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The use of a GIS in assessing the impacts of sea level rise on nature conservation along the Dutch coast: 1990-2090

A landscape ecological study of the foredunes with help of a geographic information system

F. van der Meulen,[1] J.V. Witter[2] and S.M. Arens[1]
[1]*Landscape and Environmental Research Group, University of Amsterdam, Nieuwe Prinsengracht 130, 1018 VZ Amsterdam, The Netherlands,* [2]*Water Authority 'Hoogheemraadschap West-Brabant', P.O. Box 2212, 4800 CE Breda, The Netherlands*

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Abstract

The Dutch coastline is expected to change considerably during the next 100 years. Erosion will prevail, although accretion will occur locally.

To establish a new policy for coastal defence management an integrated policy analysis study was performed. Major dune functions (nature conservation, recreation, public drinking water supply, housing and industry) have been inventarized by using a Geographic Information System.

This study reports on the part of the analysis which takes nature conservation interests into account. Evaluation of nature interests has been based on the criteria: rarity and diversity of plant species c.q. vegetation types, succession stage, and completeness. This results in a classification of nature into five classes, based on abiotic as well as biotic characteristics of the landscape. Losses of nature interests were studied due to: loss of land because of shoreline retreat, to remodelling of the foredune ridge, and to changes of the dune groundwater level.

An evaluation is given of the methods used to assess ecological impacts.

Ideas are presented for further research on the prediction of ecological impacts and on coastline management which combines traditional coastal defence with nature conservation.

Introduction

The majority of the world's coasts are eroding at the moment (Bird 1985). It is expected that particularly soft, sandy coasts will suffer erosion. Dune coasts are often found on coastal lowlands. They form an ideal natural defence system and often protect densely populated urban-industrial areas. To guarantee a safe and protective dunecoast it is important to know how much erosion will occur and how quick these erosive trends will become manifest.

This paper deals with a case study from the Netherlands. Predicted shoreline erosion was used to evaluate losses of valuable nature.

The Netherlands are a country with extensive coastal lowlands. Life highly depends on the reliability of the dunecoast. About one third of the country lies at or below sea level and is protected by dunes **(72%)** and dykes. The Dutch shoreline is expected to change considerably during the next 100 years. This is partly the result of natural coastal dynamics, caused by the complex interaction of sea-currents and the dunecoast. This interaction has even become more complex since the closure of the former Zuiderzee (now IJsselmeer) and the completion of the Delta works (a series of huge barrier dams which now close off the estuaries in the south-western part - the Delta area - after the big storm surge of 1953). In part this is the result of a lowering of the land surface with respect to sea level of about 0.1 m per century (Ronde and Vogel 1989). Possibly, these changes are also due to climatic change.

Because of the expected increase of the sea level it is necessary to anticipate the consequences of these changes. Recently, the Dutch Ministry of Transport and Public Works initiated a large inter-disciplinary policy analysis study called 'Coastal defence after 1990' (Rijkswaterstaat 1989). The study aimed at developing a new structural national policy for coastal defence. Three possible scenarios of sealevel rise were considered: 0.20m/century (a projection of the present trend), 0.60 m/century (the expected trend) and 0.85 m/century (a pessimistic scenario which takes into account expected changes in wind and wave climate (Stive *et al.* 1990).

The policy analysis studied the impact of sea level rise on all dune functions, rather than concentrating on coastal defence alone. The other main functions are: (i) nature conservation, (ii) recreation (tourism), and (iii) drinking water supply. Locally the dunes are also used as built-up area, for militairy purposes, and for industrial and harbour facilities.

The function analysis included the entire coastline (350 km), but only the foredunes were taken into account. First all functions of the foredunes (about 100-500 m or sometimes 1000 m in width) were inventarised by using a geographical information system (Hoozemans *et al.* 1989). Next, the predicted shoreline changes for the periods 1990-2020 and 1990-2090 were also put into a GIS. By combining in a GIS the maps of predicted shoreline changes and of the functions of the dunecoast, future impacts of shoreline retreat due to sealevel rise could be evaluated. The function nature conservation was given special attention. To study the impact on nature conservation an evaluation was carried out of the expected losses of nature interests due to shoreline retreat (Arens *et al.* 1989).

The policy analysis and in particular the section on nature evaluation is of interest because of the general nature of the problem. Furthermore, inventarisation and appraisal of terrain functions is a matter of interest in itself, irrespective of the occurrence of major climatic changes. What is more, climatic changes and sealevel rise will affect many other countries in the future. Their coastlines will change. Coastal lowlands with great natural and economic values will be threatened. Impact studies such as the one reported here will have to be initiated. This paper will examine the various ways coastline changes affect functions of a dunecoast, and how such future effects can be analysed. The results of the function analysis are discussed in detail elsewhere (Arens *et al.* 1989, Louisse and Meulen 1990). Only a brief account is given here. The main emphasis is on the methodology to be used in future studies of this kind.

Finally, we advocate a kind of coastal defence management which takes into account the specific landscape ecological characteristics and processes of the Dutch dunecoast (Louisse and Meulen 1990).

Coastline changes and their effects on nature interests

Coastline regression affects dune functions in two ways, directly and indirectly (*cf.* Meulen 1990). Directly because of a loss (erosion) of land with all its inherent functions; indirectly because of a change in the function of an area which is not in fact eroded but looses its original character due to erosion nearby. One might try to quantify these losses in terms of money, but this was not feasible for nature conservation. Thus, the more modest purpose has been chosen to identify effects and to describe them in physical terms.

A loss of land at several selected time intervals between 1990-2090, has been predicted within the policy analysis (Stive 1989). Predictions were made on the assumption that no counter-measures are being taken unless safety standards are at risk. The predictions, given as new shoreline positions in time for contiguous coastline segments each of 1 km in length, have been input to our study.

Apart from loss of land which implies complete loss of all basic biotopes, damage to nature interests can be due to the following:

- Re-enforcement of the foredune. When shoreline retreat occurs in a heavy storm, the remaining foredune ridge may be of insufficient width and height. The original dune profile will have to be restored to ensure safety standards again. It usually concerns a zone about 50-150 m wide lying directly inland of the dunefoot. All functions in this zone will subsequently be lost.
- Blown sand. Sometimes during and after a heavy storm much sand is transported by the wind from the foredune ridge inland. Vegetation and fauna will be affected because of the input of fresh $CaCO_3$-rich sand and because of changes in groundwater depth and radiation balance.
- Desiccation. Narrowing of the dune zone because of shoreline retreat will result in a lowering of the groundwater level (although a strong sealevel rise may compensate this under certain circumstances). In case of a major retreat as compared to the width of the dune zone, this will certainly influence groundwater-dependent vegetation of dune slacks. Dune slack vegetation usually can not tolerate a lowering of more than 10-40 cm (Laan 1979). Non-nature functions, apart from shallow groundwater abstraction, are not likely to be affected.
- Brackish interface. Narrowing of the dune zone will also result in a rise of the interface between fresh and brackish water in the deep underground of the dunes. Consequences for nature are not likely; only deep drinkwater wells will be affected.
- Inundation. Inundation of land by sea will affect all functions. The effects on nature in particular are not easy to evaluate: new wet coastal ecosystems may develop in combination with the remaining ones. Various gradient situations may develop with many different ecological niches for species.
- Saltspray. Coastline regression will also affect the amount of salt spray in an area. The characteristic zonation of coastal ecosystems will change: zones will shift more inland.

Although these effects can be identified, several of them could not be quantified due to a lack of information on the ecological response of species to such factors.

Assessment of these effects with a GIS

The extent and location of the areas to be influenced by the effects of future shoreline retreat have been assessed with help of a Geographical Information System (GIS). **A** GIS was used because it facilitated the comparison of several monothematic maps (geomorphology, hydrology, vegetation) with maps showing the position of the predicted shoreline. Moreover other data on socio-economic and recreative values of the dunecoast could also be taken into consideration (this is not the subject of our paper). Once a GIS database is established results of future sequential monitoring can be incorporated with relative ease. This is important for future coastal defence policy. The Dutch coastline has a reference system of beach poles at intervals of 1 km. Rijkswaterstaat monitors coastline development in transects at each of these poles for decades. It was therefore suggested that a raster-GIS should be used with grid cells of 1000 m length and 50 m width, lying parallel to the local coastline. The width of the grid had to be much smaller because otherwise too much variation was going to be involved in one grid. Especially in foredunes gradients - and therefore natural variation - is often aligned parallel to the coastline.

In case of non-nature functions the effects can be described rather easily, although as pointed out above, calculating the costs is extremely difficult. In case of nature conservation not only the assessment of the losses, but even the qualitative description of the effects is difficult: the interaction of the above-mentioned processes with vegetation dynamics is still largely unknown. This is a serious disadvantage. In regeneration studies for example, the manager wishes to restore natural processes (like natural groundwater regimes; see Meulen and Jungerius 1989), but does not know which variable of the groundwater regime is ecologically the most decisive one and how plant species respond to changing values of this variable. The manager needs more ecological knowledge to restore the vegetation and the landscape.

Also in environmental impact studies the scientist or the politician wishes to know how the ecosystem will respond to predicted changes in the abiotic environment.

There is insufficient knowledge about the response of species or species populations to environmental changes. As a result, the present study only analysed the loss of nature due to a loss of land, to remodelling the foredune ridge, and to changes in groundwater level. Basically, this has been performed by overlaying grid maps with information on nature with maps showing the predicted position of the new coastline at a given time, together with the areas affected by remodelling and by change in groundwater level at that time.

Information on nature was taken from 1:25 000 maps by Bakker *et* ***al.*** (1979). Separate monothematic maps were available for vegetation, geomorphology and hydrology. They were rasterized using a 1000 m x 50 m grid cell oriented with the long axis parallel to the local coastline. Our nature maps have been derived by combining grid maps of the abiotic environment (geomorphology and groundwater) with two vegetation maps. One vegetation grid map depicts the dominant vegetation; the other, the valuable and rare plant communities.

Appraisal of nature was based on the following four points:

* diversity of plant species (*c.q.* plant communities);
* rarity of ecotopes (vegetation and abiotic environment);
* succession stage (maturity of ecotope: from pioneer to forest) and estimated time required to restore the associated habitat;
* completeness; completeness is defined by us as the ecogical configuration of landscape elements in a spatial arrangement which is natural (Forman and Godron 1986). A zonation of dune landscapes from beach to inner dunes which is not disrupted or divided by human developments is called complete. Completeness was considered subjectively and on a nationwide scale using the landscape ecological maps of Doing (1988). We could not use a GIS database because whole landscapes had to be taken into account. Our database was too limited for this; it only comprised the foredunes and not the entire width of the dune zone.

Completeness is introduced because for regional planning it is often better to preserve complete sequences (assemblages) of landscape units rather than scattered small individual patches (even if they contain rare species).

The evaluation of nature resulted in a nature map with five classes, each consisting of a combination of biotic and abiotic nature:

N1: moist and wet primary and secondary dunes with moist grassland, trees and heath;

N2: dry primary dunes and moist secondary dunes, covered by shrubs, dry or locally moist grasslands or trees;

N3: dry secondary dunes, grass-covered or bare;

N4: beach and beachplanes;

N5: other.

Beach and beachplanes (N4) were ranked rather low which is not always true. This is inherent to the method used. It mainly concerns actual values. When potential values are also taken into account beaches and particularly beach planes, can have important conservation value because a variety of ecosystems may develop on them.

As an example of the methodology used, Figure 1 shows the island of Ameland, the nature gridmap for 1990, and the situation in 2090. The figure shows that there is not only coastline regression, but also local accretion (mainly at the tips of the island). Figure 1 does not show the losses due to changes in groundwater level. These were evaluated separately on other gridmaps.

Results and discussion (see also Figure 2)

Main aim of this paper is not to give a full account of the results (see Arens *et al.* 1989) but rather to present some of the gaps in the methods used to assess ecological impacts of sealevel rise on flora and vegetation. These are mainly due to a lack of knowledge on species response to changes in the abiotic environment.

When no counter measures are being taken, the main impacts on nature areas will occur at the

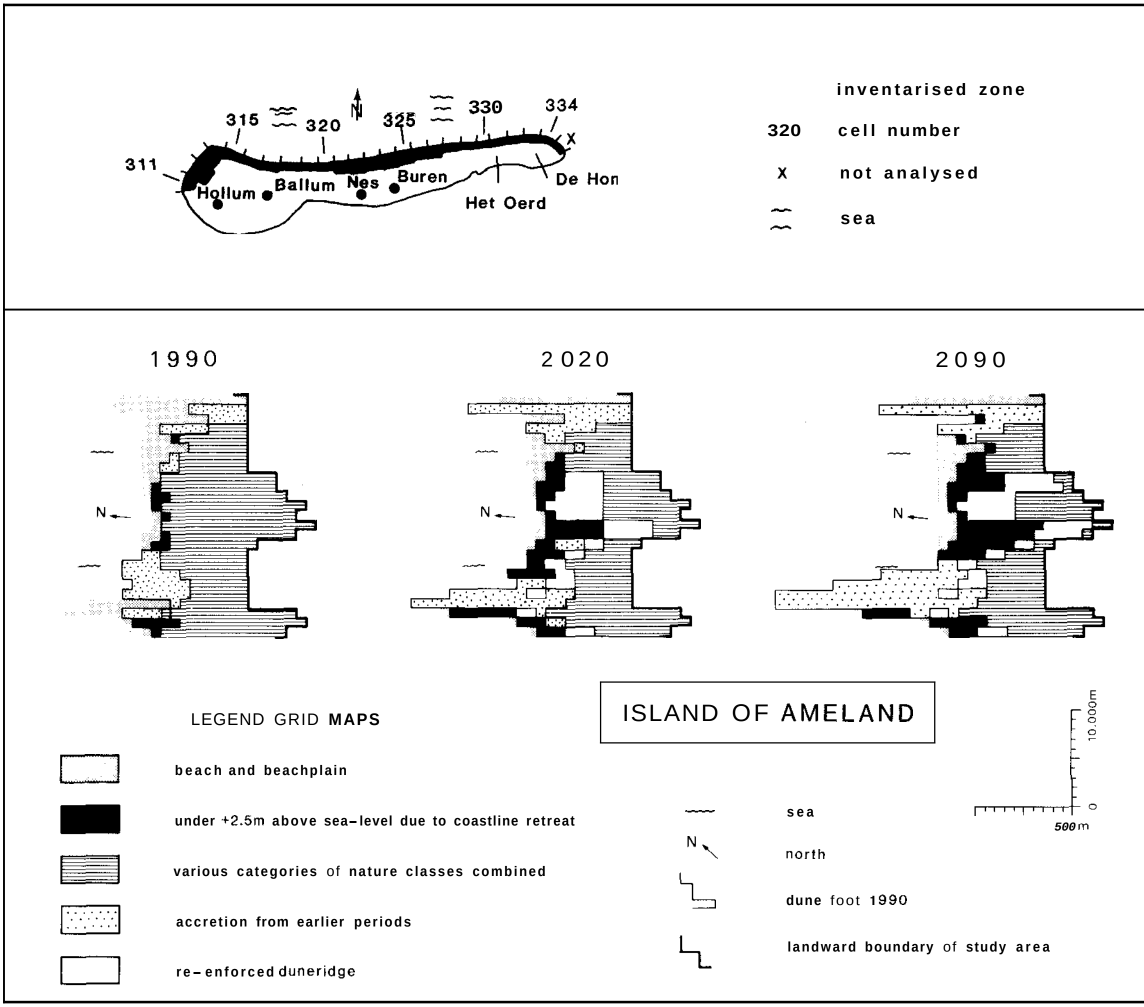
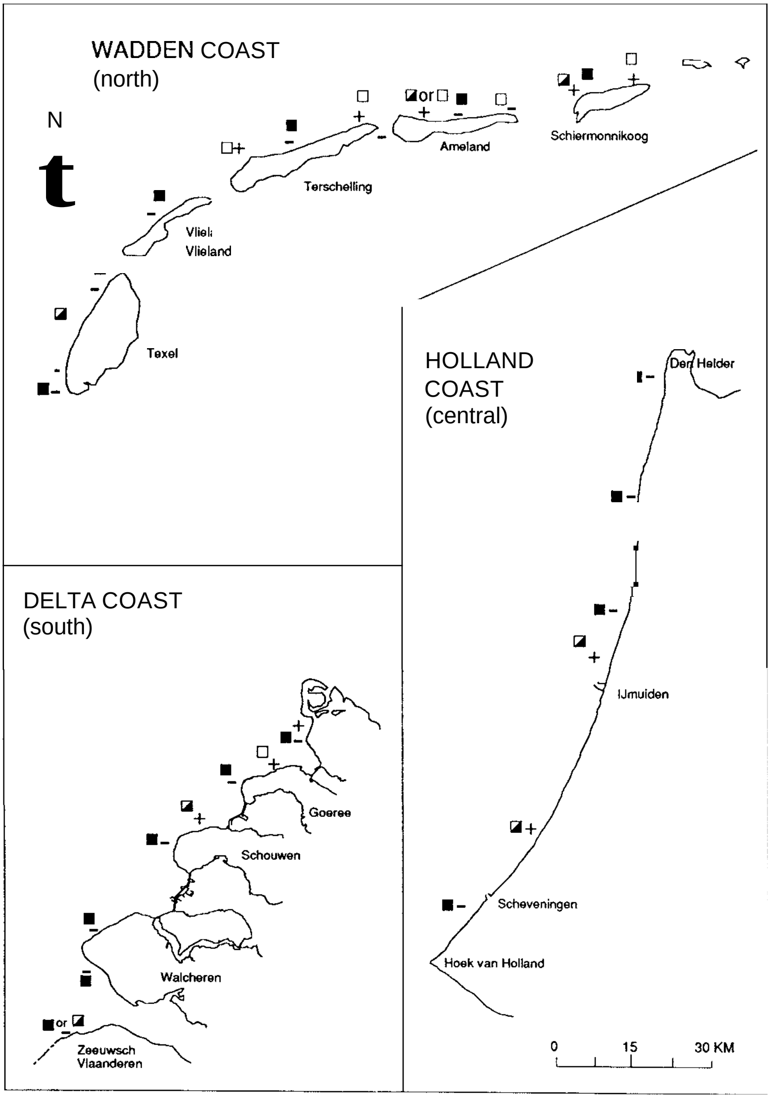


Fig. 1. Island of Ameland, the nature gridmap for 1990, and the situation in 2090 (size gridcells = 1000 * 50 m).

beginning of the next century. In particular the Wadden Islands (north) will have large losses of nature. This is due to loss of land, to lowering of the groundwater level and to remodelling of the foredune. Along the main coast of Holland (centre) erosion will occur mainly in the north. In the estuarine Delta area (south) the losses are relatively modest. Predicted coastline regression has to be 'stopped' in a very early stage to meet the safety standards because the dunes are very narrow here. Locally, free coastline development is possible at accreting, primary dune coasts. The development of dune ecosystems can possibly be integrated with the development of the 'Voordelta,' a series of offshore sand banks in front of the former estuaries which are now closed off by large dams of the Delta Plan.

The present 'state of the art' of studies assessing ecological impacts on flora and fauna of future changes in the abiotic environment, shows three serious gaps in the methods used:

(1) Inventory
For inventarisation there is lack of up-to-date, and relevant basic information. Ideally the inventarisation should be one in which ecologic processes play a role. Because of the extremely varied environmental constraints in dunes, landscape ecological and geomorphological processes often produce small patterns. Units of 50*50 m in the field should be discerned rather than the 1000*50 gridcells we



LEGEND

Coastline management		Option for development
■	fixation	protection of existing valuable dune systems
◪	flexible fixation	eolic/marine rejuvenation possible on limited scale due to protection of other functions
□	flexible: free development	building of young coastal systems; less threat because of accretion or slight erosion in case of erosion no direct danger to other functions

used. Moreover, it is important to know the exact position of a species or community in order to assess its response to groundwater lowering, for example. Small changes are already important. These can only be evaluated on large-scale maps. Also the available technology to store and handle the information by means of geographical information systems is still inadequately used. Ideally, one should have a digital terrain model, a groundwater map, a soil map, a fauna map, a vegetation map, as well as a digitized version of the topographic map. One should be especially aware that information about vegetation rapidly gets out of date. As a rule of thumb such maps must be updated every 5-10 years when scales of 1:5000 to 1:10 000 are concerned.

It is not necessary to produce maps first before starting digitizing. This introduces an extra phase of generalisation and loss of information. It pays to use scanners and special software to incorporate the information on vegetation and landscape directly from aerial photographs into the GIS-package. Yet, ground studies are necessary to verify the scanned information. When maps have to be updated, it is essential that these are of practical use to local coast management. Therefore, the GIS-package and its database should be accessible to local as well as national coast management. The area to be inventorized, either through digitizing or rasterizing maps or directly from image scanning, should be large enough. In other words the database should not be too limited. Otherwise it is not possible to evaluate whole landscapes. This is important to assess completeness, *i.e.* natural ecological configurations of landscape elements and their macro-gradients. For example, when primary dune slacks are considered, the adjacent associated dune ridges should also be taken into account. A loss of the ridge and not of the slack itself will still change the slack completely.

(2) Ecological Impact Analysis

There is lack of causal and quantitative information about the interaction of the biotic and the abiotic environment. This lack of information can only be overcome by monitoring vegetation as well as the abiotic environment, and subsequent building of interaction models. An important study in this respect is the development of a vegetation-hydrology management model for the seasonally wet dune slack environment (Noest et al. 1989; Noest, this volume). For this habitat a huge dataset is being analysed comprising vegetation and hydrological descriptions of permanent plots since 1958,

In a coastal defence analysis study at the island of Texel (Runhaar et al. 1985, Runhaar 1989) ecological impacts were quantified using ecotope types. Ecotope types are being established for the whole of the Netherlands (Stevers et al. 1987). When knowledge about ecotope habitat conditions is available, impact effects can be predicted in a certain quantitative manner. Ecotope types are primarily based on the vegetation and not on the relationship between vegetation and the abiotic environment. Therefore ecological interaction models based on long term monitoring studies are still needed.

A pilot study to monitor abiotic-biotic relationship in dunes has been performed for about one year now in the Meijendel dunes near The Hague (Harkel and Witter 1989). From the experience obtained by this project we have learned that the master abiotic variables to be monitored should ideally comprise groundwater and soil moisture, atmospheric deposition and soil chemistry, and climatological variables, notably rainfall, air temperature and radiation. These are the variables that are of greatest interest in regeneration studies and in studies on the influence of air-pollution and climatic change. Also detailed information about the soil should be available, in particular about the buffering capacity of the soil.

Such monitoring sites are preferably situated in areas with considerable fluctuations in the abiotic variables to be monitored. Also these areas should

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Fig. 2. Main threatened areas for nature conservation due to sea level rise and suggestions for 'nature-friendly' coastline management. Scenario: **20** cm per century sealevel rise (present trend). Predicted coastline development: + =accretion; - =erosion; ± =stable or slight erosion/accretion.

have a vegetation with species which are distinct ecological indicators for the abiotic variables in question. Within such a site, there should be several permanent plots where vegetation dynamics can be recorded as well.

Another project started recently on aeolian transport of sand in the Dutch foredunes (Arens and Wiersma 1990). The aim is to calculate a dynamic sand budget in which not only differences in total sand content are calculated, but also the extent to which several processes contribute to these differences; for example transport of sand onto, within and out of the foredunes. This will give more insight into the role of aeolian sand transport in coastline regression.

(3) Nature Development
So far the conclusions of the coastal defence analysis remain static. For example, what is lost remains lost. But what kind of new ecosystems will develop? Where, how soon and of what value? Then losses and 'gains' can be weighed against each other. Answers to these questions are hardly to give. This again is due to a lack of substantial information about the response of vegetation and fauna to (new) abiotic conditions. Although the overall trend in coastline development is erosion, locally substantial accretion will occur. In both cases new ecosystems will develop replacing existing ones. To know their pathways and rates of succession is of great importance to ecological impact studies.

Recommendations for coastline management

The natural dynamics of the Dutch dune coast have been tamed for several decades by too rigid stabilisation techniques for coastal defence. It is important to consider now if integration of pure coastal defence with certain ways of natural development of the coastline is desired; and if so, where this is possible. Options for a more nature oriented coastal management from the point of view of nature development are given by Louisse and Meulen (1990) and Arens *et al.* (1989). Figure 2 gives the main threatened areas as well as suggestions for coastline management in these areas. The basic idea from the point of view of nature and landscape development is

* preservation of actual valuable coastal ecosystems
* development of potentially valuable ecosystems
* establishment of a characteristic variety of dry and wet, young and mature type ecosystems along the Dutch coast as a whole.

Protection of landscapes is especially important in the case of residual dune systems. These are landscapes which are the product of a long time of development: for example primary dunes which have never developed to secondary dune systems or secondary dunes which have become stabilized long ago. If they are threatened, they should be protected. This is the case for the central parts of the Wadden Islands (Fig. 2). Also moist dune valleys with important botanical and wildlife (waterfowl) values, presently only being defended by a narrow foredune ridge, should be protected.

In other instances, the coastline should not be a priori fixed and maintained at any price (see also Ministry of Transport and Public Works 1990). In fact, acceptance of some flexibility of the coastline can lead to greater diversity, in particular when large-scale gradients between fresh and salt water and between wet and dry coastal ecosystems develop. The latter landscapes, where sea water may invade dune valleys which lie behind the first dune ridge are called *Slufters* in Dutch. As long as the natural dunecoast has no scarcity of sediment when some flexibility is allowed it will serve as a safe defence system.

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