of sand bags.

Isle of Wight	✓	✓	✓	✓	✓		✓	✓
Sussex	✓		✓	✓	✓			✓
Donegal		✓					✓	
Rosslare			✓		✓			

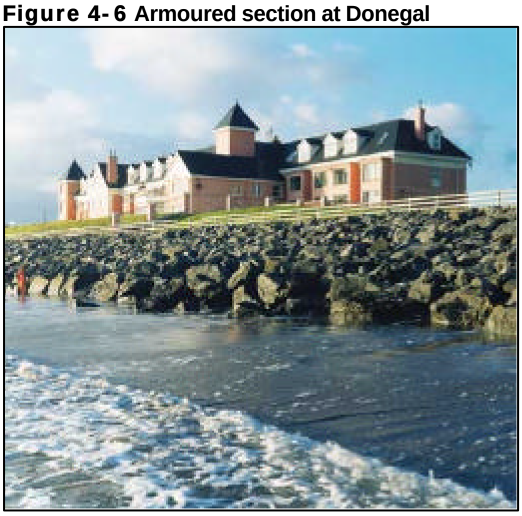
4.4.2 Hard measures

Box 4-19 Example(s) of effects of seawalls applied in the Atlantic Ocean case studies

Châtelaillon The Châtetaillon coast suffers from erosion that has mainly a structural character, continuously reducing the beach width. As a result, the risk of severe damage (also: flooding) during storms is increasing as well. In order to protect the village and the first seawall was built in 1925. Since then, the beach profiles have begun to lower. The reflection of the waves on the seawall, as well as the cross-shore transport due to the action of the waves have increased the erosion. In the 60's the beach disappeared at high tide. The foot of the seawall had to be protected by rocks in order to keep the city of Châtelaillon safeguarded from flooding. In the 1990's beach nourishments were executed, in order to provide a further protection of these constructions.

In all regional seas, the seawalls show common success and fail factors. In the Atlantic sea walls need to be built strong to resist extreme events with large wave heights.

Figure 4-6 Armoured section at Donegal



Box 4-20 shows that planning of coastal erosion defence should be planned at the right spatial scale.

Box 4-20 Example(s) of effects of revetments applied in the Atlantic Ocean case studies

Donegal (sedimentary beach with cliffs/dunes): The last sixty years, the central section of the dune front at Rossnowlagh has been eroding at rates up to 0.6 m per year. Construction of rock armour, which started with armament of the dune front in front of the Sand House Hotel, has stopped erosion at these locations (see Figure 4-6). The rock armour was not placed in one long protection, but in an ad hoc manner over short lengths. Between these armoured sections erosion has continued, giving the dune front a ragged appearance. Between two armoured locations, indentations up to 35 m have been observed as a result of ongoing erosion.

The examples in Box 4-21 and Box 4-22show that hard measures can work really well if the consequences are accepted. If erosion is predicted and accepted at other locations, the overall performance can be good.

Box 4-21 Example(s) of effects of groins applied in the Atlantic Ocean case studies

Cova do Vapor/Caparica Beach (cliffs with sedimentary beach): In an attempt to resist coastal erosion in Cova do Vapor, the urban waterfront is defended by hard coastal structures. This is done because it is felt that in such highly exposed areas, "soft" measures may not be effective. The erosion began to be a problem after the disappearance of a sand spit. The first groins were constructed between 1959 and 1963, in combination with a seawall. These works had as main objective to constitute a hard nucleus to hold the coastline. The situation became worse in 1964 and it was concluded that the influence of the downstream groins was too small to originate sand accumulation on the southern beach, and reduce/finish the erosive process. The cliffs are further away from the beaches than the influence of the groins. Therefore, between 1968 and 1971 three groins had to be expanded. Between 1972 and 2000, the coastline was more or less stable. However, the stormy winter of 2000/2001 demonstrated that this area is still very instable and vulnerable.

Box 4-22 Example of detached breakwater applied in the Atlantic Ocean case studies

Sussex (soft cliff coast with shingle beach): At the coast of Elmer (Sussex) old timber groins were unable to efficiently maintain a suitably wide shingle beach. Therefore, 8 detached breakwaters were built to reduce wave energy at the Sussex coast (see Figure 4-7). They were constructed in such a way that some littoral drift was able to continue.
The scheme is a joint project between the local authority and the national Rivers Authority (Now Environment Agency) and costs around €8,5 million. Up until now, the Elmer protection scheme seems to be successful in widening the beaches and protecting the hinterland from flooding.

Figure 4-7 Detached breakwaters at Elmer (Sussex coast).

4.4.3 Soft measures

Soft measures can be a short term solution. Erosion can continue at the same rate and soon the same action (measure) needs to repeated. This is especially the case in the Atlantic where wave heights and tidal amplitudes can be rather large.

Box 4-23 Example(s) of beach/dune nourishments applied in the Atlantic Ocean case studies

Vale do Lobo (cliff coast with sedimentary beach): The cliffs of Vale do Lobo beach are almost vertical formations of red sands, with a narrow subjacent beach. The base of the cliffs is often hit by wave breaking especially during winter. The cliffs are retreating with a rate of about 1 m/year. The retreat of the coastline is threatening the existence of a luxury golf course, although the promoters of the resort have been able to take advantage of the cliff erosion through the famous 16th hole in which the players can demonstrate their skills in passing the two chasms in the cliffs (see Figure 4-8).

Beach nourishments were applied to feed the beaches in front of the cliffs, thus reducing cliff erosion. The nourishment operation has been effective in the sense of slowing down the process of cliff erosion. However, as this is an exposed coastal stretch, the high erosive strength of the sea has taken a great part of the sand volume placed artificially on the beach. This way, it is expected that the need for new nourishments will be frequent.

Châtelaillon In 1989 the first large beach nourishment was perfromed in France. The nourishment project consisted of 330.000 m^3 on the south and middle of the site. In order to reduce erosion on the northern beach, each year between 10.000 to 30.000 cubic meters are taken from the south of the beach and brought on the north by using power shovels and dumper-trucks.

The aim of this soft solution was to create a large beach for tourists even at high tide, and to protect the city against flooding. This first beach nourishment was possible by dredging on an offshore sand bank (north to Oleron Island). The success of the solution has led to a second nourishment, which was carried out in 1998, at the middle of the beach. A third is provided for 2003, in order to protect the north of the site against flooding and offer a wider beach to the tourists.

Figure 4-8 Cliff erosion has had its effects on the famous 16th hole in Vale do Lobo

Vegetation can be part of a soft solution for dune mainentance and/or recovery. Some successful examples are shown in Box 4-24.

Box 4-24 Example(s) of vegetation techniques applied in the Atlantic Ocean case studies

Acquitaine (sedimentary coast with dunes): Aeolian sediment transport causes erosion along the Acquitaine coast. Nowadays, the most effective protection is the placing of a cover of vegetation on the dunes, which consists of placing barriers of cut branches gathered in the forest or the installation of artificial wind breakers to halt the transport of sand. Then the installation of indigenous vegetation completes the maintenance work forming a herbaceous carpet to hold the dune in place. Reshaping dunes by bulldozers is used only in case of emergency.

El Médano (sedimentary beach with dunes): In 1991, a dune regeneration experiment was started. The idea consisted of placing surpluses of various types of materials including marine material – seaweed, sea grasses – ripped up by the currents and wave action and which tend to be deposited on the sea shore on the bare areas on the eastern side of the natural area.
The material was covered with sand, in the hope that it would serve both to gradually retain more sand and for the germination on the organic material of vegetation that would allow the newly built up dune to become fixed. Although the rainfall system was not very generous, it could be determined that sand was retained and that some plant species, did successfully develop.

Dumping of chalk on the shore in the example in Box 4-25 can be seen as a soft solution. However, the total solution can be classifieds as hard because the construction works are rather irreversable.

Box 4-25 Example(s) of cliff stabilization applied in the Atlantic Ocean case studies

Sussex (cliffs): In 1935, coastal protection works were built to protect a 7 km length of the South Coast Road. A concrete seawall and promenade were built into the rock of the beach platform, behind which the cliff face was cut back (graded) to a stable 'self-weathering' angle of about 72°. The material from the cliff trimming, 200.000 m³ of chalk, was dumped on the shore platform. Groins were built outward from the seawall in order to trap beach material and thus help protect the base of the wall. The construction, which had successfully halted cliff recession, could not prevent erosion of the foreshore, and foundations were exposed and undermined. A side effect that was noticed after completion of the first seawall and groins was that the erosion of the coastline further to the east accelerated. The earlier defences were therefore extended eastward.

4.4.4 Combined measures

At many sites along the Atlantic coast, a mix between hard and soft engineering solutions is adopted for dealing with the erosion issues. Hard and soft solutions are often combined, probably due to the high energy conditions of the coast.

An example is found in Rosslare (Ireland), where erosion problems have been attributed to human interference with the natural sediment movement patterns in Rosslare Bay. In 1957, timber groins and breastworks were constructed. These works succeeded in slowing down the erosion and holding a fixed position of the shoreline. However, the success of the breastworks in reducing coastal recession led to a reduction of sediment quantities available for the natural alongshore drift. This reduction in available sediment along with the vertical nature of the timber groins and breastworks works, which reflected wave energy, resulted in a lowering of the beach level. It was evident that a more permanent solution to the problem was required.
In 1990, it was recommended that the construction of rock groins and the provision of additional beach nourishment as the optimum solution to prevent further erosion at Rosslare.

Box 4-26 **Gross Beach, Spain:example of combined measures implementation**

In Spain, Gross Beach was suffering from erosion due since the beginning of the 20th century. In 1992, the situation of instability in Gross Beach made the Ministry for Public Works and Transport (MOPT) commission a study for the analysis of the coastal dynamics of Gross Beach and possible solutions for the effective defence of the beach. Different alternatives were studied for carrying out the regeneration project. Finally, the measures that were taken were a combination of beach nourishments (about 1.1 Mm3) and the construction of a breakwater of about 1,100 m in length.The following criteria were taken into account for the beach regeneration in San Sebastian in 1994:

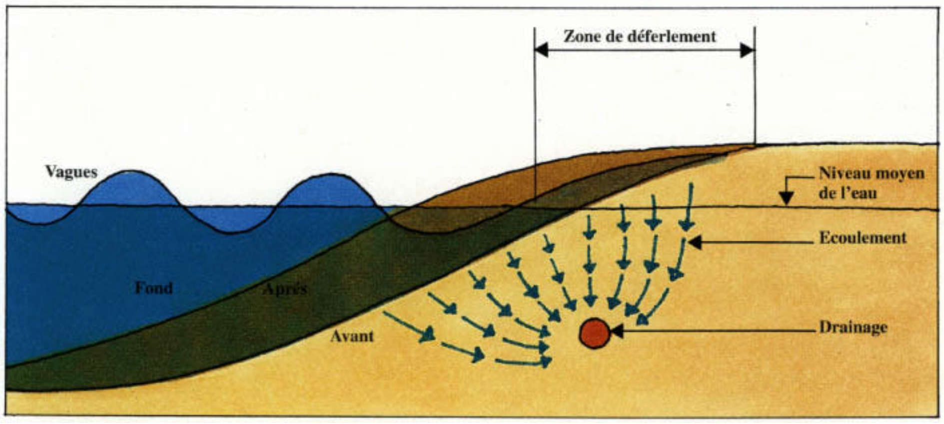
- Technical: designing a curved dike with a submerged foot perpendicular to the two main wavefronts.
- Aesthetical: designing the lowest possible crest levels for the dike, always adjusted according to technical criteria, so that visual impact is avoided and the dike is in harmony with its surroundings.
- Environmental: analysing the biological conditions of the area in order to minimise environmental stress after renourishment.
- Surfers: The characteristics of the added sand should guarantee the continuity of surfing at the

4.4.5 Innovative measures

In Sables d'Olonne a rather unusual technique was applied for increasing the resistance of the beach to erosion. Large parts of the coast were already protected by hard constructions (seawalls and revetments). Unfortunately, these measures were unable to stop the lowering of the beach profiles. Nowadays, the strategy is to work as much possible with natural processes.

In order to stop the erosion and to stabilise the beach profile, a beach drainage system was installed in April 1999 on the eastern part of the beach, which was the most erosive part (most exposed to swell).

Figure 4-9 **Beach profile with drainage system**



The system consists on a gravity drain, lowering the water table under the beach. As a result, the beach is unsaturated with water when waves break on the shore and the infiltration of the water into the sand is improved. The purpose of the system is to reduce swash velocities, sediment transport, and therefore erosion. The water flows by gravity from the drain to a pumping system. The water is then pumped into the sea or is used as (filtered) water in, for example, swimming pools or aquariums.

In March 2002, the system seemed to work and it was decided to improve the effects of the first system by a second one on the western part of the beach.
The beach drainage system seemed successful. The system does not block the littoral drift like a groin. The treated beach is stabilised and the untreated beach is continuing to be eroded.

A completely different type of measure was taken at El Médano (beach with dunes). In 1995, an experiment has started which aimed at recovering eroded sediments. In this case, it was decided to have small obstacles in a completely bare exposed area. This experiment was carried out by scattering amounts of about 2 m^3 of volcanic gravel around the eastern slope of Bocinegro mountain. The experiment is based on the volcanic gravel's capacity to retain sand, on which plants germinate, beginning the process of soil regeneration and dune formation. The experiment was effective: the retention and accumulation of sand increased, above all on the smaller obstacles.

In Estela, soft protection structures using geotextile sand filled containers have proven to have good potentialities to solve, in a short term, erosion problems. The option for the coastal defence of Estela Golf is soft. A hard solution using rock stones or concrete units does not meet the coastal defence strategy goals for this coastal stretch and is completely out of question. Therefore, 'soft' revetments were placed on the dune slope. The measures were considered to be temporary interventions. The costs of these emergency interventions were low but, regarding the frequency of new needed interventions and the uncertainty of its efficiency in a short to medium-term, it is most likely that it will be necessary to design a solution with better technical approaches. The final outcome of the project in Estela is under study.

4.4.6 Costs

The available information on costs of some coastal protection schemes in the Atlantic Sea is summarized in Table 4-11.

Table 4-11 Overview of total costs for case studies Atlantic Ocean region

	Type of measure	Costs
Châtelaillon	Beach nourishment 330,000 m^3	€ 2,000,000
	Beach nourishment 150,000 m^3	€ 900,000
Medano	Dune regeneration works	€ 120,000
Estela	Sand ripping and sand containers	€ 15,000 / year
Gross-Beach,	Beach regeneration:	
San-Sebastian	Beach nourishment (1.1 M m^3) and large groin (1,100 m)	€11,000,000
Rosslare	Beach regeneration:	
	Beach nourishment and groins	€ 1,935,000
Sables d'Olonne	Beach drainage 700 m	€ 1,000,000 *incl maintenance 10 years*
Sussex	8 Detached breakwaters	€ 8,500,000
	33 Rock breakwaters	€ 5,000,000
Vale do Lobo	Nourishment 700,000 m3	€ 3,200,000

In France the costs are approximately €6/m^3 (330,000 m^3 nourishment) while in Portugal the costs were €4,5/m^3 (700,000 m^3 nourishment).

In Box 4-27 an example is given of the division of costs for a coastal protection scheme between different parties in Ireland. This project is supported by the EU because it is part of the ECOPRO program.

Box 4-27 Rosslare, Ireland: financing coastal protection scheme by different parties

> The total cost of the works at Rosslare Strand amounts to £ 1,351 million (€ 1,935,000) approximately. The EU is providing some £ 385,000 (€ 550,000) towards this total. Irish Rail is contributing £ 220,000 (€ 315,000) in respect to its obligations to provide nourishment at Rosslare Strand. Approximately £ 375,000 (€ 540,000) is being provided by Wexford County Council. The balance, some £ 371,000 (€ 530,000) is being paid for by the Department of the Marine. The additional costs incurred by the Department on the ECOPRO project for tasks such as coastline monitoring, drafting of the sensitivity index and codes of practice and the project management tasks including design and monitoring of works are being absorbed by the Department also.

4.5 Mediterranean Sea

4.5.1 Introduction

This section gives an analysis of the technical measures that were taken to combat erosion in the European Mediterranean Sea countries. The selected sites are located at eroding parts of the Mediterranean Sea coasts and include a number of lagoons (Messologi lagoon area-Greece, Mar Menor-Spain, mouth of the Po at Goro-Italy), cliff coasts (Lu Littaroni La Liccia-Italy, Xemxija Ghajn Tuffieha-Malta, Sitges-Spain) and many sandy beaches and dunes (for example Dolos Kiti-Cyprus), and deltas (Po, Rhone etc).

For the Mediterranean Sea relative sea level rise is only a problem in the low sedimentary coasts. Although in many places hard measures were applied to ensure the safety of urban areas, in other areas soft measures are being applied as well. In many cases technical measures were applied in tourist areas.

Table 4-12 Overview technical measures at the case study areas Mediterranean Sea

	Hard measures				Soft measures			
	SW	RV	GR	DB	BN	SN	VT	CS
Dolos -Kiti		✓	✓	✓	✓			
Rhône delta		✓	✓		✓			
Lakkopetra				✓				
Messologi lagoon area			✓					
Goro Po mouth					✓			
Marina di Ravenna – Lido Adriano			✓	✓	✓			
Marinella di Sarzana			✓	✓	✓			
Vecchia Pineta				✓	✓			
Lu LittaroniLa Liccia								
GiardiniNaxos	✓	✓	✓		✓			
Marina di MassaMarina di Pisa	✓		✓	✓	✓			
Cirqaccio Ciracciello								
XemxijaGhajn Tuffieha						✓		

SW *- Seawall*
RV *- Revetment/ Slope protection*
GR *- Groins*
DB *- Detached breakwaters*
BN *- Beach- and dune nourishment*
SN *- Submerged nourishment*
VT *- Vegetation techniques*
CS- Cliff stabilization

Sitges	✓		✓	✓	✓			
Can Picafort					✓			
Castellón	✓		✓	✓	✓			
Mar Menor		✓			✓			

4.5.2 Hard measures

The main purpose of seawalls in the Mediterranean is protection of the sea front. Seawalls can be combined with a promenade. Promenades are popular with tourists. Seawalls can not protect beaches. See Box 4-28 for two examples.

Box 4-28 Examples of seawalls in the Mediterranean

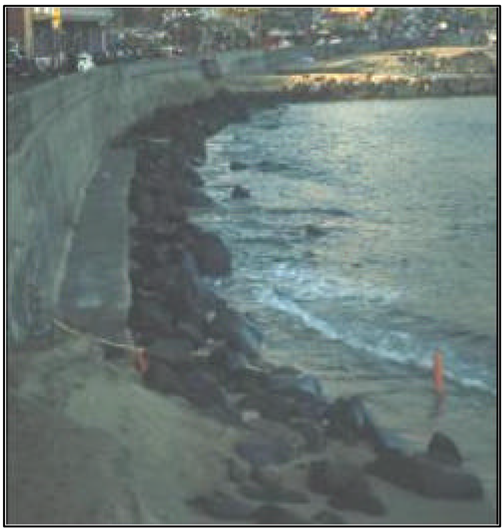
Castellón
Sudden variation in sea level is an important phenomenon on the Castellón coast because, in the pre-littoral area of the 'La Plana' region, there are large areas close to sea level. This is because they were formed from coastal bars and filled-in former marshes. Any variation in sea level can therefore have an effect on the future development of the coast and if any variation in sea level coincides with a big storm, the risk of the sea invading the low-lying coastal areas behind the beach is increased. This variations of extraordinary level can be produced by tides, very low atmospheric pressure (e.g. storms) or the effect of intense winds and waves. This is why a longitudinal **seawall** was built on Serrallo beach, just beside the Port of Castellón, in order to protect the seafront from erosion and to prevent lowlands from flooding.

Sitges
The town of Sitges is located in the Mediterranean coast, 40km south of Barcelona (Spain). It has a coastal area 18.84 km long, which is made of cliffs and sandy pocket beaches. The urban area extends in front of a large sandy beach, which is highly compartmentalised. The driving forces that cause erosion on the coast are mainly the lack of sediment transport by southward longshore drift current and easterly storms. Sitges' economy depends enormously on tourism, so the loss of beach is the main worry for all the stakeholders involved. To tackle erosion, the policy adopted by the Spanish government is to hold the line. The protection measures performed to develop this policy option were mainly of the hard type: groynes, detached breakwaters, T-shaped breakwaters, artificial islands and **seawalls**. Since a few years ago, the coastal policy chosen is to use soft measures, like beach nourishments, as much as possible.

A Seawall can be combined with revetments that protect the wall from severe wave attack. Beaches can not be protected with revetments, revetments only protect the sea front development. See Box 4-29 for an example.

Box 4-29 Example of revetments in the Mediterranean Sea (Giardini-Naxos; Italy)

The bay of Giardini is situated in the northern sector of the Ionian coast of Sicily. The study area stretches for about 5km, from Capo Taormina in the north of the bay to Capo Schisò in the south. There is evidence of the most violent erosion in the central sector, while the eroded material is transported towards the south, with a result that a large quantity of sediment is deposited in Schisò harbour. All along the northern sector of this first area, a narrowing of the beach by about 5m per year was recorded between 1967 and 1972. The erosion of the coastline is due to the construction of the pier at the port of Schisò. In the northern sector, it is caused by the increase in urbanisation, the building of a promenade and the erection of rigid protection structures. The erosive process is also favoured by a general reduction in transported solid load, due to river damming, destruction of the dune barriers and removal of inert material from riverbeds and sandy shores. The policy adopted is to *hold the line*. In some areas the policy is the removal of the causes of deterioration and erosion. Erosion is a threat for the urbanised area. Currently, along the promenade, a long sequence of hotels and private buildings are threatened.



From an observation of the evolution of some rigid constructions, it has been observed that these have often transferred the erosive effects of waves and currents downdrift. Some rigid structures have favoured the formation of protected areas of coast, which have been exploited as natural seasonal harbours for small boats.

*Photo sources: Report on Giardini-Naxos (Sicily, Italy). See appendix.

For erosion problems caused by a net longshore transport, groins can be effective. In many cases the problems were only shifted downdrift, but in case of the Messologi lagoon area (See Box 4-30) the solution did not seem to produce negative side effects.

Box 4-30 examples of groins in the Mediterranean Sea (Messalogi Lagoon; Greece)

The Messologi lagoon area is located in the western part of the central continental Greece, in the region of Aitoloakarnania. The lagoon area comprises an area of 140 m^2, and is protected by the RAMSAR convention and the EUR-79/409 EC Directive. The coastal front is currently under a severe process of erosion, mainly due to the recent construction of three dams on the River Aheloos. Wave action is the main driving force in the coastal strip, so it was decided to protect the coastal islets with a series of groynes (hard structures). These groynes were built situated every 40 meters, perpendicular to the coastline. The length of the groynes was decided to be 20m.

The construction of the groynes has proved to be the most appropriate countermeasure for the erosion problems. Sediment was trapped between them, being available for wave dissipation, and the water currents were modified by the presence of structures. These processes resulted in the elimination of the erosion problems and the creation of small pocket beaches between the groynes.

Marina di Massa – Marina di Pisa

The hard measures in the eroding area, groins and other structures, did not result in beach stabilization. Erosion still occurred further downstream and at the location of hard measures beach nourishments are still needed

*Photo source: Report on Messologi lagoon area (Greece). See appendix.

Detached breakwaters can work well in the Mediterranean because of the microtidal environment. A succesfull example is shown in Box 4-31.

Box 4-31 example of detached breakwaters in the Mediterranean Sea (Lakkopetra; Greece)

The result of constructing these detached breakwaters is very positive. Beach width has increased. No monitoring is being carried out, so possible negative effects as erosion elsewhere cannot be concluded .(yet).

4.5.3 Soft measures

Box 4-32 Examples of beach and dune nourishments in the Mediterranean Sea

Giardini Naxos

The bay of Giardini is situated in the northern sector of the Ionian coast of Sicily. The study area stretches for about 5 km, from Capo Taormina in the north of the bay to Capo Schisò in the south.

The exceptional characteristics of the site, render necessary the choice of a plan which is able to solve the problem of coastal defence while at the same time allowing the structure itself to fit easily into the natural environment and landscape. This would eliminate the degraded appearance offered by the hard protective structures as transversal groins and sub-parallel reefs.

The imported sand for the beach nourishment will be extracted from the sea-bed of the Bay of Giardini-Naxos at a depth of -5 - -10m. From an environmental point of view this is also a good choice, due to this is the material resulting from the erosion of the central area of the same bay and therefore has granulometric characteristics similar to the pre-exisisting ones.

Mallorca

"…An important fact is that between 1988 and 1997 three sand nourishment (1988, 1997, 1999) carried out by the government were done in Can Picafort area do to the gradual retreat of the beach. It is not possible to determine the sand volume injected in the area, but could attain 150000 m^3. For that reason if none nourishment has been done in the area we should expect an important retreat at the central sector and an accretion at the northern one related to the longshore transport…"

"…Artificial beach regeneration has also a bad effect on the *Posidonia oceanica* prairie, as the new injected sand strangles the plants. A recent study has corroborated that in some areas the Posidonia oceanica is hav ing a general retreat and that most of the prairies are covered with coarse sand coming from beach nourishment (Centre Balear de Biologia Aplicada & Pandion, 2002)…"

Submerged nourishments

Submerged nourishments are not found in the Mediterranean Sea. This could well be because of the indirect result of the measure. Nourishment carried out on the beach or in the dunes have a direct result: beach width increase or dune reinforcement. Often beach width is important in coastal towns.

Sand bags/ geotextile

Sand bags/ geotextile are used for various purposes. They can be used for constructing groynes and submerged breakwaters(e.g. marina di massa) or for fixing the basis of a regenerated dune (e.g. Estela). Mainly used on beaches.

Box 4-33 Geotextile sand bags in Marina di Massa (Toscana, ITALY)

The area located south of the last hard defence structure in Marina di Massa (Marina di Ronchi) had a mean shoreline retreat rate of approximately 4m/yr (1985-1999). During the last three years some experimental coastal defence techniques have been tried. Three experimental submerged groynes made of sand bags and geotextile were built. The groynes run from the body of the backshore to the –3m isobath, so they are completely covered by sand and water. The groynes are made of polypropylene bags of 3x1.8 m size, containing a volume of approx. 1.5 m^3 of sand with a mean weight of 3.7 tonnes. The sand bag weight should guarantee its stability during extreme storm events.

The medium-term beach response shows that, since the whole system has been completed, a sediment surplus has occurred, although inshore erosion is still active. A study of the downdrift beach shows no changes from the original stability conditions have occurred. However, local expansion of 10m has been experienced since 1999.

*Source : Report on Marina di Massa (Italy). See appendix.

4.5.4 Combined measures

In some areas both hard and soft measures have been applied. However, this cannot be seen as combined measures because they were not designed to be combined. Success and fail factors of hard and soft measures apply. One example of application of a mixture of hard and soft measures is the town of Sitges, which is located on the Mediterranean coast, 40km south of Barcelona. The beach and bottom sediments are sands of siliciclastic origin, light gold in colour and with a fine to medium grain size. The driving forces causing erosion on the coast are mainly the lack of sediment transport by the southwestward longshore drift and easterly storms, combined with the effect of numerous groynes and breakwaters, and marina harbours, which retain sediments on their leeside. The major impact of the erosion is loss of beach surface.

The economy of Sitges is enormously dependent on tourism (basically summer tourism), so the loss of beach is the main worry for all the stakeholders involved. Quarries and marinas are other economic sectors in the municipality. To tackle erosion, the policy adopted by the government is to hold the line. The measures adopted are both *hard measures*, such as groynes, detached breakwaters, T-shaped breakwaters, artificial islands and seawalls, and *soft measures* (beach nourishment). The numerous groynes retain the sediments that circulate in a NE-SW long shore drift, but prevent the feeding of the southwestern beaches, which are the most affected by erosion, and worsening the problem. The marina harbours to the north divert offshore an enormous part of the sediment load carried by longshore drift. As well as the effect on coastal dynamics, the groynes cause a great landscaping impact. Dredging operations for beach nourishment have also damaged the seaweed communities.

4.5.5 Innovative measures

Pro-active approaches and soft measures can be pointed as innovative in the Mediterranean because they haven't been applied much. Many hard measures as groins did not have the expected result. It seems that a lot can be achieved by raising the awareness that combating coastal erosion is an ongoing process. A lot needs to be found out about sustainable solutions. Dune regeneration and protection of 'sediment factories' as posidonia oceanica are the most innovative measures found.

In the last ten years, four "drainage systems" have been implemented in the Mediterranean Region:

- Two in the Ebro Delta area
- Lido di Ostia (Italia)
- Saint Raphaël (France)

4.5.6 Costs

A summary of the costs found in the case studies is presented in Table 4-13.

Table 4-13 Types of measures and related costs in the Baltic sea

Mediterranean Sea	Type of measure	Costs
Dolos-Kiti (Cyprus)	-	-
Rhone delta (France)	Dune building (ganivelles, moving 55,200 m^3 of sand)	1,000,000 €
	Breakwaters, groins, dams, dykes	121.600.000 €
Lakkopetra (Greece)	3 breakwaters	350,000 €.
Mesollogi lagoon area (Greece)	No information	No information
Cirqaccio-Ciracciello (Italy)	No information	No information
Giardini-Naxos (Italy)	No information	No information
Goro mouth-Po delta (Italy)	No information	No information
Lu Littaroni-La Liccia (Italy)	No information	No information
Marina di Massa-Marina di Pisa (Italy)	- Maintenance of existing structures (1995-2001)	2,071,800€
	- Beach nourishment(1995-2001)	3,880,000€
	- Submerged groins in polyprophylene bags with sand (1995-2001)	973,500€
Marina di Ravenna-Lido Adriano (Italy)	Coastal protection works:	Total : 8,620,000 € (1999-2003)
	- Submerged breakwater, groin, beach nourishment (125.000 m^3	5,790,000 € (1999)
	- Prolongation submerged groins + breakwater construction.	890,000 € (2000)
	- Beach nourishment 25.000 m^3 of sand.	380,000 € (2001)
	- Maintenance nourishment 57,000 m^3 of sand.	830,000 € (2002)
Marinella di Sarzana (Italy)	4 Groins construction	250,000 € (1999)
	Beach nourishment (17.000 m^3)	240,000 € (1999)
Vecchia Pineta (Italy)	No information	No information
Xemxija -Ghajn Tuffieha (Malta)	No information	No information
Slovenian coast (Slovenia)	No information	No information

Can Picafort (Spain)	Nourishment for the whole Mallorca island after 2001 storms	1,200,000 € (2001)
Castellón (Spain)	Rockfill semi-submerged defence and groin construction	1,201,303 € (1999)
	Beach Nourishment (8 tones rockfill + 100,000 m^3 sand)	742,657 € (2002)
	Groin construction	721,214 € (2002)
Ebro delta (Spain)	Soft measures	8,530.000 (1990-2002)
Mar Menor (Spain)	-	-
Sitges (Spain)	Beach nourishment (50,000 m^3)	480,000 € (2002)

4.6 Black Sea

4.6.1 Introduction

An overview of the technical measures for coastal protection in Bulgaria and Roemenia is presented, with emphasis on the three case studies (Shabla-Krapetz, Danube delta and Mamaia beach). The accent is on hard measures, simply because the number of soft measures on the western coast of the Black Sea have been limited. The technical measures aim to protect urban areas and tourist areas.

4.6.2 Hard measures

In the Black Sea area the problems with sea walls are the same as in the Mediterranean.

Box 4-34 Coastal protection by seawall in the Shabla municipality (Bulgaria)

The area of the Shabla community covers the northern Bulgarian coastal municipality on the Black Sea. It is a low plateau, slightly elevated and inclined towards the sea. From the Romanian border (Cape Sivribouron) to Cape Shabla there is a relatively low coast with cliff segments formed in loess sediments and huge strips of beach. From Cape Shabla to Tyulenovo village, the coast is made up of cliffs of increasing height from 5-6m up to 100m. The beaches in the area are predominantly plain or with dune systems. The erosion factors affecting this coastal strip are mainly natural driving forces, like winds, waves and storms. The abrasive impact of rough seas activates landslide processes in the dusty and sandy loess cliffs, with a landslide indent moving landward at rates of 0.3 to 2 m/yr.

In order to stop the loss of more fertile land together with valuable coastal areas protected by environmental legislation and the because of the threat to the old lighthouse facilities and buildings around it, the municipality ordered a protection plan for the coast using hard measures with some managed realignment operations. The hard structures built consist of rocky embankments, jetties and seawalls made of concrete packages. The existing walls have had the expected results: the erosion stopped, the facilities near the shore are safe and the landslides have also stopped.

*Photo source: Report on Shabla-Krapetz (Bulgaria). See appendix.

Revetment and slope protection

Revetment or slope protection have not been applied in the examples from the western Black Sea.

Detached breakwaters

Detached breakwaters have been applied on Mamaia beach (Romania)

Box 4-35 Detached breakwater at Mamaia beach (Romania)

Mamaia beach is located in the southeastern extremity of Romania, near the city of Constanta, on a narrow sand bar of 250-350m wide between the Black Sea and Siutghiol Lake. Mamaia is the largest tourist seaside resort in Romania, stretching 8km from north to south. Mamaia is acting as a beach cell due to its position between Cape Midia in the north and Cape Singol in the south. The natural driving forces (wind, waves and storms) combined with human impact on the coast (Sulina jetties in the north, Midia harbour dykes, hydro-technical work in the Danube tributaries,…) increased the erosion on the beach. The effects of waves and currents during severe storms damaged the beach tourist facilities. In addition to these factors, rising sea level has made its own contribution to the erosion process, mainly in the winter.

In the last three decades, almost the entire southern coast has been affected by erosion, requiring urgent implementation of coastal protection measures. That is why the problem was taken into account in 1975, when the stability of the Parc Hotel was endangered. After some unsuccessful measures, in 1988 6 detached breakwaters were built in front of Mamaia beach, at a depth of 5m. The main role of these structures is to dissipate wave energy and to reduce its action on the beach. In addition, artificial beach nourishment was carried out. The effects of the breakwaters are moderately positive. The southern part of Mamaia beach is protected from erosion, but the unprotected areas north and south of these structures are still in worsening erosion processes.

*Photo sources: Report on Mamaia (Romania).

4.6.3 Soft measures

Soft measures have hardly been applied on the shores of the western Black Sea. The one example comes from Romania on Mamaia beach.

4.6.4 Combined measures

The nourishment of Mamaia beach in Romania was conducted after the construction of the detached breakwaters, however, this was not intended as a combined measure. The success and fail factors of the original hard and soft measures apply.

4.6.5 Costs

The information about the costs for coastal protection is only partially available for the Shabla-Krapetz site . In the "1999 – 2003" period 600 million euro's are invested. Nearly all measures were fortifications in favour of a village.

Table 4-14 Types of measures and related costs in the Baltic sea

BLACK SEA	Type of measure	Costs
Shabla-Krapetz (Bulgaria)	National Investment Program for Landslide Coastal Fortification	603,200,000 € (1999-2003)
Danube delta (Romania)	-	-
Mamaia (Romania)	-	-

ANNEX 1 - OVERVIEW OF COMMONLY USED MODELS OF COASTAL PROCESSES THROUGHOUT EUROPE

TITLE	DESCRIPTION	LIMITS OF APPLICATION
MATHEMATICAL MODELS		
CERC equation (1950)	The CERC equation helps to predict the volume of sediment transported alongshore as a function of the wave height (in the break zone), period and obliquity. Improved versions of the CERC equation – Davies and Kamphuis (1985), Sayao, Nairn and Kamphuis (1985) – include grain size and beach slope in the model.	Applicable only in those cases where sediment transport is principally induced by waves approaching at oblique angle and have the same properties at all points along the coast. Not applicable when other driving forces (e.g. tidal currents) become significant. Not applicable either to shoals, dumping grounds or near dredged channels.
Bijker transport formula (Bijker, 1971)	The Bijker formula estimates sediment transport by modelling a “bed load transport” (Sb) and a “suspended load transport” (Ss). Those are a function of the deep water wave height, period and approach angle, current velocity, grain size and density, particle fall velocity, and bottom roughness.	Bijker formula is suitable for a wider range of applications than the CERC formula, in particular in estuaries where currents become dominant. However, it requires more field measurements.
DUROS (Veilinga, 1986)	DUROS model (=DUne eROSion) helps predict the response of a dune profile to a severe storm surge. The “storm profile” is a function of the significant wave height (deep water), the maximum surge level, the grain size, and the initial profile.	DUROS model is suitable to provide a quick assessment of whether the existing dunes are “safe” or not. For complex coastal areas including semi-enclosed bays or complex shoreline geometry, the model present limitations.
Bruun rule (1962)	The Bruun rule estimates the response of the shoreline profile to sea level rise. This simple model states that the beach profile is a parabolic function whose parameters are entirely determined by the mean water level and the sand grain size. Bakker (1968) and Swart (1976) have adapted the Bruun rule to predicts the cross-shore sediment transport.	Only applicable for small scale local sites. Over long stretches of coast, the Bruun rule and associated cross-shore transport models become complex.
Wind stress formula (Wu, 1980)	Developed by Wu (1980), the model quantifies the transfer of energy from the wind blowing over the ocean to the water surface (wind stress or wind shear), which results in an elevation of the sea level (wind set-up). The formula may be adapted to estimate the surge level.	This interaction between wind and sea surface is not well understood and the formula undeniably stands for the best approximation known. The formula depends however on empirical coefficients (e.g. “drag coefficient”) which may be un-adapted for specific situations
Wave overtopping model (Owen, 1980)	Wave overtopping is defined as the quantity of water passing over the crest of a sloping structure per unit of time. Owen's semi-empirical assumes that wave overtopping is a function of the significant wave height and mean wave period, the crest freeboard (i.e. the crest height above the still water level), the coastal structure slope, and the deep water depth. The model was primarily developed for impermeable structures, with gradient ranging from 1:1 to 1:5. However, the model incorporates a roughness coefficient that is based upon the relative run-up performance of alternative construction materials. This roughness coefficient enables the method to be adapted for permeable sea defences such as shingle beaches, storm-induced dune profiles and rock armoured slopes	The model requires the empirical determination of coefficient related to the slope. The formula does not work in the case of vertical seawalls, for which other formulas developed by Goda (1980) can be used.
COMPUTATIONAL MODELS		
MIKE 21 NSW	MIKE 21 NSW is a spectral wind-wave model, which describes the propagation, growth and decay of short-period waves (between 0.21s and 21s) in nearshore areas. The model includes the effects of refraction and shoaling due to varying depth, wave generation due to wind and energy dissipation due to bottom friction and wave breaking. The effects of current on these phenomena are included. The model is derived from the approach proposed by Holthuijsen et al. (1989). The following basic input data are required in MIKE 21 NSW: · bathymetric data · stationary wind field (optional) · stationary current field (optional) · bed friction coefficient map (optional) · wave breaking parameters (optional) · offshore wave boundary conditions	Is adapted for coastal areas where diffraction and reflection are negligible, and for the simulation of short period waves.
MIKE 21 BW	MIKE 21 Boussinesq Wave (BW) module is mainly used to study wave dynamics (significant wave height, wave disturbance coefficient, water surface elevation and the depth-averaged particle velocity) in ports and harbours and in small coastal areas. The model is capable of reproducing the combined effects of most wave phenomena of interest in coastal and harbour engineering, including shoaling, refraction, diffraction and partial reflection of irregular short-crested and long-crested finite-amplitude waves propagating over complex bathymetries, and phenomena such as wave grouping, generation of bound sub-harmonics and super-harmonics and near-resonant triad interactions.	The model has been primarily designed for coastal harbours but can also be applied for small and complex coastal embayments. Does not work on open coasts.
MIKE 21 EMS	The Elliptic Mild-Slope (EMS) Wave Module, MIKE 21 EMS, simulates the propagation of linear time harmonic water waves on a gently sloping bathymetry with arbitrary water depth. MIKE 21 EMS is based on the numerical solution of the Elliptic Mild-Slope equation formulated by Berkhoff in 1972 and is capable of reproducing the combined effects of shoaling, refraction, diffraction and back-scattering. Energy dissipation, due to wave breaking and bed friction, is included as well as partial reflection and transmission through for instance pier structures and breakwaters. Sponge layers are applied where full	Restricted to coastal areas with a gently sloping bathymetry. Is not adapted to other cases.

TITLE	DESCRIPTION	LIMITS OF APPLICATION
	absorption of wave energy is required. In addition, the model includes a general formulation of radiation stresses, based on Copeland (1985) which is valid in crossing wave trains and in areas of strong diffraction.	
MIKE 21 PMS	MIKE 21 PMS is based on a parabolic approximation to the elliptic mild-slope equation governing the refraction, shoaling, diffraction and reflection of linear water waves propagating on gently sloping bathymetry. The parabolic approximation is obtained by assuming a principal wave direction (x-direction), neglecting diffraction along this direction and neglecting backscatter. In addition, improvements to the resulting equation, cf Kirby (1986), allow the use of the parabolic approximation for waves propagating at large angles to the assumed principal direction. Furthermore, MIKE 21 PMS can produce the wave radiation stresses required for the simulation of wave-induced currents, which is very important in the computation of coastal sediment transport.	Adapted to open coastal areas with a gently sloping bathymetry and where reflection and diffraction are negligible along the principle wave direction (x-direction), i.e. in the cases of small breakwaters and groin fields, and navigation channel.
MIKE 21 ST	MIKE 21 Sediment Transport (ST) is designed for the assessment of the sediment transport rates and related initial rates of bed level changes of non-cohesive sediment (sand) due to currents or combined wave-current flow. The model provides and compares results coming from different transport theories including Engelund-Hansen, Engelund-Hansen, Zyserman-Fredsøe, Meyer-Peter and Müller, Ackers-White, and Bijker:	Is only adapted for non cohesive sediment (e.g. sand) for which it provides good results.
MIKE 21 MT	MIKE 21 Mud Transport describes the erosion, transport and deposition of mud and sand/mud mixtures under the action of currents and waves. The model is essentially based on the principles in Mehta et al (1989) with the introduction of the bed shear stresses due to waves, a stochastic model for flow and sediment interaction first developed by Krone (1962), and a non-cohesive sediment transport based on Van Rijn (1984).	MIKE 21 MT can be applied to the study of engineering applications, eg • sediment transport studies for fine, cohesive materials or sand/mud mixtures in estuaries and coastal areas, in which environmental aspects are involved and degradation of water quality may occur • siltation in harbours, navigational fairways, canals, rivers, reservoirs • dredging studies
MIKE 21 HD	MIKE 21 Hydrodynamic (HD) simulates the water level variations and flows in response to a variety of forcing functions in lakes, estuaries, bays and coastal areas. The water levels and flows are resolved on a rectangular grid covering the area of interest. MIKE 21 HD includes formulations for the effects of • convective and cross momentum • bottom shear stress • wind shear stress at the surface • barometric pressure gradients • Coriolis forces • momentum dispersion (through eg the Smagorinsky formulation) • wave-induced currents • sources and sinks (mass and momentum) • evaporation • flooding and drying	MIKE 21 HD is applicable to a wide range of hydraulic and related phenomena. This includes modelling of tidal hydraulics, wind and wave generated currents, storm surges and flood waves. It requires however a wide range of input data and significant resources.
Simulating WAve Nearshore (SWAN)	The SWAN (Simulating Waves Nearshore) model is a spectral wave model developed at the Delft University of Technology, The Netherlands. SWAN models the energy contained in waves as they travel over the ocean surface towards the shore. In the model, waves change height, shape and direction as a result of wind, white capping, wave breaking, energy transfer between waves, and variations in the ocean floor and currents. Initial wave conditions, including wave height, wave direction and wave period (time it takes for one wavelength to pass a fixed point), are entered into the model, and the model computes changes to the input parameters as the waves move toward shore. Model results are computed on a 500-m by 500-m grid for the area of research. Model output information (wave height, wave direction, and wave velocity) is produced for each cell in the model grid, and can be displayed in a map view to simplify visualization of changes in waves over the study area.	SWAN is among the best model of wave transformation in the near-shore. But it has to be combined with other models to derive sediment transport or anticipate morphological changes
STWAVE	STWAVE (STeady State spectral WAVE) is a model developed by the US Army's Corps of Engineers for nearshore wind-wave growth and propagation. STWAVE simulates depth-induced wave refraction and shoaling, current-induced refraction and shoaling, depth- and steepness-induced wave breaking, diffraction, parametric wave growth because of wind input, and wave-wave interaction and white capping that redistribute and dissipate energy in a growing wave field.	Model Assumptions for STWAVE are: (i) Mild bottom slope and negligible wave reflection, (ii) spatially homogeneous offshore wave conditions, (iii) Steady-state waves, currents, and winds, (iv) Linear refraction and shoaling, (v) Depth-uniform current, (vi) Bottom friction is neglected.
SBEACH	SBEACH (Storm-induced BEAch CHange Model) is a model developed by the US Army's Corps of Engineers to simulate cross-shore beach, berm, and dune erosion produced by storm waves and water levels. The latest version allows simulation of dune erosion in the presence of a hard bottom	
UNIBEST-DE	UNIBEST-DE is the module of the UNIBEST Coastal Software Package to compute the cross-shore profile developments during storm conditions of a coast consisting of loose material. In addition to large wave attack, these conditions are characterised by a considerable rise of the mean water level (storm surge). The intense breaking of waves generates high turbulence levels causing large amounts of sediment to suspend. Accordingly the transport of this suspended sediment is the predominant transport mechanism under such conditions. The model is verified with large scale data from physical models and field data. The model represents the cross-shore transports in a one-dimensional (cross-shore) grid with variable mesh size.	The capabilities of the models are relevant for applications such as: • Dune erosion and beach profile change under extreme conditions. • Design of beach nourishments. • Design of dune revetments.

TITLE	DESCRIPTION	LIMITS OF APPLICATION
	The model requires pre-defined time series of waves and water levels and comes with options to automate a large number of simulations. Model results are in ASCII output files which can be inspected graphically as time histories or distributions along the bottom profile.	
UNIBEST TC	UNIBEST-TC is the cross-shore sediment transport module of the UNIBEST Coastal Software Package. It is designed to compute cross-shore sediment transports and the resulting profile changes along any coastal profile of arbitrary shape under the combined action of waves, longshore tidal currents and wind. The model allows for constant, periodic and time series of hydrodynamic boundary conditions to be prescribed. UNIBEST-TC takes the principal cross-shore processes such as wave asymmetry, undertow, gravity and mass-flux below wave troughs into account. The model provides the following processes: • Wave propagation and wave decay due to bottom friction and wave breaking • Asymmetric oscillatory flow • Effects of long waves and wave grouping • Wave induced undertow • Sediment transport according to Van Rijn et al. (1995) • Wind-driven currents • Inclusion of surface roller contribution in the momentum balance • Inclusion of breaker delay in wave energy decay model	The model requires a significant amount of input data and computational resources.
UNIBEST CL+	UNIBEST-CL+ is a sediment balance model (part of the UNIBEST package of models) with which longshore transports computed at specific locations along the coast can be translated into shoreline migration. typical application is the analysis of the large scale morphology of coastal systems to provide insight in the causes of coastal erosion or to predict the impact of planned coastal infrastructure (such as a port) on the coast. But the model can also be used for considerations on a smaller scale, like the evaluation of the shoreline evolution around coastal protection works (groynes, revetments, river mouth training works and to some extent detached breakwaters). Sediment sources and sinks can be defined at any location to simulate river sediment supplies, the effect of land subsidence or sea level rise, offshore sediment loss, artificial sand bypass and beach mining. These features make it a suitable tool for the functional design of coastal defence schemes and the prediction of their impact on the coast, in the feasibility stage and in many cases also in the detailed design stage of projects. Technical features of the model include: • Curvilinear grid (thus adaptable to different types of coast including straight coasts, deltas, bays. • Computation of wave-propagation and wave-induced longshore current included. • Longshore transport and its distribution along the coastal profile can be evaluated according to several total-load sediment transport formulae for sand (such as Bijker, van Rijn) or gravel (Van der Meer & Pilarczyk). • Time-dependent response of the longshore transport on changes of the coast-orientation with time. • Input up to hundreds of combinations of wave- and tidal conditions. • Different shapes of the coastal profiles can be defined along the coast and seasonal variations in the wave climate can be simulated.	
GENESIS	GENESIS (GENEralized Model for SImulating Shoreline Change) is a model developed by the US Army's Corps of Engineers. It is a system of models for calculating shoreline change caused primarily by wave action. The system is based on the one-line theory, whereby it is assumed the beach profile remains unchanged permitting beach change to be described uniquely in terms of the shoreline position. The model can be applied to a diverse variety of situations involving almost arbitrary numbers, locations, and combinations of groins, jetties, detached breakwaters, seawalls, and beach fills. Other features included in the system are wave shoaling, refraction, and diffraction; sand passing through and around groins, and sources and sinks of sand.	
ESTMORF	ESTMORF is a one-dimensional model of estuarine morphology, which includes three-dimensional effects, developed by RIKZ. In nature, the main channel transports the water flow and the flats serve as storage areas. The ESTMORF schematisation distinguishes three parts of a cross-section: main channel, low flat en high flat. In ESTMORF, sediment is transported through the estuary via the main channels, whereas sediment exchange occurs on the flats. The flats store sediment or supply sediment to the channel. ESTMORF computations are based on a combination of empirical and physical laws. The morphological equilibrium is determined from empirical laws. It is known from observations in many estuaries around the world, that there are relationships between the size of a channel and the volume of water it transports. Similarly, there are relationships between the size of the flats and the tidal range. Thus, the equilibrium geometry of the channels and the flats can be related to the tidal flow. The equilibrium concentration and the actual concentration field (due to natural development and/or human interference) are based on physical laws. The sediment concentration field is determined from a transport equation, which includes physical properties of the sediment and the residual flow field in the estuary. Sedimentation and erosion is determined from the deviation of the actual concentration and equilibrium concentration.	Initially developed for the Western Scheldt estuary. The model may be applied to other tidal basins. It is not adapted for other types of coasts.

ANNEX 2 - OVERVIEW OF COASTAL EROSION MANAGEMENT TECHNIQUES

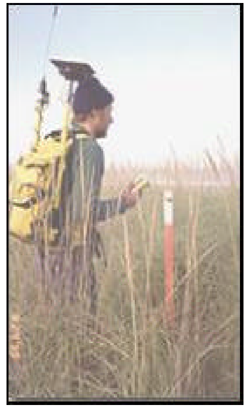
TECHNIQUES	*PRINCIPLES*	*LIMITS OF APPLICATION*
HARD TECHNIQUES		
Breakwater	Breakwaters are protective structures placed offshore, generally in hard materials such as concrete or rocks, which aim at absorbing the wave energy before the waves reach the shore.	Breakwaters reflect or diffract wave energy in destructive ways or concentrate it in local hot spots. Erosion problems and the scouring effects of the misdirected energy lead to the loss of beach / coastline and undermine the structures that were meant to be protected.
Gabion	The gabion is a metal cage filled with rocks, about 1 metre by 1 metre square. Gabions are stacked to form a simple wall.	They are used to protect a cliff or area in the short term only, since they are easily damaged by powerful storm waves and the cages tend to rust quite quickly. Gabions have the advantage of ease of use and are relatively cheap but their life span is short.
Geotextiles	Geotextiles are permeable fabrics which are able to hold back materials while water flows through. Geosynthetic tubes are large tubes consisting of a woven geotextile material filled with a slurry-mix. The mix usually consists of dredged material (eg. sand) from the nearby area but can also be a mortar or concrete mix.	Geotextiles are relatively recent but provided good results to prevent beach from retreating. Plus they are very flexible and can be re-arranged if their configuration does not provide good results.
Groin fields	Groins are structures that extend perpendicularly from the shore. Usually constructed in groups called groin fields, their purpose is to trap and retain sand, nourishing the beach compartments between them. Groins may be made of wooden or rocky materials. They interrupt the longshore transport of littoral drift. When a well designed groin field fills to capacity with sand, longshore transport continues at about the same rate as before the groins were built, and a stable beach is maintained.	Sand accumulated between groins contributes to a sediment deficit down-drift. Coastal erosion problems are then shifted to other locations. Thus, to be effective, groins should be limited to those cases where longshore transport is predominantly in one direction, and where their action will not cause unacceptable erosion of the downdrift shore.
Revetments	Revetment is a sloping feature which breaks up or absorbs the energy of the waves but may let water and sediment pass through. The older wooden revetment consists of posts fixed into the beach with wooden slats between. Modern revetments have concrete or shaped blocks of stone laid on top of a layer of finer material. Rock armour or riprap consists of layers of very hard rock with the largest, often weighing several tonnes, on the top. Riprap has the advantage of good permeability and looks more natural.	Revetments are adapted to foreshore with a gentle slope. It has the same adverse effect as seawalls though with a reduced intensity. It also results in changing the nature of the sea frontage which may lead to further changes in the foreshore ecosystems.
Seawall	Bulkheads and seawalls protect banks and bluffs by completely separating land from water. Bulkheads act as retaining walls, keeping the earth or sand behind them from crumbling or slumping. Seawalls are primarily used to resist wave action. Design considerations for these types of structures are similar. These structures do not protect the shore in front of them, however.	When bulkheads and seawalls are used in areas where there is significant wave action, they may accelerate beach erosion (much of the energy of the waves breaking on the structure is redirected downward to the toe). Bulkheads and seawalls are most appropriate where fishing and boating are the primary uses of the shore, and gently sloping areas for sunbathing or shallow-water swimming are not essential. They are also critical when risks associated to coastal erosion are imminent.
SOFT TECHNIQUES		
Artificial reef creation	Building an artificial reef which absorbs the wave energy (thus providing coastal defence), while providing a natural habitat for marine biodiversity and opportunities for recreational activities	Only few examples of artificial reef creation exist in Europe (in Sea Palling, UK mainly), but seems to provide good results.
Beach drainage	Beach drainage decreases the volume of surface water during backwash by allowing water to percolate into the beach, thus reducing the seaward movement of sediment. Beach drainage also leads to drier and "gold" coloured sand, more appreciated for recreational activities.	The technique is relatively new and experience lacks to assess its performance. It has to be noted however that beach drainage is adapted when erosion mainly occurs cross-shore (non significant long-shore drift)
Sand supply or nourishment	Artificial increase of sand volumes in the foreshore via the supply of exogenous sand. Sand supply may be achieved through the direct placement of sediment on the beach, through trickle charging (placing sediments at a single point), or through pumping. It can be also take	Beach and underwater nourishment as been very popular in the North because of the availability of sediments which has similar properties as the beach sediment. When sediment is not available and has to be imported from another region, beach

TECHNIQUES	PRINCIPLES	LIMITS OF APPLICATIO N
	place in the emerged part of the foreshore ("beach nourishment") or under the water line ("underwater nourishment") which is generally cheaper.	nourishment may not be the best decision. Nourishment schemes have also to be carefully designed as they may alter the biota (both on the beach and in the dredging area).
Beach scraping	Artificial re-profiling of the beach when sediment losses are not severe enough to warrant the importation of large volumes of sediments. Re-profiling is achieved using existing beach sediment	Beach scraping is among the cheapest techniques as it does not require importing sand. However, the process may have to be carried out several times before the right profile is found. It is also restricted to those beaches where cross-shore erosion is dominant and storms not heavy.
Cliff drainage	Reduction of pore pressure by piping water out of the cliff and therefore preventing accumulation of water at rock boundaries	May not be applicable for all types of cliffs.
Cliff profiling	Change of cliff face angle to increase cliff stability. The angle at which cliff become stable is a function of rock type, geologic structure and water content.	May not be applicable for all types of cliffs, and the techniques requires a fairly good knowledge of the cliff geologic structure and watering process.
Cliff toe protection	Protection of the cliff base by placing blocks at the foot of potential failure surface.	This technique is easy to achieved but do not stop erosion completely. It may therefore be adapted in those case where further loss of lands is still acceptable
Creation of stable bays	Increasing the length of the coastline to dilute wave energy per unit length of coast. While some coastline segments are protected, erosion continues between these hard points leading to the formation of embayments	This technique is almost not used in Europe and is still experimental. However, it has been envisaged for a number of sites (especially the Holland coast)
Dune regeneration	Wind blown accumulation of drifted sand located in the supra-tidal zone. Wind velocity is reduced by way of porous fences made of wood, geo-textile, plants, which encourages sand deposition	Adapted for those cases where wind plays an important role
Marsh creation	Planting of mudflats with pioneer marsh species, such as *Spartina sp*. Marsh vegetation increases the stability of sediment due to the binding effects of the roots, increasing shear strength and decreasing erodability. Marshes also provides cost-effective protection against flooding by absorbing wave energy.	Marsh creation is particularly popular in United Kingdom. However, the technique may be jeopardized by accelerated sea level rise. In this case, the accumulation of fine sediments necessary to the marsh creation may not occur in the proper way and the marsh finally collapse.
Mudflat recharge	Supply of existing mudflats with cohesive sediments. This is achieved via trickle charging (see beach feeding), rainbow charging, and polders	Such as marsh creation, mudflat recharge may be jeopardized by accelerated sea level rise.
Rock pinning	Prevention of slippage in seawards dipping rocks by bolting layers together to increase cohesion and stability. Does not prevent wave attack at the cliff base, but does reduce the threat of mass movement and thus reduces net erosion rates.	May not be applicable for all types of cliffs.
sand by-passing	Reactivation of sediment transport processes by pumping sediments accumulated up-drift by coastal infrastructure normal to the coastline and injecting them down-drift. A variant of sand by-passing is to use materials dredged for navigational purposes to reactivate the sediment transport.	This technique has been implemented by a number of harbour authorities (or dams authorities) in Europe as volumes of sand trapped by harbour breakwaters (resp. dams) are generally considerable. When sediments are trapped by a series of groins (or consecutive dams) the technique might not be cost effective anymore. It has to be noted that in the case of dams, accumulated sediment may be contaminated may not be re-injected in the sediment transport system.
Vegetation planting and/or stabilisation	Colonisation of coastal soils by vegetation whose roots bind sediment, making it more resistant to wind erosion. Vegetation also interrupt wind flow thus enhancing dune growth. As for cliffs, vegetation increases cohesion of surface soils on cliff slopes to prevent downhill slumping and sliding	Vegetation adapted to dune (eg. Marram grass) is generally very fragile and require integral protection and daily care to the dune system.

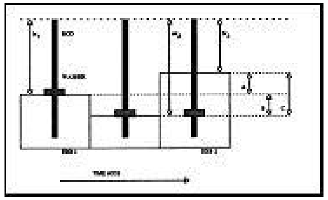
ANNEX 3 - OVERVIEW OF MONITORING TECHNIQUES COMMONLY USED IN EUROPE

	TYPE OF TECHNIQUE	NAME OF TECHNIQUE	
DIRECT OBSERVATIONS	TOPO-BATHYMETRICAL TECHNIQUES (to make beach profiles)	EMERGED BEACH	• RTK-dGPS (in-car, bag carried) http://www.ecy.wa.gov/programs/sea/swces/research/change/monitoring.htm • Total station + survey rod • Distance meter + survey rod
DIRECT OBSERVATIONS	TOPO-BATHYMETRICAL TECHNIQUES (to make beach profiles)	SUBMERGED BEACH	• Total station + survey rod • Depth-of-activity rods • CRAB (=WESP) • SLED • Profiling Bar (BP) • Sounding lead • Hydrostatic profiler
DIRECT OBSERVATIONS	TRACERS (for measure sediment transport)	• Color paint • Fluorescent paint • Radiactive tracers • Natural tracers • Magnetic sands	

Total station / distance meter + survey rod

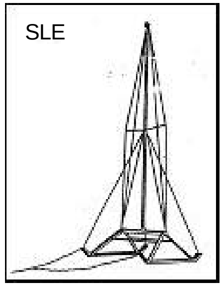


RTK-dGPS

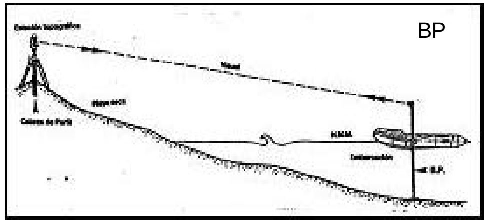


Depth-of-activity rods

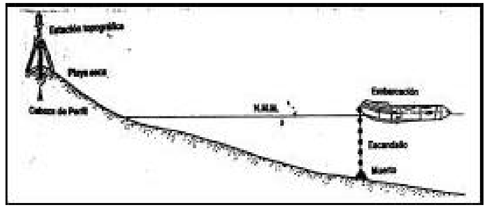
CRAB



SLE



BP



Sounding lead

REMOTE OBSERVATIONS	FIXED		• ARGUS http://www.wldelft.nl/cons/work/argus/index.html • Horizontal photography • Historical maps and navigation charts	
	MOBILE	AIRBORNE	• Aerial photography (Digital photogrammetry, Orthophotos) http://dcn.waterland.net/neonet/ • Satellite images (LANDSAT, SPOT, Ikonos...) • LIDAR (=laser altimetry; SHOALS...) http://duff.geology.washington.edu/data/raster/ lidar/laser_altimetry_in_brief.pdf • WRELADS • SAR http://dcn.waterland.net/neonet/indexeng.html http://www.sandia.gov/radar/whatis.html	
		SHIPBORNE	• Ecosounding+GPS (hovercraft, boat…) http://www.eurosense.com • Echosounding+survey rod+total station (zodiac) • SIDE SCAN SONAR http://www.kleinsonar.com/discript/sssonar.html • SBP (for ancient coastlines detection-seismic data)