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Future Coastal Defence in The Netherlands: Strategies for Protection and Sustainable Development

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ABSTRACT

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Coastal defence is a major function of the Dutch dunecoast. The dunes are considered to be important, in addition to coastal defence, as a nature conservation area and for recreation and drinking water production. At many places the dunecoast is subject to erosion. Without mitigation measures the erosive trend will continue into the next century and will probably worsen due to the increase of sea-level rise. It will have serious effects on the safety of the inhabitants of the polders and on functions of the dunes.

To develop a structural approach to coastal defence management after 1990, the Dutch government commissioned Rijkswaterstaat to carry out an integrated policy analysis study. The period considered was 1990–2090. Several scenarios of sea-level rise were taken into account: 20 (present-day), 60 (expected) and 85 (pessimistic) cm/century. The study resulted in four alternatives for coastal defence: admission of further retreat (W), selective erosion control (S), full erosion control (F) and seaward expansion at relatively weak sites along the coast (E).

Implications of these alternatives to safety measures, costs and loss of dune area along the coast are presented. An approach is proposed to integrate traditional coastal defence management with nature and landscape conservation. A method for classifying nature in the outer dunes is given. Five options for a more nature-oriented coastal defence management are discussed. The options advocate the management of the dunes as dynamic systems requiring human activities to retain or regain valuable natural features.

ADDITIONAL INDEX WORDS: *Coastal management, policy analysis, nature conservation, nature development, sea-level rise.*

INTRODUCTION

The Dutch dunecoast is of great importance for life in the Netherlands. About one third of the country is situated below sea-level and would be flooded without continuous care for coastal defence (Figure 1). The major part of the coastal defence system consists of a natural coast with dunes, beaches and shoreface. Apart from the defence function, the coastal zone and especially the terrestrial part of it, is considered a very valuable nature area. It is one of the largest more or less continuous dune areas of Europe. The Dutch government assigned the dunecoast a specific status of protected nature area (PIETERS, 1989). At the same time this area accommodates other important functions for society. Living, public drinking water supply, recreation (tourism) and some industry are the most important functions (MEULEN and MAAREL, 1989).

In the past, coastal management mainly focussed on coastal defence functions. Especially after the huge storm surge of 1953 many efforts have been made to strengthen the defence against the sea. Most famous in this context are the Delta works in the south-west of the Netherlands: a system of dams and dikes to close-off the big estuaries (see summary in WATSON and FINKL, 1990). Also important is the re-enforcement of the entire Dutch dunecoast, which led to a safety level along the coast which

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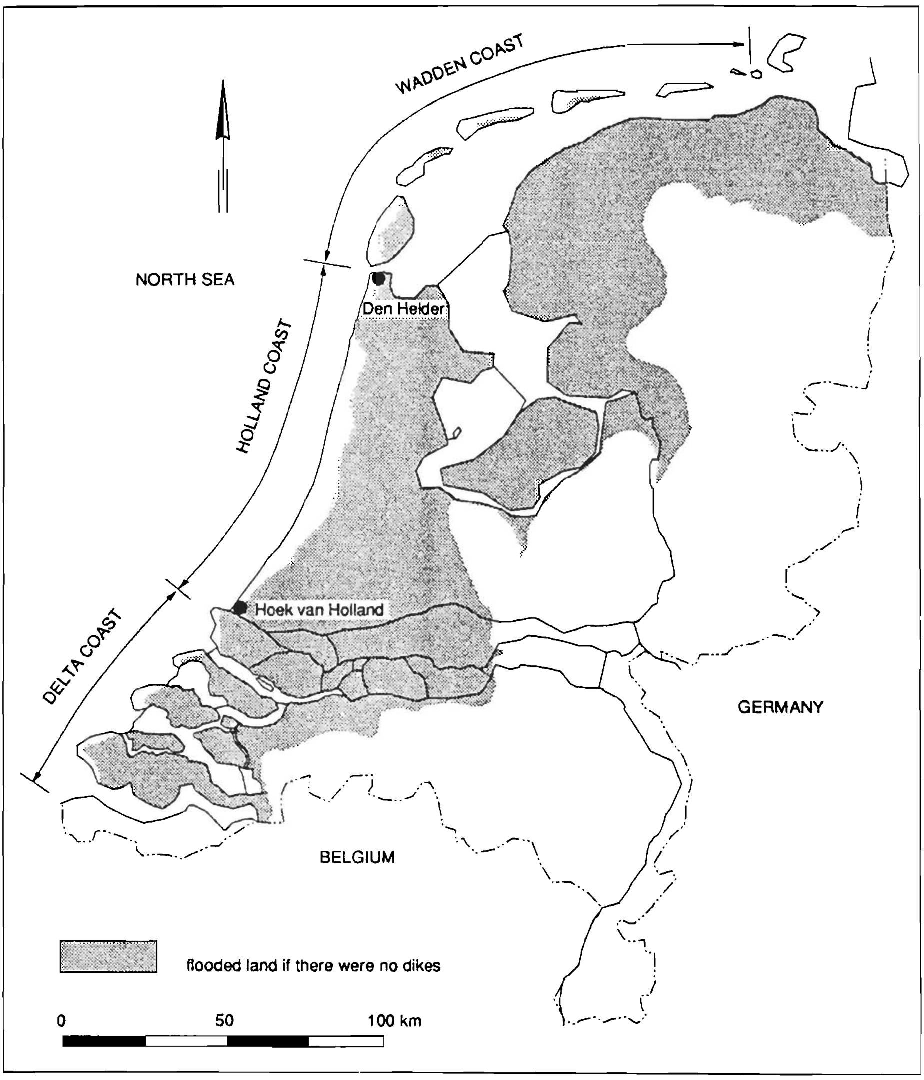


Figure 1. Map of The Netherlands showing the three main dune coast types. Hatched = area flooded without protection of dunes and dikes.

is in agreement with the standards accepted in the Netherlands. This situation was realized in 1990. Now, the major question when considering coastal defence in the next decades up to 2090 was: how to guarantee this level of safety under conditions of continuing shoreline retreat and an acceleration of sea-level rise due to climate change.

Coastal erosion will result in a growing loss of dune area and associated biotopes. Nature areas of great national and international value will be threatened or lost; the functions accommodated in this area will suffer severe damage. Increasing public awareness has resulted in a widespread concern for ecology and nature conservation as contributing to a healthy environment. This certainly holds true for the dune-coast, which is extremely rich in biotopes with a great variety of plant and animal species. Future coastal defence policy must also take this public concern into account.

In a policy analysis study for coastal defence management in the Netherlands various alternatives for a new policy of coastal defence were developed (RIJKSWATERSTAAT, 1991). The results of this study contributed to the discussion about a more nature-oriented kind of coastal defence management. With respect to nature, only conservation of actual valuable ecosystems was taken into account. This is a rather "static" view. Development of new potentially valuable ecosystems should also be considered. In the future new ecosystems may develop when more natural dynamics are allowed, for example on beach planes and sand banks when coasts are accreting, but also at new tidal inlets and foredunes when coasts are eroding.

In this paper both the static approach (only conserving the actual systems as was applied in the coastal defence study) and a more nature-oriented dynamic approach (in which development of potential values is also considered) will be presented.

The effects of coastal defence on public safety and on nature conservation are identified and the solutions that have been developed are described; also the repercussions of the solutions for a number of aspects are presented. The paper ends with options to combine coastal defence and nature-development.

THE DUNECOAST OF THE NETHERLANDS

Geomorphology and Defence Function

The Dutch coast is principally a sandy coast, at some places enforced with massive sea defence constructions. Three major physiographic units are discerned (Figure 1): in the south, the Delta coast, consisting of (former) delta's and islands; in the middle, between Hoek van Holland and Den Helder, a stretch of coast not interrupted by tidal inlets (the Holland coast), and, in the north, the Wadden coast, consisting of a chain of barrier islands with tidal inlets in between. Each of these coastal environments has a large variety of dry and wet coastal ecosystems.

The geomorphology of the shoreface is described by ALPHEN and DAMOISEAUX (1989), and MAAREL (1979) discussed the abundance of gradients between abiotic conditions and both physical and biological processes (see also Figure 2). The dunes cover about 400 km^2. This is only about 1% of the Dutch land surface. But they have a large variety of plant and animal life: 26% of all Dutch vegetation types occurs in dunes (17% of which is exclusive to the coast); 66% of the Dutch flora is found at the dunes (15% is exclusive); 87% of the Dutch breeding birds is known to breed in coastal habitats (STICHTING DUINBEHOUD, 1989; see also WESTHOFF and SCHOUTEN, 1979).

Behind the dunes is the densely populated delta of the Rhine and Maas rivers. Both the life in the low lying delta and the functions of the dunecoast are protected by the coastal defence system, which has a total length of 353 km. 252 km is defended by the dunecoast, 51 km by sea dikes and other immobile constructions. At the extreme ends of most of the Wadden barrier islands there are altogether 38 km of beach plains.

The Delta coast consists of broad river outlets with islands having dunes at their seaward tips. The shoreface of this coast often contains a channel which connects the tidal river outlets. These channels threaten the dunecoast of the 'islands' due to their tendency to shift in a landward direction. The terrestrial part of the coastal defence system often is very vulnerable: at several places only one single dune ridge defends the low lying hinterland against the sea.

The Holland coast almost entirely consists of secondary dunes. They are usually fairly broad, sometimes up to 3.5 km. A narrow strip of transverse dunes rises steeply from the beach. Further inland dune systems are parabolic. Tallest dunes reach about 50 m height. Valleys and leeward slopes have dune woodlands. The beach is straight and fairly narrow (about 100 m). The shoreface of the Holland coast consists of a breaker zone between MSL and about the 8 m-depth contour with a varying number of breaker bars (0 to 4, see VROEG *et al.*, 1988). The lower shoreface between the 8 m- and about the 20 m-depth contour, varies in width. Like the Delta coast, some stretches of the Holland coast are weakly defended too. Here coastal defence has to be enforced regularly to guarantee safety against flooding. This is not the case with the coastal sections that contain wide dunes,

Environmental factor	Topographic gradient	Process
moisture	dry-wet	inundation ↔ desiccation
soil texture	sand-clay/mud	accretion ↔ erosion sand-clay/mud
calcium carbonate content	calcareous-non calcareous	acidification ↔ enrichment of calcium carbonate
PH	acid-alkaline	- -
organic matter	humic-mineral	humification ↔ mineralisation
nutrients (N,P)	eutrophic-oligotrophic	eutrophication ↔ de-eutrophication
chloride	fresh-salt	salinization ↔ desalinization
grazing pressure (rabbits)	high-low	grazing

Figure 2. Main environmental gradients and processes in coastal dunes (after Maarel, 1979).

located for instance at the middle of the Holland coast.

The Wadden coast consists of a chain of islands with tidal inlets in between, leading to a shallow but extensive tidal marsh area (the Wadden Sea) which continues north into Germany and Denmark. The islands have wide (sometimes up to 1 km) beaches, beach plains and extensive primary dunes, especially near the ends of the islands where coasts have been accreting in the past. Coastal wetlands are also important. Morphological processes of the Wadden Sea interfere with those of the outer deltas and of the respective island coasts. Dunes of the Wadden coast are often fairly wide (1–2 km), but usually lower than those of the Delta and Holland coasts.

About 60% of the dunecoast has a defensive system which is enforced with structures like groins or pile rows. Building of groins started at about 1750 (Walcheren, Delta coast). Their appearance has gradually extended along the entire coast: nearly the whole Delta coast, the southern and northern parts of the Holland coast and the Wadden islands Texel and Vlieland have groins. The construction of pile rows is of a more recent date (about 1960); they mainly occur in the Delta area.

Other Functions of the Dunes

Although the dunes are still relatively undisturbed they fulfill a number of important functions (landuse types) for society (besides coastal defence). MEULEN and MAAREL (1989) give a matrix with impacts of 11 landuse types on dune ecosystem components. Three principal uses are briefly mentioned here: public drinking water catchment, recreation (tourism), and nature conservation.

Public Drinking Water Catchment

Most of the fresh surface water in the low countries is polluted and not potable. There is a risk that unexpected new sources of pollution may suddenly occur in the already badly affected rivers. In the past 100 years the western part of the country has depended on the dunes as a source of safe and clear drinking water. Since the early 1950's artificial recharge of groundwater has been applied. Pre-treated eutrophic river water is used for this purpose. It is infiltrated into the dunes in open reservoirs (lakes or canals). The river water is allowed to percolate through the dune sand. After being purified biologically in this way it is recovered by means of shallow wells. This technique has altered the groundwater regime at many places (MEULEN and JUNGERIUS, 1989; DIJK, 1989). The quality also differed from that of the original oligotrophic dune water. At present the technique of deep well infiltration and recovery is seen as an alternative for the production of drinking water which is less harmful for nature.

Recreation (Tourism)

The proximity of large cities like The Hague, Amsterdam and Rotterdam leads to a high recreation pressure. This is often quite incompatible with water catchment and nature conservation in the same area. The dunes are easily damaged because of their loose sandy soils and thin vegetation cover.

Nature Conservation

The unique combination of a Wadden, a Holland and a Delta coast presents a system of ecologically very rich and diverse coastal environments, both wet and dry, young and mature. The Dutch dunecoast has high actual conservations values. The past decennium has brought a wide public concern for nature conservation. The scope has widened from conservation of species and habitats to conservation of whole landscapes in their ecological setting. Because of their relatively large size and near-to-natural state, dunes are very suitable to apply such an approach. Landscape ecological principles more and more play a role in dunecoast management. The most important issue is that dunes should be managed as dynamic systems requiring human alterations to retain or regain valued natural features. This approach differs from the current view of static dune management, which is practiced in so many countries up to now (MEULEN *et al.*, 1989a). The approach opens up the way not only to conserve what is actually present, but also stimulates development of new ecosystems (shifting dunes, tidal inlets, green beaches, *etc.*). Recently, the coast is recognized by the Dutch government as one of the major conservation areas in the country.

Administration of Coastal Management

The administration of coastal management in the Netherlands is fairly complicated. The distinction between coastal defence management (shoreface, beach and front dunes, sea-dikes, groins, *etc.*) and management of the more landward part of the dune zone is important.

The Ministry of Transport and Public works (Rijkswaterstaat) is responsible for maintenance and control of the shoreface along the whole coast. Water authorities along the Delta and Holland coast are responsible for maintenance of beach and foredunes. On the Wadden islands Rijkswaterstaat is responsible for maintenance and control of both shoreface and beach and foredunes.

Also ownership and management of the more landward part of the dune zone is not uniform. There is a diversity of public and private owners of dune terrains. This often impedes integrated planning and management in which all functions of the dunecoast are taken into account. The government's policy now emphasizes large scale and integrated planning and management on a structural and not an *ad hoc* basis.

METHOD OF POLICY ANALYSIS STUDY

The policy analysis study on coastal defence was based on 20 technical studies, which were performed simultaneously in 1989 by a great number of experts from various disciplines such as coastal geomorphologists, engineers, geologists and ecologists. Some of these studies are published in the *Proceedings of the 23rd International Conference on Coastal Engineering*, Delft, (1990). In this paper these studies are not extensively dealt with. There is one exception: for a good understanding of the effects of various coastal defence measures on nature, the method for classification and valuation of nature is explained briefly here.

The main steps in the policy analysis study were:

(1) Description of all features in the coastal area, which were relevant for evaluation of alternatives for coastal defence (morphologic features like dune dimensions, parameters for control of safety, functions in the dunes, *etc.*). These data were put into a database.

(2) Prediction of the autonomous development of the shoreline for various intervals of time: 2000, 2020 and 2090. Also the effects of various scenario's of sea-level rise had to be predicted. These scenario's were: the present-day sea-level rise (20 cm/century), the expected scenario (60 cm/century) and the pessimistic scenario (85 cm/century including changes of wind- and wave-climate).

(3) Evaluation of the problems to be expected when the shoreline develops as predicted. Which damages and losses are to be anticipated?

(4) Development of coastal defence strategies

(alternatives) that solve one or more of the problems.

(5) Technical implementation of the strategies: which measures can be taken to realize the strategies?

(6) Determine the implications of these strategies: impacts for coastal defence, loss of valuable dune area and costs of coastal defence measures. In order to identify the implications of the various alternatives a policy analysis model was built. This model enabled systematic evaluation of a broad range of alternatives. The main evaluation procedure with this model was as follows: simulate the expected shoreline position, check whether safety and/or other requirements (imposed by the coastal defence alternatives) are met with, implement the technical measures and determine the impacts on nature.

CLASSIFICATION OF NATURE

Because an evaluation of the consequences of coastal defence alternatives for nature conservation is our main topic, the method used for classifying and evaluating nature is briefly outlined. The method applies to the foredunes, but can be extended to inner dunes too.

When one needs to assess terrain values this can be done for example on the basis of the present conservation status of the areas in question: is it a provincial park, a national park, *etc.* But often this does not reflect the real value of an area; similarly areas which need protection may not have obtained this status yet. Moreover, with this method comparison with other areas is hardly possible in this way. Therefore, it is better to distinguish on the basis of inherent natural terrain characteristics themselves. In this way, actual as well as potential (to be developed) characteristics can be taken into account. For the coastal defence analysis five nature classes were distinguished on the basis of actual terrain characteristics.

The actual values are systematically and quantitatively defined. However, the potential values are more difficult to assess because little is yet known about the response of processes and of plant and animal species to changing environmental conditions. Monitoring studies and the future building of ecological interaction models, based on the results of monitoring, will give more insight in this matter (MEULEN *et al.*, 1989b). Also the predictions of abiotic environmental constraints like climate, sea-level and the position of the shoreline has uncertainties. For these reasons predicting future landscapes

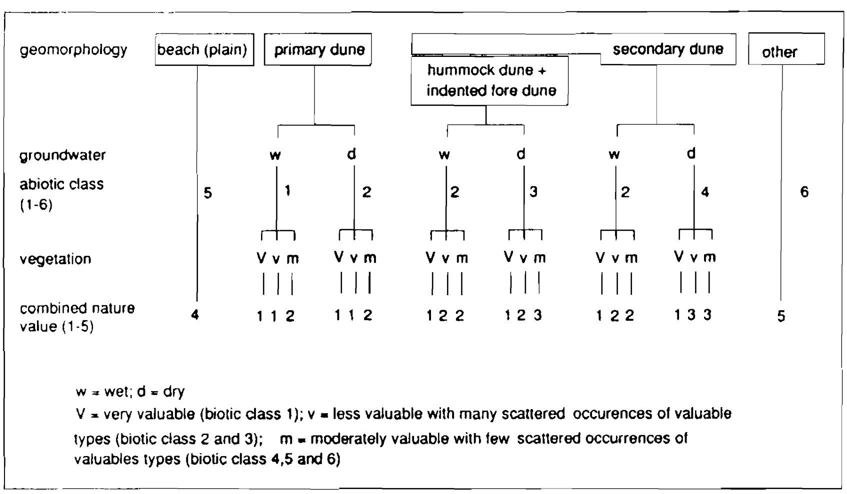


Figure 3. Classes of nature in the outer dunes of the Dutch coast, based on geomorphology, hydrology and vegetation.

and nature values was not a part of the policy analysis.

Valuation of actual terrain characteristics was based on the following: (1) rarity of geomorphological structures and of vegetation, (2) diversity of plant species within plant communities, (3) maturity of the ecosystem, and (4) the fact that complete assemblages of ecosystems *i.e.* coastal landscapes have developed and still exist. Fragments, rare though they may be, could be of less importance than complete sequences of coastal ecosystems like zonations from beach to inland dunes. This criterium was only used qualitatively on a nation-wide scale. We used 1:50,000 landscape ecological maps of the dunecoast (DOING, 1988).

In the valuation procedure the abiotic (geomorphology and hydrology) and biotic aspects (flora and vegetation) were considered separately. Faunal aspects were not considered because no systematic data on appropriate scale was available. The advantage is that valuable abiotic systems without actual, but with high potential values for biotic nature can be distinguished. For example: a dune slack may already have the appropriate geohydrological conditions, but still lack the diverse and rare flora and vegetation associated to such abiotic environments. Five nature classes were distinguished, based upon combinations of abiotic and biotic terrain characteristics (see Figure 3):

- N1 moist to wet primary and secondary dunes with grassland (dune slacks), woodland and heath
- N2 dry primary dunes and moist secondary dunes with scrub, dry or locally moist grassland (slack) or woodland
- N3 dry secondary dunes with grassland and woodland
- N4 beach and beach plains
- N5 other (disturbed dune, built up area, *etc.*).

(Beach and beach plains, N4, were ranked rather low. This is inherent to the method used, only taking actual characteristics into account. When potential values are also considered, beaches and especially beach plains have important conservation values because a variety of ecosystems may develop on them, like primary or secondary dunes, green beaches and tidal inlets.)

After having distinguished these nature classes and mapped them along the coast it is now possible to calculate the losses for nature due to shoreline retreat.

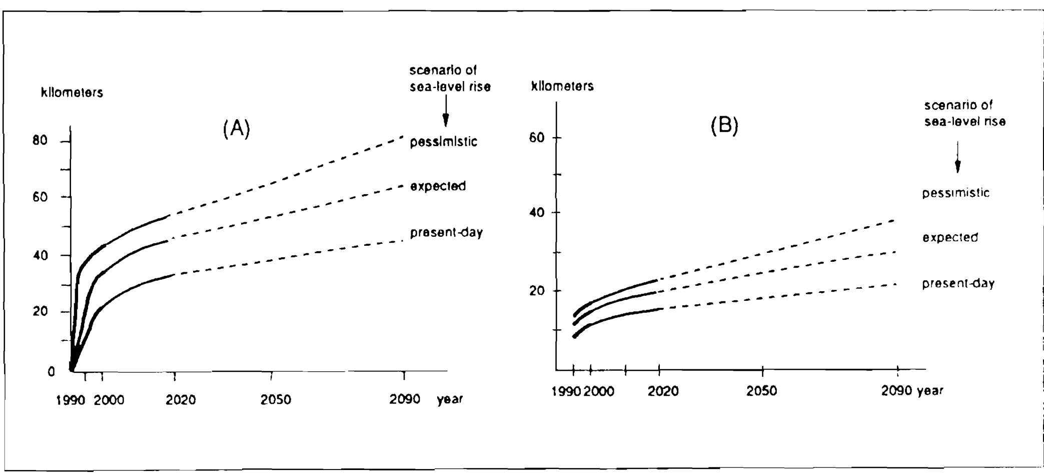


Figure 4. Length of coast where safety requirements are not met (A) and where loss of valuable nature area must be anticipated (B).

CONSEQUENCES OF PRESENT-DAY COASTAL DEVELOPMENT FOR SAFETY AND FOR NATURE CONSERVATION

Shoreline retreat (caused by coastal erosion) is the main threat for coastal defence. Coastal erosion shows up in two ways: as sudden, fairly local events and as a more gradual and global phenomenon.

In the first case high water level and waves during storm surges can suddenly cause a local loss of sand from the dune front. At an erosive stretch of coast this will result in a structural loss of sand, because the sand taken from the dunefront will (partly) be used to replenish sand lost from the shoreface. Accreting coasts, however, will show a gradual restoration of the original dune profile in course of time.

Although more gradual and global, the second case at the long run is much more threatening than the sand loss due to storm surges. Due to an often very subtle mixture of hydraulic processes, residual transport of sand bodies from one place to another takes place and results in accretion at one place and erosion at others. Long-periodic changes in erosional and accretional processes also occur and result in (quasi-) periodic fluctuations of the shoreline (with periods of tens of decades).

Shoreline retreat affects both the defensive strength of the foredunes (and as a consequence the coastal defence system as a whole) and the functions of those dunes nearest to the sea. Due to shoreline retreat sand is lost from the foredunes and the amount of sand available for defending the hinterland against the sea decreases: the coastal defence weakens. Each part of the coast has its own critical width, depending upon the geometry of the coastal profile. At this critical width the required level of safety can just be guaranteed.

The length of coast where this level of safety is no longer present is depicted in Figure 4A for the three scenarios of sea-level rise for the whole time interval studied (up to 2090). With the present-day sea-level rise, already in the year 2000 more than 20 km is 'unsafe.' This rises to about 40 km in 2090. In the pessimistic scenario, an increase with a factor 2 must be anticipated.

The effects of shoreline retreat on dunes and their functions for society are also evaluated. Figure 4B shows the length of coast where loss of very valuable nature (classes N1 and N2) can be expected. At the present-day trend of sea-level rise in the year 2000 about 40 km of coast with very valuable nature is lost. In 2090 this will increase to about 60 km, which is some 40% of the total coast length where valuable nature (N1 + N2) occurs. In a pessimistic scenario, an increase with about 50% may be expected.

The impacts taken into account are the direct loss of land (with valuable nature) due to a landward shift of the shoreline and the direct loss of valuable nature due to the landward shift of the back side of the foredunes: since this foredunes must guarantee a minimum level of safety, the foredunes (with minimum dimensions) must shift landward with the same pace as the shoreline retreats. Due to the landward shift of the (minimal) foredunes a wet dune valley (or slack) for instance, can be buried by sand. This could also happen to the other functions located immediately behind the foredunes (buildings *etc.*).

An indirect effect which will damage nature in the long run (especially the vulnerable moist biotopes) is the lowering of the groundwater table. Such a lowering will occur when the dune zone is narrowed by shoreline retreat and when it is not compensated by a strong rise of the sea-level.

ALTERNATIVES FOR COASTAL DEFENCE MANAGEMENT

Four alternative coastal defence strategies were formulated. They all had one feature in common: safety against flooding of the polders behind the dunes should always be guaranteed. With respect to nature it was stated a priori that conservation of actual values was the most realistic aim in this study. The alternatives each have different measures for coastal defence:

W: Withdrawal: allow further retreat of the shoreline, except for the places where just minimum safety can be guaranteed;

S: Selective erosion control: counteract further shoreline retreat at places where economical functions like drinking water supply, recreation, *etc.* are present or where valuable nature area (N1, N2) is threatened;

F: Full erosion control: counteract further shoreline retreat at all places where this occurs;

E: Expansion: seaward expansion of the shoreline at places where the coastal defence is relatively weak. The aim is to improve the defence system. This alternative is more offensive than the others. Structures of hard material, like groins and dams are chosen (PLUIJM, 1990).

Two types of measures for coastal defence must be distinguished for the first three alternatives. Both make use of additional sand supplies. In this way the natural character of the coast is not irreversibly affected and there is much experience with this type of defence measures (ROELSE, 1990).

When shoreline retreat must be allowed, the defensive strength of the foredunes must be maintained. This is realized by 'shifting' sand from the seaward side of the foredunes to the landward side. Regardless of the total width and height of the dune area at the Holland and Delta coast, the dimensions of the foredunes are maintained at the minimum level. At the Wadden coast a natural process of shoreline retreat resulting in a gradual degradation of the foredunes was introduced. Both approaches are more or less in agreement with the present procedure of 'conducting' shoreline retreat.

Shoreline retreat is counteracted by beach nourishments and in some situations by enforcement of the dunes through sand supply at the landward side of the foredunes. In all cases regular coastal defence policy is maintained: maintenance of groins, prevention of blowing sand, *etc.*

EFFECTS OF THE COASTAL DEFENCE ALTERNATIVES

The alternatives have different implications for the criteria used to compare the alternatives. These criteria are:

(1) Length of coast where measures have to be taken to guarantee safety.
(2) Loss of dune area with economic functions or valuable nature; although landward displacement of the shoreline will eventually affect the entire width of the dunes, only changes of the foredunes were considered. Other impacts, for instance changes in groundwater-level in the dunes were not taken into account.
(3) Costs for coastal defence measures.

The basic policy analysis was performed for the present-day sea-level rise of 20 cm/century. The consequences of the alternatives are given in Figure 5 as the locations along the coast where in the year 2000 coastal defence measures are needed. For the alternative Withdrawal, the largest effort is concentrated at the Delta coast, where coastal defence is relatively weak. For the alternative Selective erosion control, measures are needed both at the Wadden (to protect valuable dune area of classes N1 and N2) and Delta coast (unsafe situation). Full erosion control results in a further increase of locations where measures need to be taken: in fact all the places that suffer shoreline retreat.

The length of coast to be protected increases as a function of time for alternatives **W** and **S**; for alternative **F** this parameter shows a rather constant path as a function of time. Because the loss of dune area is inversely related to the efforts for coastal defence, it will be clear that the loss is relatively large for alternative **W** (about 3.5 km^2 in 2000), smaller for alternative **S** (1.5 km^2 in 2000) and that no loss is expected for the alternatives **F** and **E**. As is shown in Figure 6A the losses increase in the course of time for the alternatives **W** and **S**. The bars indicate the uncertainties of the values shown.

The loss of valuable nature areas (classes N1 and N2) is depicted in Figure 6B. Because in the alternative **S** these classes are protected and there is no loss for this type of nature area. The yearly losses for the alternative **W** decrease from about 2 km^2 in 2000 to about 1.4 km^2 in 2090.

The costs follow about the same pattern as does the length of coast where measures are needed. They amount to about 35 million guilders (about 20 million dollars) per year in 2000 for alternative **W**, about 45 million guilders per year for alternative **S**, and about 60 million guilders per year for alternative **F** (see Figure 7). The costs for alternative **W** appear to increase as a function of time; for alternative **F** the costs decrease. This is caused by the relative favourable prediction of shoreline development for some coastal areas on the longer run. For alternative **S** this results in a fairly stable picture of the costs as a function of time.

The alternative seaward expansion (**E**) has not yet been worked out in so much detail as the other alternatives; the estimates of the costs are therefore more tentative and amount to about 80 million guilders per year (in 2000).

Acceleration of sea-level rise from 20 to 60

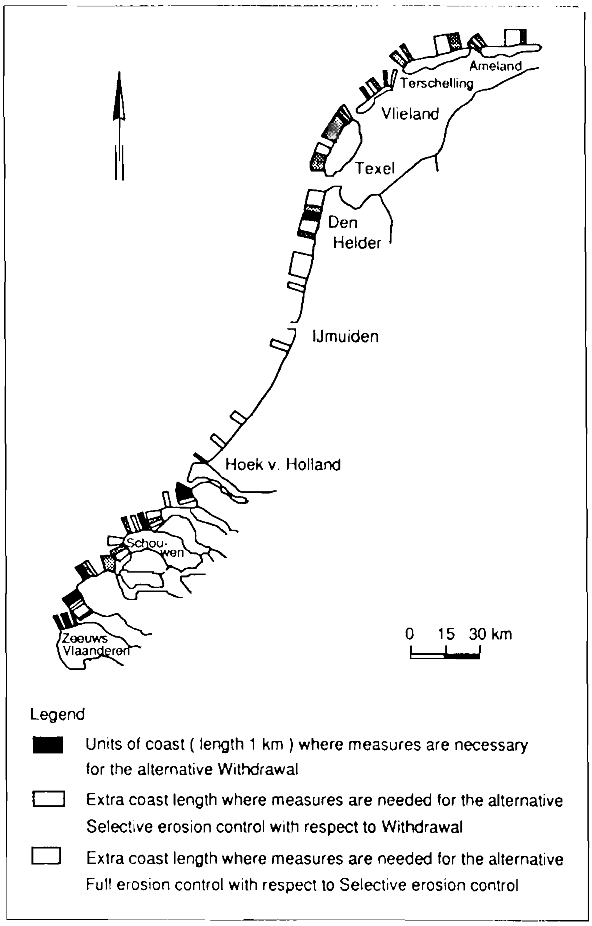


Figure 5. Coastal areas where in the year 2000 measures need to be taken for the alternatives W, S and F. W = Withdrawal; S = Selective erosion control; F = Full erosion control.

cm/century results in a 25% increase of costs for measures to counteract the erosion and the loss of dune area. The extra costs and losses of dune area for a scenario of 85 cm/century (including changes in wave climate) amount to about 80% with respect to the case of 20 cm/century sea-level rise.

INTEGRATION OF COASTAL DEFENCE AND NATURE CONSERVATION

The four coastal defence alternatives all take the view that the best solution for nature in the dunes is conservation of all existing values. But it may be wise for new coastal (defence) management programmes to incorporate a more active policy with respect to nature development. Since coastal defence is an important function of the dunecoast, it is advisable to investigate the possibilities for integration of the traditional way of coastal defence management with a more nature-oriented dune management. The main issue in this discussion is to which extent natural dynamics can be (re)introduced into the coastal ecosystem.

Basically, there are two aspects from the point of view of nature and landscape development: (1) preservation of actual, valuable coastal ecosystems, and (2) development of potentially valuable ecosystems.

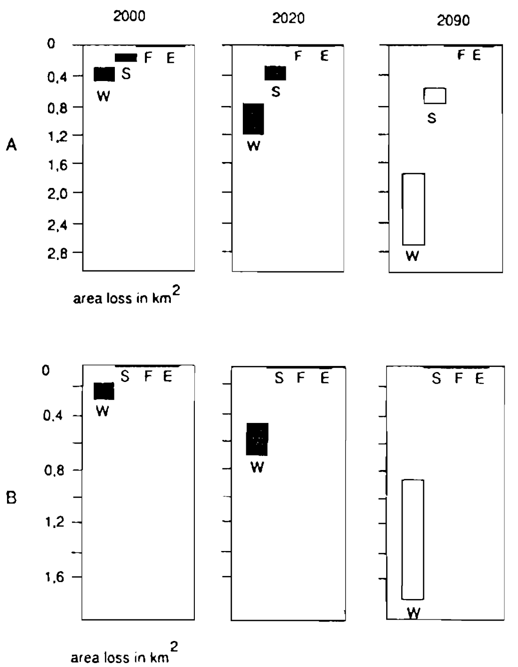


Figure 6. Loss of dune area (A) and loss of valuable nature areas (B) for the various coastal defence alternatives. For meaning of W, S and F see Figure 5; E = E (seaward) Expansion.

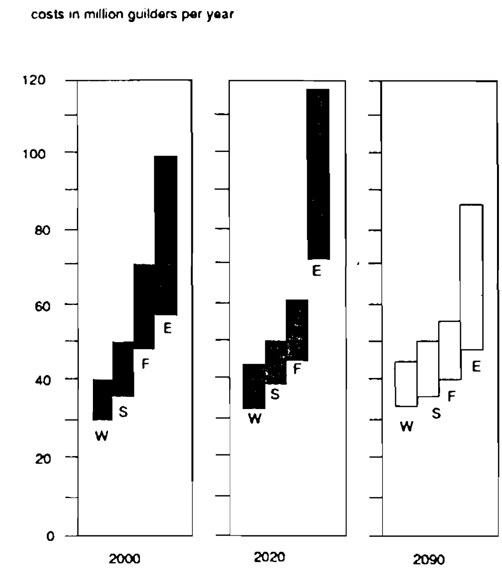


Figure 7. Costs for measures against shoreline retreat for the various coastal defence alternatives. For meaning of W, S, and F see Figure 5; E = E (seaward) Expansion.

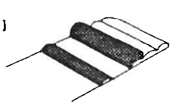
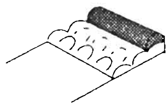
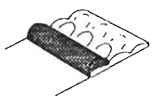
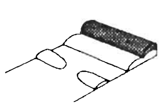
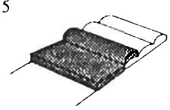
In both cases it is advocated to "work" as much as possible with existing, or better, with expected coastline processes (*i.e.* does erosion prevail or accretion?). The overall aim is to stimulate the development of large-scale gradient situations between wet and dry and between young and mature type coastal ecosystems along the Dutch coast. Thus a variety of habitats will be available for plant and animal life.

We present five options for a more dynamic coastal (defence) management (Figure 8). The options are all based on "soft" defence measures (sand replenishment, stabilisation of sand by fences *etc.*). The costs and the relationship with other functions of the dunes are only briefly taken into account at this stage for matters of simplicity. In Figure 8 the hatched structures indicate the part of the dunecoast which guarantees safety. Such parts can be strengthened either by stabilisation or by replenishment with sand.

Option 1 can be applied at accreting coasts. Locally a flexible shoreline should be allowed. The option favours pioneer plant communities, both wet and dry, of primary dunes with associated animal (especially bird) life. Processes need decades, possibly even up to a hundred years to develop. Often the first results can already be seen after some years. An area of 0.1 to several km^2's is necessary for nature development. Possibilities to realize this option are mainly found on the Wadden islands.

Option 2 can be applied at any type of coast where re-enforcement is necessary. The effect on ecosystem development is different and depends on the place where the nourishment is actually carried out in the dunes. This option could be combined with option 4. The dunes lying seaward of the main defence line should not have any other important function than nature development. A flexible shoreline is advocated. Various dry and wet coastal ecosystems are favoured in this way. The minimum time and space respectively required is decades up to a hundred years and from 0.1 to several km^2's.

Option 3 chiefly concerns inward dunes. The shoreline can be either flexible or stable. It

OPTIONS		DESCRIPTION	ECOSYSTEM DEVELOPMENT	MINIMUM SPACE/TIME SCALE	LOCALITY (COASTAL DEVELOPMENT
1		1. building of new sand (accumulation) dams on beach plains	primary seaward dunes; primary dune slack; beach with embryo dunes; green beach	(sh), md, lg 10-100's ha	Wadden (accretion
2		2. replacement of major enforcement zone towards the back of a dune system and leaving the outward dunes free for actions of wind and sea; perhaps combine with 4;	various dry and wet dunes	md, lg 10-100's ha	Wadden (indifferent)
3		3.eolic mobilization of dune behind the front dunes; type: blow-out	various dry and wet dunes	sh, md 10 (-100's) ha	Holland coast Wadden Delta (indifferent)
4		4.opening up of weak and non essential ridges in front of former beach plains or dune slack systems, leading to marine rejuvenation (type: slufter on Texel);	tidal marshes; green beach	md, lg 10-100's ha	Wadden Dellta (erosion)
5		5. (re)enforcement of existing beach and/or front dune to protect valuable older dune systems behind the front dunes.	dry and wet secondary residual dunes	md, lg 10-100's ha	Wadden Holland coast Delta (erosion)

parts of dunecoast which guarantee safety against flooding  sh=years md=decades lg = up to 100 years 's = multiple amount of

Figure 8. Options for nature-oriented coastal defence management form the point of view of nature and landscape development.

involves the (re)introduction of more aeolian dynamics in dunes. This favours the development of secondary blow-outs. Dry and wet dune ecosystem are associated with this development. The option can be applied at all places where the dunes are wide enough, independent of the other alternatives. Blow-out development already takes place within a couple of years and on areas of about 0.1 km^2. This small scale makes the option particularly suitable for the Holland coast. There is relatively few place for the other options in this coast section, because of the many other functions.

Option 4 can be applied at eroding coasts, but only if there is a second defence line more landward, which can be kept in proper condition for safety reasons. A flexible coastline is involved. The option particularly favours tidal salt marshes and green beaches. Nature development requires decades up to a hundred years and areas from 0.1 to several km^2's in size. Possibilities to realize this option are found at the coasts of the Wadden islands and locally at the Delta coast.

Option 5 focusses on the protection of residual extremely valuable coastal landscapes. They are the product of a long time of development, for example primary dunes which have never become secondary or secondary dunes which have become stabilized long ago. If such residual dune systems are threatened they should be protected. This is the case along several parts of the Delta, Holland and Wadden coast. In all such cases the shoreline should remain stable through stabilization or beach nourishment.

It will be clear that some of the options

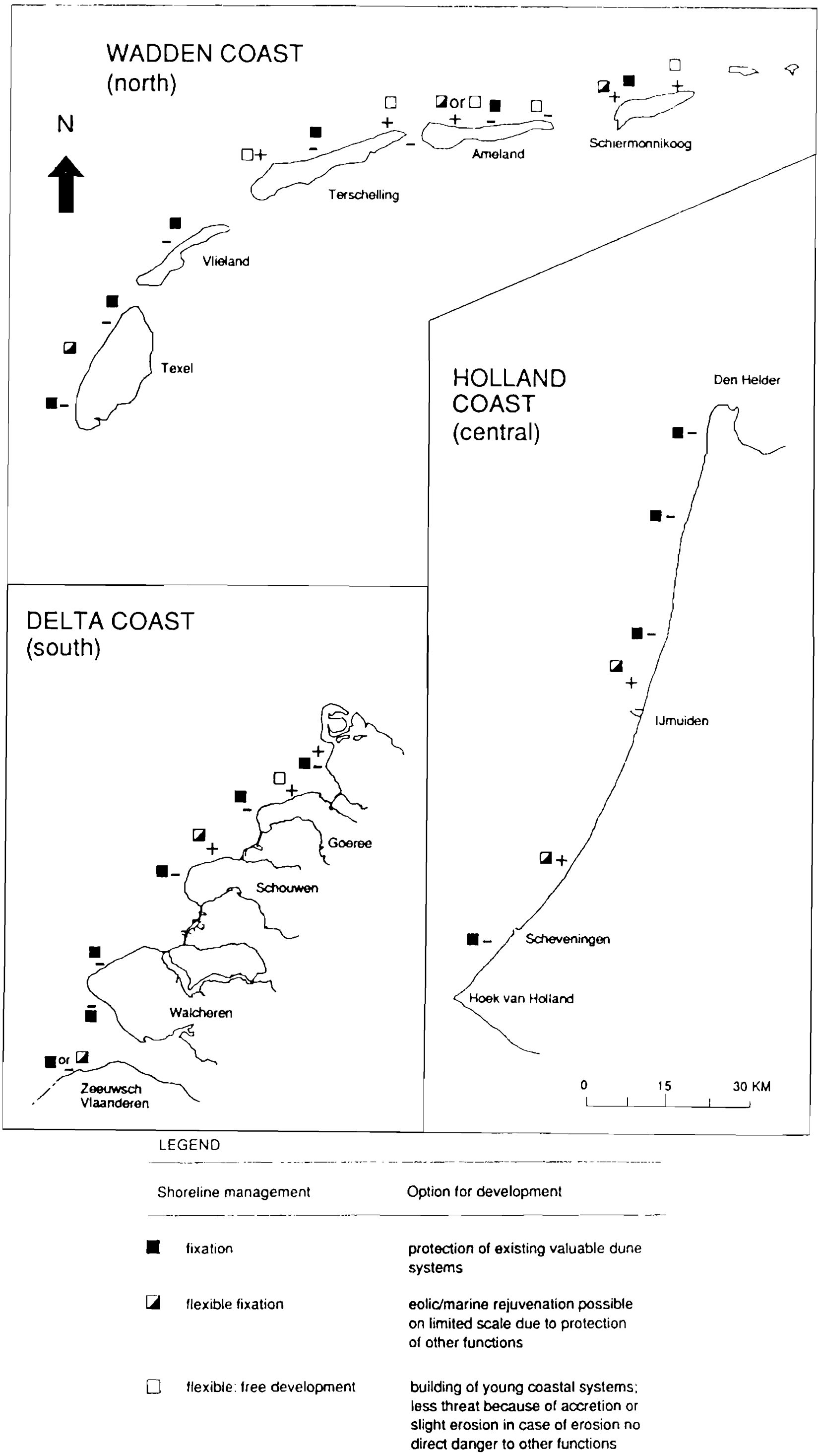


Figure 9. Main threatened areas for nature conservation due to sea-level rise and suggestions for nature-oriented shoreline management. Scenario: 20 cm/century sea-level rise. Predicted shoreline development: + = accretion; − = erosion; ± = stable or slight erosion/accretion; meaning of boxes explained in legend.

demand extra sand in the beach and dune environment. As a matter of fact this sand must be brought up from the nearshore zone, resulting in a redistribution of sand in the coastal profile. It may be questioned whether this shift is favourable for the strength of the coastal defence. To prevent weakening of this defence extra amounts of sand will have to be supplemented artificially from elsewhere. For option 1 an accretion of about 500.000 m^3 of sand is estimated for the entire Dutch coast. The cost of 1 m^3 of sand is about DFl 10,- ($5–6). At present there are already areas where nature-oriented coastal management is applied, for instance the so called slufter on the Wadden island Texel (Option 4). This slufter demands about 100.000 m^3 of sand per year. At this place the sea has broken through the foredune ridge and created a tidal-inlet. A huge dune valley behind the ridge is inundated regularly by seawater now.

Apart from the options in Figure 8 other extra measures to be considered are:

(1) Creation of wet dune valleys immediately behind the front dunes by excavating sand which is then used to restore foredune profiles.
(2) Landscape ecological shaping of dune enforcement works. This means that one tries to construct more natural dune forms instead of the traditional straight and underbroken sand dikes.

The main promising areas for a more nature oriented shoreline management along the Dutch coast are shown in Figure 9.

We advocate that the coastal zone in its entire width should be managed as a whole organic system, incorporating all parts of the transect such as foreshore, surfzone, beach, foredune, mid- and back dune. This may require larger management units than are presently existing. At least the management plans of different terrain owners should be integrated to the level of large coastal "sectors." The Dutch government recently started a policy to achieve this aim (PIETERS, 1989).

CONCLUDING REMARKS

The coast by its own nature is a highly dynamic system. Wise use of the coast is only possible through a thourough understanding of the systems dynamics, both marine and terrestrial. This can only be achieved in a multidisciplinary approach to coastal management, primarily featuring the many processes that are active in this environment. At some places the coast has suffered considerable damage from landuse; restoration of natural dynamics will be necessary. At other places further stimulation of natural development already taking place will lead the way to new ecosystems. To strike the right balance between use of the dunecoast and free development of its nature, in other words to achieve a sustainable development, that is the challenge for engineers, ecologists and planners.

LITERATURE CITED

ALPHEN, J.S.J.L. VAN and DAMOISEAUX, M.A., 1989. A geomorphological map of the Dutch shoreface and adjacent part of the continental shelf. *Geol & Mijnbouw* 68, 4.

DOING, H., 1988. Landscape ecology of the Dutch coast. (In Dutch) (With separate maps scale 1:50 000). Leiden: Stichting Duinbehoud.

DIJK, H.W.J. VAN, 1989. Ecological impact of drinking water production in Dutch coastal dunes. *In*: Meulen, F. van der, Jungerius, P.D. and Visser, J., (eds.), *Perspectives in Coastal Dune Management*. The Hague: SPB Academic Publications, pp. 163–182.

MAAREL, E. VAN DER, 1979. Environmental management of coastal dunes in the Netherlands. *In*: Jefferies, R.L. and Davy, A.J., (eds.), *Ecological Processes in Coastal Environments*. London: Blackwell, pp. 543–570.

MEULEN, F. VAN DER and JUNGERIUS, P.D., 1989. The breakdown and restoration of geomorphological and hydrological processes in Dutch coastal dunes. *In*: Gimingham, C.H., Ritchie, W., Willetts, B.B. and Willis, A.J., (eds.), *Coastal Sand Dunes, Proceedings Royal Society of Edinburgh*, 96B: 219–229.

MEULEN, F. VAN DER and MAAREL, E. VAN DER, 1989a. Coastal defence alternatives and nature development perspectives. *In*: Meulen, F. van der, Jungerius, P.D. and Visser, J., (eds.), *Perspectives in Coastal Dune Management*, The Hague: SPB Academic Publications, pp. 183–195.

MEULEN, F. VAN DER; WITTER, J.V., and ARENS, B., 1989b. Assessing impacts of sealevel rise on natural dune functions along the Dutch coast 1990–2090. *In*: Meulen, F. van der, Jungerius, P.D. and Groot, R.S. de, (eds.), *Landscape ecological impact of climatic change on coastal dunes in Europe*, The Netherlands: Discussion report for the European Conference on Landscape Ecological Impact of Climatic Changes (LICC), pp. 115–123.

PIETERS, J.B., 1989. The policy of the Dutch government towards dune conservation. *In*: Meulen, F. van der, Jungerius, P.D. and Visser, J., (eds.), *Perspectives in Coastal Dune Management*, The Hague: SPB Academic Publications, 231–238.

PLUIJM, M., 1990. Seaward coastal defence for the Dutch coast. *Proceedings International Conference Coastal Engineering, Delft* (in press).

ROELSE, P., 1990. Beach and dune nourishments in the Netherlands. *Proceedings International Conference Coastal Engineering, Delft* (in press).

RIJKSWATERSTAAT, 1989. A new coastal defence policy for the Netherlands. The Hague: Ministry of Transport and Public works.

VROEG, J.H. DE; SMIT, E.S.P., and BAKKER, W.T., 1988. Coastal genesis. *Proceedings International Conference Coastal Engineering, Malaga*: 2825–2839.

WATSON, I. and FINKL, C.W., JNR., 1990. State of the art in storm surge protection: The Netherlands Delta Project. *Journal of Coastal Research*, 6 (3), 739–764.

WESTHOFF, V. and SCHOUTEN, M.J., 1979. The diversity of European coastal ecosystems. *In*: Jefferies, R.L. and Davy, A.J., (eds.), *Ecological Processes in Coastal Environments*, London/Oxford: Blackwell, pp. 3–21.

□ RÉSUMÉ □

Les défenses côtières sont une fonction majeure des dunes littorales hollandaises. Les dunes sont une importante réserve naturelle, une zone de récréation et de production d'eau potable. En de nombreux sites, la dune bordière est en érosion. Cette tendance se poursuivra dans le siècle à venir et s'aggravera du fait de la montée du niveau de la mer. Elle aura de facheux effets sur la sécurité des habitants des polders et sur la fonction des dunes.

En vue de développer une approche structurelle de l'aménagement des défenses còtières après 1990, le gouvernement hollandais a demandé au Rijkswaterstaadt de conduire une étude intégrée. La période considérée est 1990–2090. Plusieurs sénarios de hausse du niveau de la mer sont envisagés: 20 (époque actuelle), 60 (prévue) et 85 (pessimiste). L'étude envisage 4 alternatives de défense: admission d'un retrait ultérieur, contrôle sélectif de l'érosion, contrôle total de l'érosion, et expansion marine sur des sites relativement faibles de la côte.

Ces alternatives impliquent des mesures de sécurité, des coûts et des pertes de secteurs dunaires. On propose un moyen d'intégrer l'aménagement des défenses côtières traditionnelles à la préservation de la nature et du paysage. Une méthode de classification de la nature des dunes externes est donnée. Cinq options, visant à un aménagement des défenses côtiéres plus orienté vers la nature sont débattues. Elles plaident en faveur d'un aménagement des dunes comme systèmes dynamiques, demandant à l'activité humaine de retenir ou de regagner des ensembles naturels de valuer.—*Catherine Bousquet-Bressolier, Laboratoire de Géomorphologie EPHE, Montrouge, France.*

□ ZUSAMMENFASSUNG □

Küstenschutz ist eine wichtige aufgabe an der holländischen Dünenküste. Daneben bilden die Dünen ein bedeutendes Gebiet für Naturschutz, Erholung und Trinkwasserproduktion. An vielen Stellen unterliegt die Dünenküste der Erosion. Ohne Gegenmaßnahmen wird der erosive Trend ins nächste Jahrhundert hinein anhalten und sich wahrscheinlich aufgrund des Meeresspiegelanstiegs verstärken. er wird ernsthafte Folgen haben für die Sicherheit der Polderbewohner und die Funktion der Dünen.

Um das Küstenverteidigungsmanagement nach 1990 weiterzuentwickeln, hat die niederländische Regierung Rijkwaterstaat zur Entwicklung eines Analysemodells beauftragt. Der Zeitraum soll die Jahre 1990–2090 umfassen. Dabei wurden verschiedene Szenarien für den Meeresspiegelanstieg berücksichtigt: 20 cm (gegenwärtiger Trend), 60 cm (erwarteter Wert) und 85 cm (pessimistische Annahme). Die Studie führt zu vier Alternativen des Küstenschutzes: Hinnahme eines weiteren Rückganges (W), ausgewählte Erosionkontrolle (S), vollständige Erosionskontrolle (F) und seewr̈tiger Vorbau an relativ schwachen Stellen der Küste (E).

Die Wechselwirkungen dieser Alternativen auf Sicherheitsmaßnahmen, Küsten and Dünenverlust an der Küste werden vorgestellt. Die Vorschläge umfassen eine Integration traditioneller Küstenschutzmaßnahmen in den Naturschutz. Ein Klassifikationssystem für den Außendünenbereich wird erstellt und fünf Optionen für eine naturnahe Küstenverteidigung werden diskutiert. Dabei wird insbesondere empfohlen, die Dünen als dynamischens System für menschliche Aktivitäten zu betrachten und als vertvolle Naturerscheinungen zu erhalten oder wiederzugewinnen.—*Dieter Kelletat, Essen, Germany.*